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From Paradox to Policy: The Problem of Energy Resource Conservation in Britain and America, 1865-1981

ABSTRACT:

The idea that we can ‘save energy’ has become a commonplace homily. But with a moment’s reflection it is clear there is nothing self-evident about saving energy. Do we save fuel or a system’s ability to ‘do work’? Do we conserve for perpetuity or to prolong use? Is the motivation resource economy, scarcity, productivity, or - more recently - climate change mitigation? And what stops the fruits of individual parsimony being consumed elsewhere? This thesis offers a history of the idea that we can conserve energy by using it more efficiently. In recounting this story, it is argued that conserved energy is a ‘metrological resource’ produced by practices of measurement, calculation, and computation. A second argument is that the history of ERC offers an under examined example of a ‘resource ontology’; the social processes through which nature is imbued with utility and value. Accordingly, the study of, what is termed, *energy resource conservation* (ERC herein) involved a novel research method which focused upon the scientific and intellectual processes of resource making, as much as the material. This thesis begins in 1865 with the publication of William Jevons’ *The Coal Question* (1865), in which the resource conservative principles of Classical political economy were overturned. Jevons argued that increased efficiency of coal use would serve only to increase the rate and scale with which coal was used. Proceeding from this anti-thesis, the following chapters outline how, irrespective of Jevons’ claim, policies based on the principles of scientific management were applied to the conservation of fuel resources for conserving natural resources. In pre-war America, a complex system of ‘pro-rationing’ extraction licenses were introduced to conserve the productive capacity of petroleum wells. However, a significant shift occurred during the Cold War, as the conservation of fuel became increasingly conflated with the econometrician’s notion of efficient resource allocation. But the most significant developments occurred in the nineteen-seventies, in response to a perceived crisis in energy supply. Fuel policy became a

more systemic ‘energy policy’, which drew on scientific management, graph theory, systems theory, statistical mechanics, and computational econometrics in an attempt to quantify and demonstrate how society could act to conserve energy resources by increasing the efficiency of energy use. The resulting science, and its concomitant policies were an odd mix of cold war rational decision making theories, détente science, scientific radicalism, and liberal economic theory, all given a countercultural and environmentalist gloss in the latter half of the decade. On the basis of this conflation of ideas, a new approach to energy saving that emerged, which transformed the principles of energy resource governance, shifting the onus to conserve from producer to consumer, with distinct implications for post-war theories of political economy.

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ABBREVIATIONS:

AAAS	American Association for the Advancement of Science
AEC	Atomic Energy Commission
API	American Petroleum Institute
APS	American Physical Society
BAAS	British Association for the Advancement of Science
BSSRS	British Society for Social Responsibility in Science
CBA	Cost Benefit Analysis
CEGB	Central Electricity Generating Board
CIA	Central Intelligence agency
CONAES	Committee on Nuclear and Alternative Energy Systems
COPEP	Federal Committee on Public Engineering Policy
CPRS	Central Policy Review Staff
CSRA	California State Resources Agency
CSRC	Conservative Systems Research Centre
DOD	Department of Defence
DSIR	Department of Scientific and Industrial Research
DTI	Department of Trade and Industry
ECO	European Coal Organisation
ENIAC	Electronic Numerical Integrator and Computer
ERC	Energy Resource Conservation
ERDA	Energy Research and Development Administration
ERDA	Energy Research and Development Administration
ETSU	Energy Technology Support Unit
FLOPP	Floating Offshore Power Plant
FOCB	Federal Oil Conservation Board
FORTRAN	Formula Translating Code
FPC	Federal Power Commission
FRB	Fuel Research Board
ICE	Institute for Civil Engineers
IDA	Institute for Defence Analysis
IEA	International Energy Agency
IRRPOS	Interdisciplinary Research Relevant to the Problems of Society
JP	Jevons' Paradox
LBL	Lawrence Berkeley Laboratory
MINTECH	Ministry of Technology
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NIFES	National Industrial Fuel Efficiency Service
NPC	National Petroleum Council
NSF	National Science Foundation
NUM	National Union of Mineworkers

OAPEC	Organization of Arab Petroleum Exporting Countries
OECD	Organisation for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
OR	Operations Research
ORNL	Oak Ridge National Laboratory
OSRD	Office of Scientific Research and Development
PAU	Programmes Analysis Unit
PAW	Petroleum Administration for War
PG&E	Pacific Gas and Electric
PPBS	Planning Programming Budgeting System
PSRU	Public Sector Research Unit
RAND	California's Research and Development Corporation
RANN	Research Applied to National Needs
RFF	Resources for the Future
SDS	Students for a Democratic Society
SESPA	Scientists and Engineers for Social and Political Action
TCQ	The Coal Question
UKERC	United Kingdom Energy Research Council
UNFCCC	United Nations Framework Convention on Climate Change
WFTC	World Future Trends Committee

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INTRODUCTION:

When we switch off lights or lower home heating we might act in the belief that our actions conserve energy. We do this with little thought to either the infrastructural or intellectual basis by which this action is believed to result in a requisite energy saving. What is the chain of causation by which our action translates into a related amount of fuel not being consumed? Physics tells us that as energy is transformed entropy increases; thus, energy becomes progressively less usable. The laws of thermodynamics appear inviolable. In a similar way, economic theory argues that a reduction in demand will lower the price of energy, according to the principle of utility maximisation. According to the same principle, a lower price would encourage energy consumption elsewhere. Given the orthodoxy of these two positions, the idea that increased efficiency can achieve the conservation of energy resources seems exceptional. Accordingly, I suggest history of what I term, the emergence of a science and policy of energy resource conservation is a significant if underappreciated historical event in the long twentieth century[1]. The purpose of this thesis is to develop a detailed understanding of the circumstances which led to this development of this idea, and the consequences of its growing orthodoxy.

In recent years, this commonplace idea, that we can 'save' energy by using it more efficiently, has taken on an eschatological significance. In December 2015, one-hundred and ninety-five states signed the most recent United Nations Framework Convention on Climate Change (UNFCCC) agreement at the conclusion of the Paris meeting. A move former UN Secretary General Ban Ki-Moon described as 'a monumental triumph for people and our

[1] For the purposes of this thesis this refers to the period 1865-1981. The long twentieth century is a commonplace historical periodisation that acknowledges that advances in science and technology in the last decades of the nineteenth century were critical to the twentieth, as this thesis testifies to. See Maier, C. (2000) 'Consigning the Twentieth Century to History. Alternative Narratives for the Modern Era', American Historical Review, Vol. 105, Iss. 3, pp. 807-831.

planet'[2]. The aim is that signatories will significantly reduce their nation's greenhouse gas emissions to collectively lower global emissions of greenhouse gases by between 31 and 44 giga-tonnes of carbon dioxide equivalent by 2030. Their purpose is to try and ensure the mean global climate warms only by 1.5 to 2° degrees Celsius, as beyond this level the fear is that changes to Earth's climatic system may have catastrophic impacts on human life[3]. How signatories attempt this? Alongside the deployment of renewable energy, and cleaner fossil fuel use, targeted measures to increase energy efficiency are considered 'a crucial enabling factor'[4], and it is hoped that such increases could 'decouple' economic growth from energy use by 2.6 per cent per annum, enabling the global economy to continue to grow as emissions fall[5]. Given that increased energy efficiency would also boost economic productivity, Ban Ki-Moon told signatories that 'energy efficiency is our best tool to reduce CO_2 emissions'[6].

The Paris agreement, as the culmination of thirty years of discussion to try and form a resolution to the possibly catastrophic effects of climate change, is underwritten by the idea that increased efficiency of energy use can reduce the rate and scale of fossil fuel combustion, limiting emissions, and helping mitigate humankind's vast accumulation of

[2] Falkner, R. (2016) 'The Paris Agreement and the New Logic of International Climate Politics', International Affairs, Vol. 92, Iss. 5, pp. 1107-1125.

[3] Schleussener, C., Rogelj, J., Schaeffer, M., Lissner, T., Licker, R., Fischer, E., Knutti, R., Leverman, A., Frieler, K., Hare, W. (2016) 'Science and policy characteristics of the Paris Agreement temperature goal', Nature Climate Change, Vol. 6, Iss. 9, pp. 827-835. Falkner, R. (2016) 'The Paris Agreement and the New Logic of International Climate Politics', International Affairs, Vol. 92, Iss. 5, pp. 1107-1125.

[4] Rogelj, J., Gunnar L., Robert P., Kriegler, E., Schaeffer, M., Krey, V., Riahi, K. (2015) 'Energy System Transformations for Limiting End-of-Century Warming to below 1.5^{O}C." Nature Climate Change, Vol. 5, Iss. 6, pp. 519–27.

[5] Gielen, D., Boshell F., Saygin, D. (2016) 'Climate and Energy Challenges for Materials Science' Nature Materials, Vol. 15, Iss. 1, pp. 117-120.

[6] UNFCCC (2015) 'Press Release: Renewable Energy and Energy Efficiency Can Unlock Climate Solution', Dec. 7. Available at: http://newsroom.unfccc.int/lpaa/renewable-energy/press-release-lpaa-energy-renewable-energy-and-energy-efficiency-can-unlock-climate-solution/

hydrocarbon emissions in past centuries[7]. Given this weight of expectation, it is odd that the history of this central tenet of humankind's efforts to combat the worst effects of climatic change has gone largely unremarked upon. Whilst the history of the other approaches to climate change mitigation, namely renewable and clean energy, and geo-engineering have invited scholarly scrutiny[8], energy conservation via increased energy efficiency has not done so, beyond of the field of energy analysis.

Seen historically, the idea that increasing the efficiency of energy use might curtail emissions seems incongruous. Most obviously, an unprecedented increase in the efficiency of energy-using engines occurred in Britain in the mid-nineteenth century during the industrial revolution. Rather than saving fuel, marked increases in energy efficiency occurred alongside significant increases in energy consumption: between Tudor and Victorian periods, per capita energy consumption increased five-fold[9]. In part, the problem was one of scale, as in Europe over the last two centuries the efficiency of energy use doubled, but the economy grew fifty times larger, and energy consumption has increased twenty-five fold[10]. And globally, though it is evident that the *intensity* of energy use, measured in units of energy consumed per unit of gross domestic product (e/GDP), has fallen in many countries, global energy consumption and related emissions have nonetheless increased[11]. An 'energy transition' has not occurred,

[7] Contemporary climate change, as Malm notes, is a 'backloaded' event, in which our industrial history is impacting on present-day industrial growth. See Malm, A. (2016) Fossil Capital: The Rise of Steam Power and the Roots of Global Warming. Verso Books.

[8] Fleming, J. (2010) Fixing the Sky: The Checkered History of Weather and Climate Control. Columbia University Press; Righter, R. (1996) Wind Energy in America: A History. University of Oklahoma Press; Smil, V. (2010) Energy Myths and Realities: Bringing Science to the Energy Policy Debate. AEI Press.

[9] From 19,167 terrajoules in 1561 to 96,462 in 1850. Wrigley, E. A. (2010) Energy and the English Industrial Revolution. Cambridge University Press; p. 93-96; See also Warde, P. (2007) Energy Consumption in England and Wales: 1560-2000. Consiglio Nazionale delle Richerche.

[10] Warde, P., Malanima, P., Kander, A. (2013) Power to the People. Energy in Europe in the last five centuries. Princeton University Press. p. 10

[11] From 1000 gigagram equivalent in 1850 to 8700 gigagram., e. in 2000. Bond, T., Bhardwaj, E., Dong, R., Jogani, R., Jung, S., Roden C., Streets, D., Trautman, N. (2007) 'Historical Emissions of Black and Organic Carbon Aerosol from Energy-Related Combustion, 1850-2000', Global Biogeochemical Cycles, Vol. 21, Iss. 2., Tooze, A., Warde,

so much as the *addition* of considerable amounts of new sources of energy to the global industrial economy, from coal to gas, and most recently electricity[12].

Despite this evidence, the UNFCCC agreement calls on signatories to decrease the energy intensity of the economy at an historically unprecedented rate in order to *lower* rather than *increase* rates of fossil fuel combustion. Why might this be so? Given the evidence, the idea that increased energy efficiency (or lowered energy intensity) might decrease global energy use would be historically unprecedented. Though, irrespective of this fact, contemporary climate change mitigation policy suggests increased efficiency of energy use can and will lead to a rapid decrease in fossil fuel consumption, as part of a wider 'rapid decarbonization' effort for lowering the climatic impacts of the global energy economy[13].

Within such discussions about rapid decarbonisation, the terms 'decoupling' and 'energy efficiency' are commonly used, and can be considered as cognates of 'energy conservation'[14]. There are however some subtle differences in meaning. Energy efficiency implies the use of a technology that requires less energy to perform a given function than another, whereas energy conservation implies the use of less energy in total. Thus the term energy efficiency is normally applied to specific technologies, whereas energy conservation is used to refer to systemic, structural or collective outcomes of increased energy efficiency[15].

P. (2005) 'A long run historical perspective for uncoupling economic growth and CO2 emissions: Submission to Stern Review. Available at: http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/media/2/1/climatechange_drjatooze_1.pdf

[12] Fressoz, J. (2014) 'Pour une histoire désorientée de l'énergie', Trevenot, D., 25émes Journées Scientifiques de l'Environnement – L'économie verte en question. Créteil, France.

[13] Williston, B. (2016) The Anthropocene Project. Virtue in the Age of Climate Change. Oxford University Press.

[14] Moezzi, M. (1998) 'The Predicament of efficiency', ACEEE Summer Study on Energy Efficiency in Buildings, Washington, August, 1998. Available at: http://aceee.org/files/proceedings/1998/data/papers/0425.PDF

[15] Pérez-Lombard, L., Ortiz, J. Velåzquez, D. (2013) 'Revisiting Energy Efficiency Fundamentals', Energy Efficiency, Vol. 6, pp. 239-254.

It is the history of this idea of a systemic, structural, and collective means of energy saving toward which this thesis is addressed.

The UNFCCC cast energy efficiency in suitably systemic conservative terms, stating that 'energy efficiency measures must become universal and systematic', in order to avoid the combustion of hydrocarbons and reduce emissions[16]. The term energy conservation, in this sense, is distinct from the thermodynamic concept of the conservation of energy, though the two are often conflated. The latter is a statement of a physical law. The first law of thermodynamics, first formalised around 1850, states that energy can neither be created nor destroyed. In this sense, energy is *always* conserved. The former meaning of energy conservation is meant as a statement of resource economy, referring specifically to the conservation of those resources from which energy is derived. Given the risk of conflating energy conservation and the first law of thermodynamics, I will use the term energy resource conservation (ERC) for clarity and brevity.

INTELLECTUAL HISTORY AND RESOURCE GEOGRAPHY

What kind of geographical inquiry is this? Geographers have been consistent and salient analysts of the human response to climate change, as a concern that both testifies to and challenges the discipline's explanatory schemas[17]. But this research is not focused directly upon climate change, so much as one of its intended means of resolution, the conservation of energy resources via increased efficiency of energy use. Regarding this subject, the emphasis is on the intellectual, scientific and conceptual basis of the idea that society could

[16] UNFCCC (2015) LPAA Focus on Energy. Blue zone. Observer Room 10. Programme from Paris COP15. Available at: http://newsroom.unfccc.int/media/547434/programme-lpaa-focus-on-energy.pdf

[17] Demeritt, D. (2001) 'The Construction of Global Warming and the Politics of Science', Annals of the Association of American Geographers, Vol. 91, Iss. 2, pp. 307-337; Bailey, I., Compston, H. (2010) 'Geography and the Politics of Climate Policy', Geography Compass, Vol. 4, Iss. 8, pp. 1097-1114.

systemically, structurally, and collectively conserve energy resources rather than on climate change more generally. As the economist Erich Zimmermann stated 'resources are not, they become', and the way in which conserved energy has come to be considered as a resource is the focus of this work[18]. Given the scientific and intellectual practices but which this concept has come into being, geography's conventional concern with the non-human world and spatiality is not our direct topic of inquiry. Instead, this thesis is intended to place intellectual history at the heart of resource geography, the study of the human use of a finite earth[19].

This thesis is undertaken with the aim of showing how the history of ideas plays an important constitutive role in the realisation of conserved energy as a resource[20]. But rather than solely relying upon the history of ideas, I trace the intellectual history of ERC in relation to the material history of fuel and energy supply, and the emergence of new technologies from which new concepts were induced, in order to arrive at an empirically rich account of the history of conserved energy as a resource[21]. Historical geographers have long made efforts to show how the history of ideas has had implications for how space is conceived of and used[22]. However, such efforts have primarily focused upon geography's own intellectual history, or the adoption of other disciplinary schema within geography[23]. Instead, this work is intended to show how the concerns of political economy, engineering, systems analysis,

[18] Zimmermann, E. (1933) World Resources and Industries. Harper and Row.
[19] Mitchell, J. (2016) 'Resource Geography', in Dunbar, G., ed. Modern Geography: An Encyclopaedic Survey. Routledge.
[20] As such, it might be seen as part of wider 'spatial turn' in geography and history, though one which looks to the spatial consequences of ideas, or a constructivist account of resource making, rather than the spatial determinants of idea formation. See Withers, C. (2009) 'Place and the "Spatial Turn" in Geography and in History, Journal of the History of Ideas, Vol. 70, No. 4, pp. 637-658.
[21] Abourahme, N., Jabary-Salamanca, O. (2016) Thinking against the sovereignty of the concept', City, Vol. 20, No. 5, pp 737-754.
[22] Withers, C., Mayhew, R. (2011) 'Geography: Space, Place and Intellectual History in the Eighteenth Century', Journal for Eighteenth-Century Studies, Vol. 34, Iss. 4, pp. 445-452.
[23] Withers, C. (2011) 'Geography's Narratives and Intellectual History', in Agnew, J., Livingstone, D. eds. The Sage Handbook of Geographical Knowledge. Sage Publishing, London; Barnes, T. (1996) Logics of Dislocation: Models, Metaphors, and Meanings of Economic Space. Guilford Press.

econometrics, and physics came to matter for the geography of resources. In some sense then, this work is an exercise in 'intellectual geography', in so far as it demonstrates how geography played a determinate role in the intellectual history of ERC[24]. But given that I am also concerned with the opposite dynamic, how ideas brought a new kind of resource into being, I will refer to this work as an intellectual history of a unconventional resource.

This emphasis on the resource making capacity of ideas does not mean a return to a form of historical idealism. Rather, as conceptual historian Reinhart Koselleck has argued, to claim history results solely from concepts, or – for that matter - material conditions, is to create 'a theoretically irredeemable short circuit'. Instead, he suggests a 'tension' exists between concepts and materiality, which at different points in history is either transcended, or 'seemingly insoluble'[25]. Two prominent examples of this dynamic, a tension and its resolution that existed between the material and ideational, emerge in this thesis. They are as follows: 1.) material scarcities of energy resources encouraged actors to develop new ideas about how limits might be alleviated, and 2.) changing ideas about the concept of energy had material consequences, in so far as the notion of ERC encouraged a new approach toward energy resource use and conservation. As such, this thesis does not attempt to negate recent scholarly enthusiasm for a renewed interest in the agency of the material world, so much as re-assert the role of the ideas, as geographers Bruce Braun and Sarah Whatmore suggest, as 'intellectual resources' which are involved in the 'composition of common worlds' composed of both thought and matter[26].

[24] Ogborn, M. (2011) 'What is Intellectual Geography?', keynote address to the Intellectual Geography Conference, Oxford, September 2011.
[25] Koselleck, R. (2006) Futures Past: On the Semantics of Historical Time. Trans. Tribe, K. Cambridge: MIT Press., p. 87.
[26] Braun, B., Whatmore, S. eds. (2010) Political Matter: Technoscience, Democracy, Public Life. University of Minnesotta Press.

In this respect, the thesis revisits some of the earlier concerns of economic geographers. After all, the history of political economy and history of economic thought were, in the nineteen-seventies, at the centre of the radical geographic project. David Harvey famously compared David Ricardo, Thomas Malthus, and Karl Marx, to argue against ideology-free, essentialist categories, including notions of resources and scarcity[27]. Though Harvey's use of Marx, and other political economists was later criticised for being overly literal, and imposing their abstract, theory-based reasoning at odds with the idiographic objectives of geographic research, and moreover at odds with the cultural or so-called 'postmodern' turn within the discipline more broadly characterised by a scepticism toward 'unhelpful determinism and economism'[28]. Partly as a result of this rejection of intellectual history in geographical research, contemporary resource geography has more recently undergone a 'new materialist' turn and now has surprisingly little to say about the history of ideas (Chapter 2).

How can this be resolved? So far, few geographers have engaged with the notion of energy conservation as a geographical idea. Steve Hinchliffe offers one exception. He argues that extant energy analysis is often narrowly economistic, and starts from a 'self-limiting set of assumptions': energy analysts assume that there is a system for translating efficiency increases into energy savings known as 'the market'; and that the energy user can be reduced to an individual consumer who automatically attempts to maximise the use they can derive from scarce resources[29]. As a recent survey of the field of 'energy studies' and its journals indicates, economics and engineering dominate the field of energy analysis. Without other disciplinary perspectives, as psychologist Paul Stern portrays it, energy analysts are left to

[27] Harvey, D. (1974) 'Population, Resources, and the Ideology of Science', Economic Geography, Vol. 50, No. 3, pp. 256-277.

[28] Peet, R. (1989) 'Introduction: New Models of Uneven Development and Regional Change III', Peet, R., Thrift. Eds. New Models in Geography: The Political Economy Perspective. Volume 1. Routledge.

[29] Hinchliffe, S. (1995) 'Missing Culture: energy efficiency and lost causes', Energy Policy, Vol. 23, pp. 93-95.

'fiddle perpetually with their models and retain core theoretical assumptions based on economics and engineering'[30].

As historical geographer Trevor Barnes has argued, a discipline's reliance on abstract explanatory models, such as the utility maximising individual, or 'the market' for that matter, does not explain anything beyond its own frame of reference. In fact, he argues the use of abstract economic reasoning is itself something which needs to be explained if we are to understand historical change[31]. Without offering an explanation for the use of abstract reasoning, analysis remains stuck in an explanatory tautology (as Stern illustrated), and which Barnes suggests is logically incoherent; as explanation can only be justified using terms the analyst have themselves constructed[32]. Just as Barnes argues for the value of a contextual history of ideas in economic geography, I argue for a similarly grounded analysis of the dominant ideas in the science and policy of ERC. Contextualisation of this kind is intended to deconstruct established ideas, to open up the closed system of reference and allow historical change to come to the fore[33]. Accordingly, in this thesis, I historicise the theoretical basis of ERC by returning to the historical context in which these ideas emerged[34]. In doing so, this work is intended to go beyond narrow economism and to relativize the idea by returning to the sites of epistemological formation. The aim, following Barnes (and Curry), is

[30] Sovacool, B. (2014) 'What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda'. Energy Research & Social Science, Vol. 1. pp. 1-29. Sovacool, B. (2014) 'Diversity: Energy Studies need Social Science', Nature, Vol. 511, Iss, 7511, pp. 529-530

[31] Barnes, T. (1996) Logics of Dislocation: models, metaphors, and meanings of economic space. Guilford.

[32] Ibid, Chapter 3.

[33] Ibid, p. 56.

[34] Barnes, T. (1987) 'Homo Economicus, Physical Metaphors, and Universal Models in Economic Geography', Le Géographe Canadien, Vol. 31, No. 4, pp. 299-308,

to contextualise this history through an examination of the specific situations in which 'concepts are acquired and used in actual practice'[35].

Philosophers and sociologists of scientific knowledge have long argued that historical contextualisation is a form of epistemic relativism, returning to the time before an idea existed, or before its claims were upheld, provides a means of achieving a sociological explanation for the affirmation of scientific knowledge[36]. Accordingly, rather than adopting a linear, developmental approach to the history of ERC, my intention is to analyse its history as a sequence of *knowledge controversies*. In the history and sociology science, controversies are seen as 'empirical events', sites of epistemic uncertainty. Their close study is intended to reveal the detailed construction of knowledge by historical actors[37]. The moment of controversy re-invokes factual uncertainty and avoids presentism. Thus, this project could be considered an attempt at analysing a shifting field of controversial situations over time[38].

The aim is to *de-essentialise* the idea of ERC, and to reveal both the order and the mess, the precision and the in-exactitude, and the proven and unproven assumptions which lie behind contemporary claims about the veracity and quantity of energy resources which can be conserved in our fight against climate change. By documenting the development of constructive and deconstructive intellectual rationales regarding the efficacy of various systemic, structural, and collective means of energy saving. By doing so, I argue that there is

[35] Barnes, T., Curry, M. (1982) 'Towards a contextualist approach to geographical knowledge', Transactions of the Institute of British Geographers, Vol. 8, No. 4, pp. 467-482.

[36] Barnes, B. (1974) Scientific Knowledge and Social Theory. Routledge.

[37] Shapin, S. (1992) 'Discipline and bounding: the history and sociology of science as seen through the externalism-internalism debate', History of Science, Vol. 30. pp. 333-369.

[38] Barry, A. (2012) 'Political Situations: Knowledge Controversies in Transnational Governance', Critical Policy Studies, Iss. 6, Vol. 3, pp. 324-336.

nothing self-evident about the idea that individual acts of efficiency conserve energy collectively, or that a quantity of conserved energy can be considered a resource.

SCIENCE AND POLITICS

It is argued that the period 1865 to 1981 was marked by a distinct shift in how ERC was understood and operationalized in the United States and Britain. This thesis argues that ERC, aside from its historicity, is of scholarly interest for four main reasons. First, the development of policy based upon the rationale of conserving energy provides a clear example of the relationship between scientific knowledge and political decision making. As sociologists of science have long observed, the relationship between science and politics is never one directional; the two are indivisible, and often co-constitutive[39]. Much of this thesis documents the application of science to policy, from the turn of the twentieth century onward, leading to what Jürgen Habermas once described as the 'scientization of politics'[40], the replacement of political practices with those of science. Equally, this thesis shows how the science of ERC, the ability to demonstrate resource savings, produced a specific form of political authority, particularly during the energy crises of the 1970s. As historians and sociologists of science remind us, scientific knowledge, owing to its perceived objectivity, has a political utility beyond the specific epistemic claim that is made[41]. Hence there has been a long tradition within science studies to try and discern the relation between science and politics[42].

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[39] Shapin, S., Schaffer, S. (1985) Leviathan and the Air-Pump, Princeton: Princeton University Press; Jasanoff, S. ed. (2004) States of Knowledge: the co-production of science and social order, London: Routledge.

[40] Habermas, J. (1971) 'The Scientization of Politics and Public Opinion' in Toward a Rational Society, Boston, MA: Beacon Press.

[41] Shapin, S and Schaffer, S (1985).

[42] Weber, M. (1948) 'Science as a Vocation' and 'Politics as a Vocation' in H Gerth and C Wright Mills, eds., From Max Weber, London; see also Breiner, P. (2013) 'Karl Mannheim and Political Ideology', in Freeden, M., Stears, M. eds. The Oxford Handbook of Political Ideologies. Oxford University Press; Habermas, J. (1971) 'The Scientization of Politics and Public Opinion' in Toward a Rational Society, Boston, MA: Beacon Press

More recently historian of science William Thomas has argued for a post-critical approach to the relation between science and politics, in which 'sciences of policy', in contrast to the more critical accusation (raised by Habermas amongst others) that politics is becoming governed by scientific rather than humanistic principles, is seen as well-meaning attempts to rationalise decision making for collective benefit rather than demonstrations of particular ideological or hegemonic thinking[43]. In contrast to this benign reading, I argue the case of ERC clearly demonstrates an attempt to 'naturalise' a political decision[44]. With ERC, the anti-political imposition of science on politics is clear. As physicist Alvin Weinberg noted, with growing political orthodoxy, it was as if society was to be reordered on 'thermodynamic imperatives' in order to save energy[45]. Once considered, it is clear that the physics of energy conservation is distant from the principles of economics, but to pursue a new model of political economy in accordance with a fundamental physical law, as will be recounted, lent credibility; it implied a literal coherence between nature and society[46].

A related argument is that the idea that society can collectively conserve energy came with significant political consequences. In his book *Carbon Democracy,* historian Timothy Mitchell writes, 'fossil fuels helped create both the possibility of modern democracy and its limits'[47]. In light of this observation, the proposition that modern democracies can significantly decouple industrial processes from fossil fuel use must come with its own political implications. In the nineteenth century, the limited accessibility of coal mines gave

[43] Thomas, 2015; see also Turnbull, T. (2016) 'I need a hero: reaffirming critical diagnoses of science-society relations', Science as Culture, Vol. 26, Iss. 2., pp. 260-265.

[44] Habermas, J. (1971).

[45] Weinberg, A. (1978) 'Reflections on the Energy Wars', American Scientist, Vol. 66., No. 2., pp. 153-158.

[46] Mirowski, P. (1994) 'The Realms of the Natural', in Mirowski, P. Ed. Natural Images in Economic Thought. Cambridge University Press.

[47] Mitchell, T. (2011) Carbon Democracy: Political Power in the Age of Oil. Verso. New York and London.

miners control over the flow of energy; strikes could be used to demand rights, helping forge the basis for welfare economics. Conversely, liquid oil was able to be mechanically extracted, often under its own pressure. Its geography, an infrastructure of wells, pipelines and tankers, meant energy flow was harder to disrupt, and was maintained by a smaller and more distant workforce, whose political demands were more easily quashed.

Mitchell uses philosopher Jacques Rancière's two definitions of democracy: the first, a genuine egalitarian impulse; the second, the containment of this impulse[48]. He then re-describes the twentieth century as a contest between these divergent democratic models, as contested via the control of energy infrastructure. As he argues, authoritarian Middle Eastern regimes were supported by the West in order to allow corporate capitalism and economic growth to continue unimpeded. In Mitchell's term, such incidents show how control over the supply of energy resources could be used as a means of 'engineering political relations'[49]. Despite discussing strikes, embargoes, and the 'conscientious withdrawal of efficiency'[50], he does not consider the politics that could be engineered by intentionally *reducing* demand for energy.

My intention is to extend Mitchell's argument about the relation between energy and politics by considering the democratic affordances of conserved energy[51]. In this thesis, it is argued that, just as Arab nationalists and coal miners were able to impose distinct forms of politics by restricting or enabling flows of energy[52], those who proposed a science and policy driven

[48] Rancière J 2006 Hatred of democracy Verso, New York, London.

[49] Mitchell, 2011, p. 5.

[50] Mitchell, 2011: 22, ft. 26.

[51] Turnbull, T. (2014) 'Review of Carbon Democracy: Political Power in the Age of Oil', *Area*, Vol. 46, Iss.1, pp. 115-117.

[52] Mitchell, T. (2011) Carbon Democracy: Political Power in the Age of Oil. Verso.

approach to reducing the nation's reliance on their energy, raised the prospect of a shifting form of energy-based political relations in post-war Britain and America. Whereas in the first half of the long twentieth century, the notion of conservation enshrined centralised political control, by the second half, the onus to conserve energy had come to imply the need for political liberalisation. Following Ranciere's definitions of democracy, it could be assumed that conservation as liberalisation marked the realisation of genuine egalitarian politics, by moving away from a state-controlled energy economy. But before coming to such a conclusion it is worth recognising that liberalisation did not remove political mechanisms of regulation and control, so much as redistribute them diffusely[53].

RESOURCE ONTOLOGY

The history of ERC is not confined to the history of the physical principle of energy conservation. Instead, it covers a collection of policies which – on occasion - employ the language and methods of physics to develop means for increasing the economic productivity of a given amount of fuel. The history of the 'Conservation Movement' has been richly researched by historians. Most famously, Samuel Hay's *Gospel of Efficiency* provided a detailed account of the increasingly scientifically informed use of natural resources in turn-of-the-century America[54]. But this is not a thesis about the conservation movement per-se. Nor is it a thesis about the conservation of energy as it is understood in physics. Though occasionally the principles of ERC did make literal recourse to physics. For example, in Chapter 7 we will see how some of America's leading physicists of the nineteen-seventies,

[53] Rose, N. (1999) Powers of Freedom: Reframing Political Thought. Cambridge University Press.
[54] Hays, S. (1959) Conservation and the Gospel of Efficiency. The Progressive Conservation Movement, 1890-1920. Pittsburgh University Press.

made use of physical chemist Josiah Willard Gibbs's notion of 'available energy' as a means of calculating quantities of energy that could be considered conserved in a given system[55].

Instead, the aim of this work is to show how the history of ERC lies not just in the policies of America's Progressive era 'conservation movement', led by President Roosevelt, and later – with less enthusiasm - by Howard Taft, but also in an older history grounded in the discovery of the laws of thermodynamics. With the discovery of first and second laws in the 1840s, the use of steam engines suddenly appeared not only inordinately productive, but also profligately wasteful (Chapter 2). Industrialists and engineers became pre-occupied with using fuels with utmost efficiency, and maximising the work that could be derived from irreversibly consumed and geologically distributed resources such as coal (Chapter 3). This work would develop into a science and policy of energy resource conservation would combine the conservationists' call to use resources wisely for the benefit of future generations, with these earlier engineers' concern with maximising work and minimising waste.

Central to my distinction, is my claim that over the course of the twentieth century, the physical principle of energy conservation came to be discussed as if it were a resource like any other. With the rise of ERC, as science and policy, both scientists and politicians came to discuss energy efficiency increases as if they were a source of energy supply[56]. Such thinking persists. Only recently the International Energy Agency (IEA) described energy efficiency as

[55] Socolow, R. et al. (1975) 'Efficient Use of Energy', Physics Today, Vol. 28, Iss. 8, pp. 23-33; Gibbs, J. (1878) 'On The Equilibrium of Heterogeneous Substances', Transactions of the Connecticut Academy, Vol. III., pp. 108-248.
[56] Meier, A., Wright, J., Rosenfeld, A. (1983) Supplying Energy Through Greater Efficiency. The Potential for Conservation. University of California Press., p. viii.

a ‘hidden fuel’, whose ‘output’ in 2010 exceeded that of all other sources of power[57]. Statements of this kind, which seem to exemplify what scholars in anthropology have begun to described as ‘resource ontologies’, defined as ‘assumptions about what resource substances are, their affordances, and what sustains them’[58]. Conserved energy, this thesis will argue, is an idiosyncratic example of such ‘resource making’, though one in which resource value is determined via acts of ‘epistemological and ontological creativity’ rather than physical processes of material extraction[59].

But clearly the constitution of things, such as ‘resources’, is an historical process. Philosopher Ian Hacking has proposed the term ‘historical ontology’ to describe how ‘comings into being’ take place in time[60]. Ontology, since the seventeenth-century, has meant a branch of metaphysics, is a means of talking about how objects come into being. Historical ontology supports that some objects or effects do not exist in any recognisable form until they are subjected to study, scientific or otherwise. Practices, both intellectual and physical bring phenomenon into being, as new ‘styles of reasoning’ spread, and solidify objects of knowledge[61]. That is not to say that resources are solely a ‘social construction’. Hacking points out that Thomas Kuhn famously dismissed the tenets of social constructivism by pointing out the absurdity of claiming ‘nature itself, whatever that may be, has seemed to have no part in the development of beliefs about it’[62]. Clearly the history of ideas has a material substrate, and ideas have material consequences.

[57] Saunders, H. (2015) ‘Recent Evidence for Large Rebound: Elucidating the Drivers and their implications for Climate Change Models’, The Energy Journal, Vol. 36 Iss. 1.

[58] Richardson, T., Weszkalnys, G. (2014) ‘Resource Materialities: New Anthropological Perspectives on Natural Environments’, Anthropological Quarterly, Vol. 87, Iss. 1, pp. 5-30.

[59] Richardson, T., Weszkalnys, G., 2014, p. 12.

[60] Hacking, I. (2002) Historical Ontology. Harvard University Press. p. 5.

[61] Hacking, 2002, p. 11.

[62] Ibid.

Accordingly, the principles of historical ontology allow discussion of both the material and ideational 'coming in to being' of resources. Like all resources, conserved energy has a dualism; which as geographer Gavin Bridge suggests for resources more generally, is partly an aspect of the physical world of obdurate materials and partly a cultural appraisal of the worth of using these materials[63]. So the alternative risk is to claim too great a role for nature in constructing historical objects, such as resources[64]. Clearly nature plays a role in establishing the ontology of resources, particularly in the more obviously obdurate and material cases of coal or petroleum, but so too do the human practices of prospecting, surveying, geological analysis, refinement, and speculation. The quantification of resources has always, to some degree, relied on ideational processes, such as 'speculation', the 'observation of potentiality'[65].

As Hacking's argument proposes, the project of historical ontology, in this thesis' case, remains somewhat philosophical, as the coming into being of resources is, in part, ideational work. The idea being that the potentiality of a resource is not fully known, but some action must be taken on the basis of anticipating a return. Speculation often involves hypothetical reasoning: this rock type has indicated the presence of oil here, so we can assume oil can be found wherever this rock is found. On this understanding, resources can assume an imagined or conceptual form before they are physically realised. As the anthropologist Giza Weszkalnys argues, resources are 'simultaneously social, aesthetic, and deeply politicized as

[63] Bridge, G. (2009) 'Material Worlds: Natural Resources, Resource Geography and the Material Economy', Geography Compass, Vol. 3, Iss. 3. pp.1217-1244.

[64] Hacking, 2002, p. 17.

[65] Weszkalnys, G. (2015) 'Geology, Potentiality, Speculation: On the Indeterminacy of First Oil', Cultural Anthropology, Iss. 30, No. 4. pp. 611–639.

well as materially and biophysically grounded'[66]. To adapt Hacking's point on the need for both ideational and material analysis, we can note that, what might be called 'resource practitioners' are engaged in identifying resources, but a resource is a metaphysical concept, in so far as it is a human category for a natural thing. Concepts, in turn, are often reduced to words and knowledge, text or speech acts which are carried out in specific sites, and which are granted different measures of authority, influence, and consequence[67].

METROLOGY

My third argument is that conserved energy is a particular kind of resource. Rather than being formed over periods of geological time, mined, and refined, conserved energy comes into being through acts of measurement. That is, through the work of engineers who estimate or design efficiency increases, and by modellers who create simulations and forecasts that demonstrate how these increases might be achieved in the wider system of energy use. As geographer Andrew Barry has noted, drawing on the work of Belgian philosopher of science Isabelle Stengers, the act of measuring conversions in energy, including the measurement of work that can be derived from a given amount of fuel, is a constructive act. Moreover, measurement is not only an empirical exercise; it takes place in reference to a theoretical concept: the law of the conservation of energy. In estimating the amount of energy that can be conserved by a given intervention, conservationists, be they policy analysts, physicists, or engineers compare measurements, models, and simulations to an idealised rate of conversion that can never achieved in practice; the fictional notion of a perfectly efficient, and thus perfectly conservative, rate of energy conversion[68].

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[66] Weszkalnys, G. (2016) 'A Doubtful Hope, Resource Affect in A Future Oil Economy', Journal of the Royal Anthropological Institute, Vol. 22, Iss. S.1, pp. 127-146.

[67] Hacking, 2002, p. 17.

[68] See Chapter 7 in particular. And Barry, A. (2015a) 'Thermodynamics, matter, politics', Distinktion: Journal of Social Theory, Vol. 16, Iss. 1, p. 117.

Measurement is not something divorced from material reality. Far from it, in fact, measurement bridges the material and the theoretical: the properties of the material world are quantified in reference to theoretical constructs, such as units of distance; and, accumulated metrological information is used to form new theories[69]. Similarly, as noted, measurements of energy conversion are made in reference to a specific theoretical construct, a perfectly efficient engine. This fictional device, as Barry, following Stengers, notes, allows measurements of energy conversion to made against a universal benchmark: there is a an 'intrinsic relation between energy and measurement'[70]. Drawing on Isabelle Stengers' history of thermodynamics, *Cosmopolitics* ([2003] 2010), Barry claims the physicist and engineer's concept of energy, as a theory of agency rather than a thing-like resource, is apparent wherever the 'quantitative measure of energy transformations' occurs[71]. Acts of measurement, empirical quantification made in reference to theory, are central to the construction of the concept of energy, and also to its manifestation as a 'resource'. As such, the focus of this thesis will be upon the range of sites in which such measurements of energy transformation occur, whilst also extending this analysis to identify the ways in which these measurements are folded into political life[72].

But the act of metrology takes on geographic significance. Advocates of energy conservation combine practices of energy measurement with the belief that the efficient use of energy acts within a determinate system that assures a proportion of material fuel or electricity, is conserved from use as the result of increasing energy efficiency. Throughout this thesis I

[69] Kuhn, T. (1961) 'The Function of Measurement in Modern Physical Science', Isis, Vol. 52, No. 2, pp. 161-193.
[70] Barry, A. (2015a) p. 117.
[71] Stengers, I. (2010) Cosmopolitics I. University of Minnesota. Trans. Bononno, R.
[72] Barry, A. (2015a).

argue that ERC is best understood as a 'metrological resource', something granted the ontological status of a resource via acts of measurement, calculation, and computation[73]. That is not to suggest that other more obviously material resources such as petroleum are not subject to processes of measurement, or that measurement plays does not play important role in geologists' forecasted estimates of 'petroleum reserves' for example[74]. But the act of using energy efficiently and then estimating the amount of energy resources that have been 'conserved' as a result, is a form of resource ontology in which measurement proves both the availability and the *existence* of that resource, without recourse to material proof[75].

THE GEOGRAPHY OF ENERGY

In contrast to other sources of power, conserved energy has attracted little interest from geographers[76]. This is despite the fact that human geographers have held a sustained interested in the subject of energy. In fact, a subfield, later termed 'energy geography' emerged in the post-war period. French Vidalian geographer Max Sorre's 1948 *Fondements de la Géographie Humaine* contained three chapters on the geography of energy[77]. The first monograph on the subject, French Marxist geographer Pierre George's 1950 *Géographie de l'Énergie*, offered a post-war account of modern energy systems in the Communist and Capitalist spheres, in which he argued that the rate and efficiency of energy production was socially determined, in a historically materialist way, rather than naturally given[78]. Energy seemed particularly amenable to quantitative analysis as there had a profusion of energy

[73] Barry, A. (2006) 'Technological zones', European journal of Social Theory, Vol 92, Iss. 2., pp. 239-253.

[74] Bowden, G. (1985) 'The social construction of validity in estimates of US crude oil reserves', Social Studies of Science, Vol. 15, pp. 207-40

[75] We return to the evidential and material consequences of ERC in the thesis's conclusion.

[76] With the exception of Steve Hinchliffe, Hinchliffe, S. (1995) 'Missing Culture: energy efficiency and lost causes', Energy Policy, Vol. 23, Iss. 1, pp. 93-95.

[77] Sorre, M. (1948) Fondements de la Géographie Humaine. Colin, Paris.

[78] George, P. (1950) Géographie de l'Énergie. Paris, Librairie de Médicis.

statistics following World War II[79]. Drawing on this information, in the 1960s and 1970s Anglophone geographers John Chapman, Peter Odell, and Gerald Manners developed their own approaches toward energy geography, respectively focusing on quantitative data on energy use, oil's geographical distribution and the networks of its trade, and energy as a complex of dispersed fuel producers and consuming industries. All drew on contemporary methods in economic geography, which were largely uncritical and descriptive[80].

The history of energy geography appears closely coupled to that of human geography more generally; As Barnes has noted, a post-war trust in the objectivity of numbers was combined with new statistical and econometric methods and the computing hardware to carry out the necessary calculations. The transformation was theoretical as much as methodological, as geographers increasingly turned to the use of abstract theory rather than the description of geographical specificity[81].

But energy could have played a more significant role for the discipline. In 1965, the British Geographical Association's annual conference theme was 'The Geography of Energy'. Geomorphologist David Leslie Linton (1906-1971) gave the presidential address, and acknowledged George and Manner's work, though he stated that they had only dealt with 'the economic geography of mechanical and electrical energy', whereas he wished to discuss 'literally the geography of energy with no qualifications as to either the kind of geography of the kind of energy'. His proposition was that all changes on earth's surface could be

[79] Chapman, J. (1961) 'A Geography of Energy: An Emerging Field of Study', Canadian Geographer, Vol. 1, pp. 10-15.

[80] Odell, P. (1963) An Economic Geography of Oil. Routledge; Chapman, J. (1961); Manners, G. (1964) The Geography of Energy. Hutchinson's University Library, London. On this economistic turn in geography more generally see Barnes, 1996.

[81] Barnes, T. (2008) 'Geography's underworld: The Military-Industrial Complex, Mathematica Modelling, and the Quantitative Revolution', Geoforum. Vol. 39, Iss. 1. pp. 3-16.

described 'in the physicists' sense' as 'work has been done'[82]. Somewhat playfully, but with apparent sincerity, Linton proposed that energy might offer a means to reunite the discipline, as if human geography were considered 'energy in the service of man' and physical, as 'energy transformations where man has no part', then the watt and calorie could provide a common unit of analysis[83].

However, a younger geographer, David Stoddart (1937-2014), would propose an even more general explanatory device[84]. Stoddart argued that geographers should describe both biological and physical processes in the single language of 'general systems', defined as a 'set of objects together with relationships between the objects and between their attributes'[85]. As a result, energy geography, along with geography more generally, moved away from idiographic, specific description, toward nomothetic, systematic explanation[86]. As we will see in the course of this thesis, the science of ERC followed a similar trajectory. Concerns over the supply of energy would challenge economic orthodoxy (Chapters 3, 7), raising doubts about the value of abstract economic theorisation, and suggesting that maybe economic analysis should be replaced by 'energy analysis', a form of political economy in which the supply and demand of energy resources was considered as the determinative factor for economic growth. As it was, like in geography, this school of thought was subsumed by the rise of systems analysis (Chapter 6).

[82] Linton, D. (1965) 'The Geography of Energy', Geography, Vol. 50, No.3, pp. 197-228.

[83] Ibid., p. 198; 227.

[84] Malanson, G. (2014) 'Physical geography on the methodological fence: David Stoddart (1965): the ecosystem as a geographic principle and method', Geography, Vol. 38, No. 2, pp. 251-258.

[85] Stoddart. D. (1965) 'Geography and the Ecological Approach: The ecosystem as a geographical principle and method', Geography, Vol. 50, Iss. 3, pp 242-251.

[86] Barnes, 1996.

More recently, a 'new geographies of energy' movement has been announced[87], which acknowledges the growing use of social and critical theory in the geography of energy, with an explicit emphasis on the specific materiality and infrastructural composition of fuel and inter-fuel geography[88]. Another, older influence has been an interest in Marx and other political economists, and attempts at a post-positivist and less doctrinaire approach to historical materialism[89]. Such work unknowingly resuscitates the claims made by Pierre George, recent work informed by political ecology, has stressed the role of social relations in natural resource 'construction'[90].

This turn has been tempered with a renewed interest in the constructive role of non-human agency, and a move away from the incursion of purely 'social' theory[91]. Though there is no single explanation, one important theoretical influence on this materialist turn has been the school of 'Actor Network Theory' associated with social theorist Bruno Latour, who famously railed against social constructivism's side-lining of non-human agency. In response, human geographers have re-affirmed their commitment to 'more-than-human' geographies', material, and multiple[92].

[87] Zimmerer, K. (2011) 'New geographies of energy', Annals of the Association of American Geographers 101 Iss. 4. pp. 705-711.

[88] Calvert, K. (2015) 'From 'energy geography' to 'energy geographies': perspectives on a fertile academic borderland', Progress in Human Geography, Vol. 40, Iss. 1, pp. 105-125.

[89] Agnew, J. (2003) 'The return of time and the need for a new materialism', Political Geography, Vol. 12, No. 1, pp. 84-86.

[90] Bakker, K., Bridge, G. (2006) 'Material worlds? Resource geographies and the 'matter of nature', Progress in Human Geography, Vol. 30, Iss. 5. pp. 5-27; Huber, M. (2008) 'Energizing Historical Materialism: Fossil Fuels, Space and the Capitalist Mode of Production', Geoforum, Iss. 40, pp. 105-115.

[91] Anderson, B., Wylie, J. (2009) 'On Geography and Materiality', Environment and Planning A., Vol. 41, Iss. 2, pp. 300-332.

[92] Whatmore, S. (2006) 'Materialist Returns: Practising Cultural Geography in and for a more-than-human world', Cultural Geographies, Vol 13, Iss. 4, pp. 600-609.

As it stands, diverse new materialisms in geography has led to a wide-ranging body of work ranging from neo-vitalism to network analysis[93]. Broadly, the turn might simply be described as a re-affirmation of worldly assemblages as acts of 'co-constitution between humans and non-humans', that should have always been at the forefront of human geography[94]. The materialist turn, it is claimed, has revived resource geography, in so far as it has led the discipline to reconsider the locus of agency in resource making, and transformed the notion of construction, by asserting the heterogeneity of ways in which resources come into being[95]. As Gavin Bridge asserts, geographers must continue to unsettle the essentialisation of 'resources'[96]. Accordingly, this thesis will attempt to do so for ERC, by returning to the historical circumstances in which conserved energy became recognised as a *resource*.

Geographer Matthew Huber recently observed the geography of energy is witnessing a 'boom', feeding off renewed interest in energy in the humanities and social sciences. There has clearly been an 'expansion in scope and theoretical plurality'[97]. Within which, as Huber notes, the emerging sub disciplines of ecocriticism, energy humanities, and the anthropology of energy have promoted the idea that the energy that is derived from resources has a causal relation to the more diffuse notion of 'power' as it is understood in social theory[98]. The anthropologist Dominic Boyer, for example, proposes a new use of Foucault's biopolitics, the study of how power is manifest via the decentralised or even internalised control of bodies

[93] Müller, M. (2015) 'Assemblages and Actor-Networks: Rethinking Social Material Power, Politics, and Space', Geography Compass, Vol. 9. Iss. 1, pp. 27-41.

[94] Ibid.

[95] Bakker, K., Bridge, G. (2006) 'Material worlds? Resource geographies and the 'matter of nature', Progress in Human Geography, Vol. 30, Iss. 5. pp. 5-27.

[96] Bridge, G. (2009) 'Material Worlds: Natural Resources, Resource Geography and the Material Economy', Geography Compass, Vol. 3, Iss. 3. pp.1217-1244.

[97] Calvert, K. (2015) 'From 'energy geography' to 'energy geographies', perspectives on a fertile academic borderland', Progress in Human Geography

[98] Huber, M. (2015) 'Theorizing Energy Geographies', Geography Compass, Vol. 9, Iss. 6, pp. 327-338.

and population, can be reconceptualised as 'energo-politics' the study of similarly decentralised 'power over (and through) energy'[99]. Social theory is being increasingly applied to the study of fuels and the changing infrastructure of energy use in order to show how social construction plays a role in energy 'transformations', but this is being done so in a way which acknowledges the agency of the physical world in constraining and thus co-constructing such change[100].

But, as Andrew Barry has noted, energy geographers have yet to explain the significance of 'the concept of energy' as it is understood in physics and engineering for the discipline[101]. In fact, what some geographers pluralistically term 'energy geographies' could be seen as fairly conventional resource geographies. As Barry argues, a more specific geography of energy, of the kind which is undertaken in this thesis, should address the concept of energy in the specific sense that it is understood in physics and engineering, as a measurement of a systems ability to do work, rather than making the mistake of describing energy as it were a thing in and of itself. By returning to the constructive acts of measurement by which ERC comes into being, this work is intended, following Bridge, to destabilise the essentialisation of conserved energy as a resource[102].

ENERGY, RESOURCE, CONSERVATION

In a further deviation from geography's orthodox canon, in order to explain what I mean by ERC, I draw on the history of science in order to connect the intellectual history of energy to

[99] Boyer, D. (2011). Energopolitics and the anthropology of energy. Anthropology News 52(5), pp. 5–7

[100] Appel, H., Mason, A., Watts, M. eds. (2015) Subterranean Estates: Life Worlds of Oil and Gas. Cornell University Press.

[101] Barry, A. (2015a) 'Thermodynamics, matter, politics', *Distinktion: Journal of Social Theory*, Vol. 16, Iss. 1, pp. 110-125.

[102] See note 91.

resource history. The history of energy, like the history of science more generally, reminds us that scientific knowledge is a human achievement, attained by working with the material world[103]. As discussed, the term 'energy' only came to assume a specific meaning in the mid-nineteenth century, when, as geographer Vaclav Smil reminds us, but 'rather an abstract collective concept, adopted by nineteenth century physicists to cover a variety of natural and anthropogenic phenomena'[104]. In 1929, George Sarton, 'father' of the discipline, proposed the discovery of energy as a 'classic' example of 'positive knowledge', the progressive unveiling of an inherent, internal, scientific truth through systematic work and occasional insight[105]. But most famously Thomas Kuhn described how in Europe, the concept of energy was simultaneously discovered by at least four groups of European natural philosophers between 1842 and 1847. Drawing on a range of observations, experimental evidence and pre-existing ideas about nature, all identified 'a single "force," which could appear in electrical, thermal, dynamical, and many other forms'[106].

This discovery was driven by more than mere curiosity, as the force derived from transforming lumps of coal into a scalding jet of steam in an engine, for example, that could be exploited for human use. Steam engines, as crystallographer and historian of science J.D. Bernal observed, following Marx and Engels, were vital to the unparalleled growth of mechanised industry in the nineteenth century, their operation transformed a mineral into mechanical force that could be applied to myriad industries[107]. Accordingly, the force

[103] Shapin, S. (2010) Never Pure: Historical Studies of Science as if it Was Produced by People with Bodies, situated in Time, Space, Culture and Society, and Struggling for Credibility and Authority. Johns Hopkins University Press.

[104] Smil, V. (2006) Energy: A Beginners Guide. Oxford.

[105] Sarton, G. (1929) 'The discovery of the law of conservation of energy', Isis, Vol.13, Iss, 1. pp 18-44.

[106] Kuhn, T. (1977) 'Energy Conservation as an Example of Simultaneous Discovery', Essential Tension. Chicago University Press, p. 68.

[107] Bernal, J. (1953) 'Science, Industry and Society in the Nineteenth Century', Centaurus, Iss. 3, pp 138-165.

generated from coal came to be understood as conceptually akin to human labour, and able to be described with the same term: energy[108].

Owing to this new found usefulness, coal, like other forms of energy – including the somatic labour of a horse or human – was increasingly considered as if they were in some way analogous *resources*[109]. This second term in my formulation, resource, assumes a very anthropocentric meaning. A resource is an asset, something that usefulness can be derived from, either immediately or at some point in the future. The recipient of this usefulness is the one that categorises the other as a resource.

German American economist Erich Zimmermann (1888-1961), who we will encounter in Chapter 4, would write in 1933 that 'resources are not, they become'[110]. This functional theory of resources is readily apparent in relation to coal. As thanks to the popularisation of steam engines in the eighteenth and nineteenth century, a common mineral became a fundamental source of industrial power and prosperity. Whether the engine drove prosperity or prosperity encouraged the use of steam engines is still hotly debated[111]. But given its prodigious concentration of energy, in the mid-nineteenth century coal came to be considered a resource of central importance to political economy. As a result, the physical properties of coal use became a governmental concern, surveys of national coal reserves took place, and experts considered its efficient extraction and use[112].

[108] Wise, N. (1988) 'Mediating Machines', Science in Context, Vol. 2, Iss. 1, pp. 77-113.

[109] Rabinbach, A. (1990) The Human Motor: Energy, Fatigue, and the Origins of Modernity. University of Califonia Press.

[110] Zimmermann, E. (1957) Conservation in the Production of Petroleum. Yale University Press.

[111] For example, Wrigley, 2010, adopts a systems theoretical approach, in which multiple feedbacks (including demographic pressure, agricultural growth, and the emergence of small scale industry) are identified, and presented in a non heirachical manner, in order to avoid the over determination of any one factor in the history of industrialisation.

[112] Madureira, N. (2014) 'The Rebound Effect', Key Concepts in Energy. Springer, pp. 33-52.

Before the mid-nineteenth century 'conservation principles', the idea that something persisted or was always present in nature despite evident and continual changes, had long provided a means for theorising about the constancy of the universe and the potential steady state that could be achieved in political economy[113]. In Antiquity Aristotle had explained the circularity of planetary motion as the result of 'perfect' simplicity, as observed orbits took the shortest possible route: a circumference. In 1644 René Descartes (1596-1650) calculated that if two bodies collided, the force of motion was conserved. It was this constancy which, he argued, had allowed God to construct the universe. French mathematician Pierre Maupertuis (1698-1759) extended the idea of nature's simplicity, drawing on the physics of mechanics, he stated a general principle that nature accorded to a principle of least action[114]. It followed that nature's minimal expenditure acted to conserve natural agency. In general, pre- and Enlightenment natural philosophers tended to describe 'the balance of nature' in terms of 'equality, equilibrium, and conservation', deviations from which, it was observed, would be eventually be corrected by those same natural forces[115].

So, in being conserved, energy conformed to a more general set of conservation principles in physical thought[116]. But at the same time, measurable losses in energy were readily apparent in its myriad conversion processes. As early as 1783, French engineer Lazare Carnot (1753-1823) had noted machines consumed more force than they expended. His son, Sadi Carnot

[113] Wise, N., Smith, C. (1989) 'Work and Waste I: Political Economy and Natural Philosophy in Nineteenth Century Britain', History of Science, Vol. 27, Iss. 3, pp. 263-301.

[114] Yourgrau, W., Mandelstam, S. (1968) Variational Principles in Dynamics and Quantum Theory, Pitman London.

[115] Wise, N., Smith, C. (1989) 'Work and Waste I: Political Economy and Natural Philosophy in Nineteenth Century Britain', History of Science, Vol. 27, Iss. 3, pp. 263-301., p. 268.

[116] A point made, contra Kuhn's 'simultaneous discovery' narrative in Cohen, I. (1969) 'Conservation and the Concept of Electric Charge: An Aspect of Philosophy in Relation to Physics in the 19th Century', p. 362. in Clagett, M. ed. Critical Problems in the History of Science, University of Wisconsin Press.

(1796-1832) wrote perhaps the first text on fuel economy *Reflexions on the Motive Power of Fire, and On Machines Adapted to Develop that Power* (1824 [trans. 1899]). In attempting to answer the question of whether engines could indefinitely increase in efficiency, Sadi had noted there was always disequilibrium between the heat generated in combustion and the power an engine could exert. This meant a perfectly efficient engine was impossible, fuel would always be imperfectly transformed into motive power[117]. What would later be known as 'energy' appeared to be used only at a loss.

As philosopher of science Isabelle Stengers notes, a theoretical construct, the perfectly efficient engine allowed calculations of energy conversion to be made in relation to a metaphysical idea, an impossibly efficient means of converting energy into work. Though conceptual, this idea allowed measurements of energy transfer to be made against a universal benchmark, though one that was entirely fictional[118].

With similar ambition but a different effect, philosopher of science Émile Meyerson (1859-1933) recognised that Carnot's observation challenged the conception of a 'universe eternally immutable'[119], as the dissipation of heat in an engine demonstrated that all systems 'constantly dissipate'[120].

[117] Smith, 1998, p. 89.

[118] Stengers, 2010; Barry, 2015a.

[119] Meyerson, É. (1991) Explanation in the Sciences, Boston. Trans. Siple, M., Siple, D., p. 23.

[120] Meyerson, É. (1989) Identity and Reality. Routledge. p. 41; 215. Trans. Lowenberg, K. Like Stengers, Meyerson argued that, in doing so, energy, which he termed the 'causal postulate', became 'a concept impossible to clearly define in its entirety' without the support of metaphysical constructs such as a perfect heat engine.

Carnot's observation was increasingly formalised into a law, a universal principle that useful energy tends irrecoverably to dissipate[121]. In light of this discovery, energy was increasingly understood as a wasting asset, which had to be used efficiently else potential use value would dissipate. As the British natural philosopher and engineer William Thomson (1824-1907) noted in 1849, drawing on Carnot's observation: 'work is lost to man irrecoverably; but not lost to the material world'[122]. For example, in an engine, coal's energy could be conserved as ambient heat, but this heat would have little practical use. Energy, as argued, was only useful insofar as it could do 'work'. Energy was conserved, but it was no longer a resource, as it was no longer in a useful form, hence first and second law of thermodynamics did not contradict one another.

This rather anthropic idea betrayed that thermodynamics grew from engineering principles. As American physicist Percy Bridgman (1882-1961) famously described the laws of thermodynamics, they 'smell more of their human origin' as compared to other physical laws[123]. It is no surprise that the discovery of the conservation of energy placed the concepts of work and waste at the centre of political economy, and in doing so, implied that society was engaged in harbouring depleting energy resources, rather than something based on more stable principles of conservation[124].

As Meyerson had argued, an immutable universe had been replaced with one of constant dissipation. The implications of this, as the historian Norton Wise later suggested, armed with this new knowledge, the advancement of civilisation became an urgent project which

[121] Smith, 1998.

[122] Wise, N., Smith, C. (1989) 'Work and Waste II: Political Economy and Natural Philosophy in Nineteenth Century Britain', History of Science, Vol. 27, Iss. 4, pp. 391-449.

[123] Bridgman, 1941, p. 1.

[124] Wise, N., Smith, C. (1989).

'depended on directing this decline into productive work'[125]. More comprehensively still, for philosopher Ivan Illich, the dissipative implications of the laws of energy meant the 'universe itself is placed under the regime of scarcity' and that as a result, humans are 'no longer born under the stars but under the axioms of economics'[126]. It was this economisation of nature which framed nineteenth century efforts to use fuel more efficiently (Chapter 2) and this same fear of irreversible scarcity which led to the twentieth century science and policy ERC.

Historical changes in how energy came to be understood, which we can consider epistemologies of energy, have remained under interrogated as agents of political and social transition[127], despite their potential significance to the history of resources more generally. To provide evidence for this claim one only needs to think of the 'paradigm destruction' the discovery of the laws of thermodynamics precipitated midway through the nineteenth century with regard to the principles of natural philosophy thought applicable to material resources. The discovery of energy conservation destroyed an earlier conception of the universe as something governed by reciprocal Newtonian dynamics, and instituted in its place a theory of 'energy', a theory of causal relations which imposed irreversible limits upon the conversion of material resources into productive power[128].

Within nineteenth century political economy there was a persistent controversy over whether, according to the new epistemology of energy, society acted to conserve or expend energy.

[125] Wise, N. (2002) 'Time Discovered and Time Gendered in Victorian Science and Culture', From Energy to Information: Representation in Science and Technology, Art, and Literature. Ed. Clarke and Henderson. Stanford: Stanford University Press.

[126] Illich, I. (2010) 'The Social Construction of Energy', New Geographies 2., Landscapes of Energy. Ed. Ghosn, R. Harvard University Press.

[127] A notable exception is Smith, C. (1998) The Science of Energy: A Cultural History of Energy Physics in Victorian Britain. Athlone Press: London.

[128] Kuhn, T. (1962) The Structure of Scientific Revolutions. University of Chicago Press.

For example, in 1832 Belgian statistician Adolphe Quetelet (1796-1874) ruminated that 'analogy would lead one to believe that in the social state one may anticipate finding in general all the principles of conservation that one observes in natural phenomena'[129]. Whereas Jevons, in his 1865 *Coal Question*, stated that 'while other countries mostly subsist upon the annual and ceaseless income of the harvest, we are drawing more and more upon a capital which yields no annual interest, but once turned to light and heat and motive power, is gone for ever into space'[130]. Conflicting energy 'cosmologies' of these kinds can be found at different points in the history of ERC. The emergence of a new notion of societal conservation of energy, documented here, might be thought of as a new energy epistemology contributing to a distinct energy cosmology, the idea of a society of 'Maxwell's demons' working against entropy via personal acts of asceticism[131].

THE HISTORY OF ENERGY CONSERVATION AS A RESOURCE HISTORY

As philosopher Ivan Illich once wrote, there 'is little in common between "e" when a physicist writes it and "energy when the word is used by an economist, political or windmill fan'[132]. And as we shall see, for most of its history ERC was a science more concerned with conservation and resources rather than anything more recognisably thermodynamic. Though there are some commonalities (as we shall see in Chapter 7). But in the early twentieth century America, the term conservation also came to be applied to the 'wise use' of natural resources, with the suggestion that careful use conserved Earth's abundance. The early

[129] Porter, T. (1986) The Rise of Statistical Thinking. Princeton University Press.

[130] Jevons, W. 1865, p. 412.

[131] Weinberg, A. (1982) 'On the relation between information and energy systems: a family of Maxwell's Demons', Interdisciplinary Science Review, Vol. 7, Iss. pp. 47-52.

[132] Illich, 2010.

history of the conservation movement has a rich history and historiography[133]. However, so far unacknowledged, is the shifting semantics of conservation, and with it, the political techniques by which society could act in a resource conservative way, though for a specific kind of resource: those from which energy could be derived.

Conservation in the first half of the twentieth century implied the prohibition or reduced rate of extraction of natural resources, including fuels. But, this designation soon shifted, and by the second half of the twentieth century, conservation meant increased efficiency of resource use: the onus shifting from producer to consumer (Chapter 4). In some sense then, this thesis can be seen as a conceptual history of the term 'conservation', but not conservation alone. Conservation became a cognate of 'efficiency', itself a term with a history stretching back to Aristotelian scholastics, and which, in modern engineering, came to mean doing more with less[134]. Efficiency is central to the demonstration and application of thermodynamics, a means of bringing energy under ever more perfect human control[135] (Chapter 2). As we will see in Chapter 7, the idea that energy could be conserved by redefining the notion of efficiency would prove central to the ontological claims made by conservationists. Only then, would conservation come to be discussed in explicitly thermodynamic terms.

But in general, historical accounts of energy, as Barry has noted in the case of energy geography, tend to similarly focus on a circumscribed set of specific fuels, industries, or

[133] Hays, S. (1959) Conservation and the Gospel of Efficiency. The Progressive Conservation Movement, 1890-1920. Pittsburgh University Press; Tyrrell. I. (2015) Crisis of the Wasteful Nation: Empire and Conservation in Theodore Roosevelt's America. Chicago.

[134] Karns Alexander, J. (2008) The Mantra of Efficiency: From Waterwheel to Social Control. Johns Hopkins University Press.

[135] Alexander, J. (2009) 'The Concept of Efficiency: An Historical Analysis', Gabbay, D., Meijers, A., Woods, J. eds. Handbook of the Philosophy of Science: Philosophy of Technology and Engineering Sciences. Elsevier, pp. 1007-1030.

technologies of energy production. For example, Shellen Wu and Peter Shulman both trace the relation between coal and empire, in China and America respectively[136]. Wu argues the import of German geological knowledge caused an 'underlying reconceptualization of resources', that had been underutilised, and their potential role in industrialising China. Shulman's focus is distinctly more materialist, and he describes coal's role in consolidating America's global empire, as both a commodity and a fuel allowing long-distance transport networks, long before the commonplace use of oil[137]. Christopher Jones has described how the power lines of electric conveyance created 'landscapes of intensification', geographies which encouraged increased energy use[138].

Joan Bromberg's account of the development of nuclear fusion in America is one of the few energy histories which addresses the 'invention of a new energy source'. She describes how such invention is as much a process of political and financial feasibility, as technological and scientific[139]. Aside from a few examples, there has been a lack of interest in energy demand rather than supply. David Nye is an exception, having surveyed the sources of energy consumption, informed by both the history of consumerism and the constraints placed on this by technological systems[140].

But there has been almost no interest in the historical significance of the idea that reductions in energy demand could be considered a means of supply. Part of the reason for this is that

[136] Wu, S. (2015) Empires of Coal: Fuelling China's Entry into the Modern World Order, 1860-1920. Stanford University Press.

[137] Shulman, P. (2015) Coal and Empire: The Birth of Energy Security in Industrial America. Johns Hopkins University Press.

[138] Jones, C. (2014) Routes of Power: Energy and Modern America. Harvard University Press.

[139] Bromberg, J. (1982) Fusion: Science, Politics and the Invention of a New Energy Source. MIT Press.

[140] Nye, D. (2012) 'Chapter 16: Consumption of Energy', in Trentmann, F., ed. The Oxford Handbook of Consumption. Oxford University Press.

historians of science' earlier pre-occupation with the history of the concept of energy is not folded into such 'resource histories'. My contention is that historians have missed the significance of ERC, which marked a dramatic reinterpretation of the properties of energy resources, their possible limits, and their means of control[141].

To recap, the objective of this thesis, in outlining a sequence of historical problems regarding the conservation of energy resources and their attempted resolution, is to show how, from the late 19th century onwards, a variety of ideas, events, discoveries, and forms of knowledge coalesced into the belief that society could act, collectively, as a mechanism for conserving energy. The principles of ERC that emerged transformed the government of energy, shifting the onus to conserve from producer to consumer, and in so doing, limiting the legitimacy of government to intervene in the allocation of energy resources. My argument is that the science of ERC is of analytical significance beyond the fields of energy studies, geography, or environmental history, as the objective of conserving energy imposed an idea about how the state should govern. The establishment of energy conservation policy is not just an episode in the history of energy; it has had distinct implications for post-war theories of political economy.

[141] Turnbull, T. (2014) 'Review: Carbon Democracy: Political Power in the Age of Oil', Area, Vol 46, Iss.1, pp. 115-117.

CHAPTER 2. RESITUATING JEVONS' PARADOX

In 1865 William Stanley Jevons warned that Britain's coal could be exhausted in a century's time. Jevons' argument, developed in his book *The Coal Question* (TCQ), contained a paradox. His contention was that increasingly the 'economical' (i.e. efficient) use of coal would do nothing to avert its exhaustion. On the contrary: increased efficiency would lower the cost of coal consumption, inducing demand and counter-intuitively increasing coal use over time. In the twentieth century, what become known as 'Jevons' Paradox' (JP) has provoked continuing controversy in response to growing calls for increased energy efficiency to conserve energy resources and to limit emissions. This thesis argues that there is nothing self-evident about the idea that society can act collectively to conserve energy resources, and that the history of this idea deserves close historical examination, particularly given its central role in contemporary efforts to mitigate climate change. Within this wider thesis, JP is important as an antithesis to the idea of ERC. In most contemporary accounts of JP, the original significance and referents toward which the paradox was addressed are lost. In response, this second chapter re-situates JP in its historical context, reconstructing the ideas toward which Jevons' argument was directed. In order to do this, I address JP from the perspective of the history of economic thought and the history of technology. In doing so, it is argued that JP was directed toward two nineteenth-century ideas. The first, that the increasing technical efficiency of engines and industry could preserve Britain's coal for far longer than it would otherwise last. The second, that Britain's coal could be preserved by either supplementation with other forms of capital (factors of production), or by increasing the efficiency of capital via technological ingenuity. The identification of these two positions makes it clear that, before Jevons' despite increased rates of coal use, the conservation of coal was believed entirely possible. In effect there was nineteenth-century belief in the possibility

of coal preservation. Jevons disagreed with this proposition, as this chapter will outline, as he sought to apply the science of energetics to aggregate human behaviour. This leads this chapter to the conclusion that Jevons' considered the conservation of coal impossible owing to the social consequences of the law of energy conservation.

INTRODUCTION

In *TCQ,* the political economist William Stanley Jevons responded to contemporary concerns about the exhaustion of Britain's coal with a remarkable argument. His contention was that improvements in the efficiency of steam engines, smelting, and other types of engineering increased rather than decreased the rate of coal use. As he wrote:

> *'Whatever, therefore, conduces to increase the efficiency of coal, and to diminish the cost of its use, directly tends to augment the value of the steam engine, and to enlarge the field of its operation'*[142].

This was a period of dramatic increases in the efficiency of steam power. In the second half of the nineteenth century, the efficiency of engines tripled, and the cost of providing steam power fell fourfold[143]. Jevons argued that increased the efficiency of coal-use, though sensible in terms of household economy, would not mean coal would be 'laid up for the use of posterity'[144]. In fact, it was the 'very economy' of industry that was responsible for coal's 'extensive consumption'[145]. This was Jevons' paradox (JP) His intervention had an immediate impact, prompting Chancellor William Gladstone (1809-1889) to launch a Commission on the problems of fuel economy, making efficient fuel use an explicit political

[142] Jevons, W. (1865) The Coal Question; An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines. Macmillan, p. 78. *TCQ herein*.

[143] Fouquet, R. (2014) 'The Role of Energy Technologies in Long Run Economic Growth: A Historical Perspective', International Association for Energy Economics, IEAEE, New York, June.

[144] TCQ, p. 123.

[145] TCQ, p. 141.

concern for government for the first time[146]. Jevons' was not the first to address the question of coal's duration, but his work was notable for its sophisticated analysis of the societal dynamics of coal demand[147].

To some extent, my intention here is to suggest we should consider Jevons' work within the geographical canon. As geographer Andrew Barry has recently written, 'the history of geographical concepts should not be confined to the writings of geographers', and that returning to older, forget texts, can provoke contemporary reasoning[148]. Though Jevons was not a geographer, his work can be considered one of the founding texts of both resource and energy geography[149]. Moreover, his work is of consequence for geographers, as his contributions to economic theory subsequently proved highly influential in spatial science and economic geography, as Trevor Barnes has documented[150].

As noted in the thesis' introduction, under the guise of the 'rebound effect' JP has since returned as a concern for policymakers, first in the nineteen-seventies as a result of concerns about resource scarcity and the 'energy crisis'[151], and more recently, in light of contemporary concerns about climate change[152]. According to the United Nations Framework Convention

[146] HMSO (1871) Report of the Commissioners Appointed to Inquire into the Several Matters relating to Coal in the United Kingdom. Vol. 1. HMSO, London.

[147] Warde, P. (2013) 'Commentary: W. S. Jevons, The Coal Question', in Robin, L., Sorlin, S., Warde, P. eds. The Future of Nature: Documents of Global Change. Yale University Press.

[148] Barry, A. (2015) 'Geography and other disciplines: genealogy, anamnesis and the canon', Journal of Historical Geography, Vol. 49. pp. 85-93.

[149] Bridge, G. (2009) 'Material Worlds: Natural Resources, Resource Geography and the Material Economy', Geography Compass, Vol. 3, Iss. 3. pp. 1217-1244.

[150] Barnes argues that Jevons played a critical role in essentialising utlity maximisation as a principle in economic geography, see Barnes, T. 1(1996) Logics of Dislocation: Models, Metaphors, and Meanings of Economic Space. Guilford Press, p. 68.

[151] Khazzoom, D. (1980) 'Economic implications of mandated efficiency in standards for household appliances', The Energy Journal, Vol. 1, No. 4, pp. 21-40.

[152] Brookes, L. (1990) 'The Greenhouse effect: the fallacies in the energy efficiency solution', Energy Policy, Vol. 18, Iss. 2, pp. 199-201.

on Climate Change (UNFCC), one of the main ways by which it is hoped that global climate change can be mitigated is via increasing energy efficiency, thereby 'decoupling' economic growth from energy use[153], and reducing forecasted levels of fossil fuel emissions. Nonetheless, those involved in formulating the UNFCCC's mitigation strategies have recently begun to consider the possible implications of the rebound effect in undermining the contemporary global emissions abatement strategy[154]. Uncertainty regarding JP persists at the heart of this global political initiative[155]. It is also argued, drawing on Barry's call for expanding the geographic canon as a means of addressing present concerns, that the intellectual genealogy of the idea of ERC and its disputation resonate with contemporary political problems and theoretical concerns[156].

In order to address this contemporary problem and the renewed salience of the JP in public policy, this Chapter re-situates JP in its historical context in two ways. First, the paradox is re-situated within the history of economic thought. An earlier generation of geographers, most notably David Harvey, lent on the history of economic thought in discussing the role of social relations for the geography of resources[157], but this approach is largely absent from contemporary resource geography, which increasingly emphasises materiality and non-human agency at the expense of the ideational[158]. If Harvey's materialist analysis often had

[153] Semieniuk, G. (2016) 'Fossil Energy in Economic Growth: A Study of the Energy Direction of Technical Change, 1950-2012', SPRU, Working Paper Series.

[154] Saunders, H. (2015) 'Recent Evidence for Large Rebound: Elucidating the Drivers and their implications for Climate Change Models', The Energy Journal, Vol. 36 Iss. 1,

[155] Wagner, L., Ross, I., Foster, J., Hankamer, B. (2016) 'Trading Off Global Fuel Supply, CO2 Emissions and Sustainable Development', PLoS One, Vol. 11, Iss. 3, pp. 1-17.

[156] Barry, A. (2015).

[157] Harvey, D. (1974) 'Population, Resources, and the Ideology of Science', Economic Geography, Vol. 50, No. 3, pp. 256-277.

[158] Bridge, G. (2009) 'Material Worlds: Natural Resources, Resource Geography and the Material Economy', Geography Compass, Vol. 3, Iss. 3. pp.1217-1244.

little explicit to say about the materiality of resources, the 'new materialism' of geographical theory has surprisingly little to say about the history of ideas[159].

Resituating discussion of JP in the history of economic ideas is intended to elucidate that the paradox should be understood in the first instance, less as a critique of technological solutions to energy scarcity, as some contemporary environmentalist and energy studies scholars claim[160], than a means of exemplifying Jevons' political economy. In particular, JP demonstrates Jevons' central claim value was determined subjectively according to scarcity. At the time, following the principles of contemporary political economy, some argued, particularly Marx, that value was determined by inputs of labour or other forms capital, and that increases in non-coal capital, or more efficient use of capital, could prolong the value of Britain's supply of coal. Importantly, at this time, the prolongation of coal use was not discussed in terms of conservation, but in terms of preservation, economy, and posterity. Secondly, JP has to be re-situated within the history of technology[161]. In this context, it can be seen as an attack on the idea that new types of engines, known as economizers or regenerators, could preserve Britain's coal; or that new sources of motive power might supersede coal power, thereby preserving it. Those making this argument, it is argued, acted in a period of uncertainty regarding both the principles of thermodynamics and their societal consequences.

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[159] An exception to this has been a recent special issue of the *Journal of Historical Geography* which discusses the geographic canon, see Barry, A. (2015) 'Geography and other disciplines: genealogy, anamnesis and the canon', Journal of Historical Geography, Vol. 49. pp. 85-93.

[160] York, R. (2010) 'The paradox at the heart of modernity: The Carbon Efficiency of the global economy', International Journal of Sociology, Vol. 40, Iss. 2 pp. 6-22.; Missemer, A. (2012) 'William Stanley Jevons; The Coal Question beyond the rebound effect'. Ecological Economics, Iss. 82, pp. 97-103.

[161] Mayr, O. (1971) 'Adam Smith and the Concept of the Feedback System: Economic Thought and Technology in 18th Century Britain', Technology and Culture, Vol. 12, No. 1, pp. 1-22., and Morgan, M. (2012) The world in the model: how economists work and think, Cambridge University Press, Cambridge.

Energy analysts and ecological economists have tended to ignore or misunderstand the paradox's relation to his wider body of work. One example is ecological economist Blake Alcott, who in the only monograph on JP, attempted 'a decisive, policy-useful *judgement'* on the question of whether 'efficiency was part of the solution or the problem?'[162] of climate change. The result is something intellectual historian Quentin Skinner would describe as absurd 'non-history' in which past ideas are reduced to anticipations of later ones and awareness of historical change is lost[163]. Alcott mistakenly assumes that the work of Jevons and his predecessors 'contain all the concepts in today's debate'[164]. This Chapter responds to the weakness of Alcott's work, both as an account of JP and its history. I argue that the paradox remains an object of controversy precisely because those engaged in its study fail to suitably historicise it, and in doing so, they miss the specific ideas against which Jevons' argument was directed. More importantly, in de-historicising the paradox, Alcott and others ignore two significant historical events[165]. First, they miss that in *some* sense, the conservation of coal was considered possible in the nineteenth-century: indeed, this was the idea Jevons wanted to refute. Second, if Jevons argued against a nineteenth-century notion of coal conservation, as a prominent and orthodox economist, on what basis did later thinkers claim that energy resources could be conserved?

It is this later discontinuity with Jevons' thought, which I have termed energy resource conservation (ERC), which is the focus of this thesis. In order to begin the history of ERC,

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[162] Alcott, B. (2008) 'Historical Overview of the JP in the Literature', in Polimeni, J., Mayumi, K., Giampietro, M., Alcott, B., eds. The Jevons Paradox and the myth of resource efficiency improvements. Earthscan. London.

[163] I thank Andrew Barry for re-introducing Skinnerian Intellectual history to geographic inquiry, see Barry, 2015; Skinner, Q. (1969) 'Meaning and Understanding in the History of Ideas', History and Theory, Vol. 8, No. 1, pp. 3-53.

[164] Alcott, 2008, p. 13.

[165] Sorrel, S. (2009) 'Jevons Paradox Revisited: The evidence for backfire from improved energy efficiency', Energy Policy, Vol. 37, pp. 1456-1569.

this chapter provides an intellectual history of its antithesis, told from the perspective of the history of economic thought and the history of technology. In doing so, I follow Skinner's intellectual historical approach, inspired by Collingwood, which argues the history of ideas becomes absurd when it deviates from the study of the specific speech acts and referents, criteria, and classifications that were available to historical actors at the time[166].

WILLIAM STANLEY JEVONS

William Jevons was born in Liverpool in 1835 to a family of iron traders. Jevons' father Thomas (1791-1855) had invented the first iron-hulled ship, while his mother Mary-Anne Roscoe (1795-1845) was a poet. Both were Unitarians, religious modernisers who rejected the holy Trinity and believed in a monist God, a view commonly associated with an ascendant middle-class who believed in rationality and the public good[167]. Mary introduced Jevons to political economy at the age of eight, with a book by logician Richard Whately (1787-1863) titled *Easy Lessons on Money Matters for the use of Young People* (1836) intended to 'inculcate correct principles, and to guard against specious fallacies' with regard to money. Uninformed, Whately feared adults may come to consider money matters as 'revolting paradoxes'[168]. Jevons later acknowledged this early inspiration, and stated 'a sounder and more judicious thinker and writer never lived'[169]. Though intellectually nourishing, Jevons' childhood was unsettled. Mary died suddenly in 1845, the first of a succession of tragedies, including the death of his brother Roscoe, and the collapse of the family business in the mid-1840s following a speculative crash in the railway industry[170].

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[166] Skinner, 1969: 29.

[167] Maas, H. (2005) William Stanley Jevons and the making of modern economics. Cambridge University Press.

[168] Whately, R. (1836) [1853]) Easy Lessons on Money Matters for the use of Young People. John W. Parker and Son.

[169] Black, R.C.C. (ed.) (1981: 52) Papers and Correspondence of William Stanley Jevons. Volume VII. Macmillan.

[170] Peart, S. (1996) The Economics of William Stanley Jevons, London: Routledge.

Aged sixteen, Jevons began studying mathematics, chemistry, and logic at London University, later known as University College London ('UCL'). Despite his prodigious abilities, the failure of his father's business meant Jevons left university in 1854 to accept work as an assayer at Australia's Sydney mint. There, in his own time, he began studying political economy, reading Adam Smith's *Wealth of Nations* (1776) amongst others, whilst also publishing on his experiments in meteorology and chemistry. These varied interests led Jevons to consider how he could achieve the 'mathematical exactness' of natural science in analysing commerce. His first study in political economy, pertinent given the failure of his father's business, was on Australia's railways[171]. In 1859 Jevons returned to UCL to complete a joint degree in mathematics, logic, philosophy, political economy, classics, and history. It was at this time he believed he had discovered a unified mathematical approach to political economy. In a letter to his brother in 1860 he summarised his idea, stating that if value could be considered as a 'ratio of utility', or usefulness, one could demonstrate '*all the chief laws at which previous political economists have previously arrived, only arranged in a series of definitions, axioms, and theories almost as rigorous and connected as if they were so many geometrical problems*'[172]. Political economy, he argued, could become a science rather than an art.

Continuing his studies, in 1862 Jevons was awarded a Masters in mental philosophy and political economy ('the moral sciences'). That year he had a paper read at the Cambridge meeting of the BAAS, titled a 'Notice of a General Mathematical Theory of Political

[171] White, M. (1982) 'Jevons in Australia: A Reassessment', Economic Record, Vol. 58, Iss., 1, pp. 32-45.

[172] Black, R. D. 'Introduction' (1970) WSJ [1865] The Theory of Political Economy. Reprint. Penguin Books.

Economy'[173]. In the paper Jevons set out a 'true theory of Economy' where 'the springs of human action' were determined by 'feelings of pleasure and pain', which as correlates of utility and disutility could provide information on individuals' economic decision-making. Such decisions were aggregated in markets, where groups of individuals negotiated suitable prices for products that gave pleasure, as compared to their cost in terms of the strains of work: prices gave a quantitative indication of utility, and on this basis, he proposed that a mathematical approach to political economy could be developed[174].

Jevons argued that political economists had mistakenly considered value 'a fixed and invariable quantity of a substance, like its colours, density, hardness, or conductivity'[175]. Theorists such as Smith and Ricardo had considered the costs of labour, land, and other forms of capital as the determinants of prices, and therefore the root of economic value. Whereas Jevons, with a Robinson-Crusoe-like example of '*a man in total solitude upon an island in the Pacific Ocean, where there are twenty bread-fruit trees',* argued that '*If the fruit of one tree is amply sufficient to sustain him, then we must allow that the fruit of the other nineteen trees has no utility'*[176]. Hence value, the use or 'utility' that could be derived from something, was not a fixed attribute, but something that varied with an individual's material and physiological circumstance. In suggesting this ephemeral value, 'utility', could be

[173] Grattan-Guinness, I. (2002) "In some parts rather rough": a recently discovered manuscript version of William Stanley Jevons's "General Mathematical Theory of Political Economy" (1862)', History of Political Economy, Vol. 34, Iss. 4., notes that in absentia presentations were not unknown, but were contrary to the BAAS's requirements. This may have accounted for some of the disinterest the paper received.

[174] Jevons, W. (1874) 'The Mathematical Theory of Political Economy', Journal of the Statistical Society of London, Vol. 37, No. 4 pp. 478-488.

[175] WSJ, 1874: 480.

[176] ibid: 482, see White, M (2013) 'Assume a Can Opener' Making of an "Economic Robinson Crusoe', Working Paper, Available at: http://docs.business.auckland.ac.nz/Doc/12-Mike-White.pdf

calculated[177] Jevons believed he had found 'the solution to all the problems of political economy'[178]. Utility, the source of all value, was not material, it was relational, subjective, and tended to decrease.

Despite his grand claim, Jevons' diary notes the paper was 'received without a word of interest or belief'[179]. It failed to receive approval from the BAAS and was published without acclaim four years later as 'miscellanea'[180]. Despite the knock, Jevons embarked on a successful academic career as a political economist, expanding on his mathematical theory of economics, most notably in his (1871) book *The Theory of Political Economy* (herein 'TOPE'). Jevons wrote widely, producing pamphlets, treatises, and newspaper articles in an attempt to promote his ideas, whilst still working in other disciplines (meteorology, chemistry, logic, and others), and using these insights to inform his work in political economy[181]. The publication of *TCQ* proved particularly significant, and drew on his knowledge of geology and engineering. Its success lead to Jevons' first academic appointment in 1866 as Cobden Professor of Political Economy at Owens College, Manchester (later Manchester University). He would be later appointed to the Chair of Political Economy at UCL before resigning in 1880 to devote himself to writing. But in 1882

[177] Utility could be calculated according to the quantity of a commodity consumed and the degree of utility derived from each unit of that commodity over time. This could be represented graphically as an area graph, Jevons, 1874: 483.

[178] ibid: 484

[179] Black, R.D (1962) 'W.S. Jevons and the Economists of his Time', The Manchester School, Vol, 30, Iss. 3, pp. 203-221.

[180] Grattan-Guinness, I. (2002).

[181] Schabas, M. (1990) A World Ruled by Number: William Stanley Jevons and the Rise of Mathematical Economics. Princeton University Press. Princeton, New Jersey.

Jevons drowned whilst swimming near Hastings, aged forty-seven[182]. His intended masterwork, *Principles of Economics,* was published unfinished in 1905[183].

JEVONS' CONTRIBUTION TO ECONOMIC THOUGHT

Jevons' two main contributions to economic thought were his redefinition of value as the result of subjective evaluations of usefulness ('utility') at the marginal increment in quantity of a given good or service. Secondly, he recast individuals as economic actors who, on aggregate, sought to maximise their derivation of utility in response to scarce resources. These ideas would become central tenets of modern economics, the so-called 'marginal theory of value' and 'utility maximisation'[184]. As a result, the historian of economic thought Robert Collison Black called Jevons the 'father' of modern economics[185]. So well before the rediscovery of his work on coal in energy studies and ecological economics, Jevons was considered central to the development of modern orthodox economics. But this is odd, as far from emphasising the energetic-physical basis of the economy, as later energy analysts and ecological economists attempted to do to do (Chapter 8), Jevons' stressed the determinant role of subjective valuation, and led a theoretical shift that later heterodox ecological economists would rail against[186].

[182] Peart, S. (1996) The Economics of William Stanley Jevons, London: Routledge; Schabas, M. (1990) A World Ruled by Number: William Stanley Jevons and the Rise of Mathematical Economics. Princeton University Press. Princeton, New Jersey., Maas, H. (2005) William Stanley Jevons and the making of modern economics. Cambridge University Press.

[183] Herbert Jevons, William's son, edited the published *Principles*. See Chapter 3.

[184] Blaug, M. (1962) Economic Theory in Retrospect. Cambridge University Press.

[185] Murphy, A., Prendergast, R. (2009) 'Professor Robert Denis Collison Black (1922-2008)', European Journal of the History of Economic Thought, Vol. 16, Iss. 2, pp. 357-360.

[186] Martinez-Alier, J. (1987) Ecological Economics: Energy, Environment, and Society. Oxford: Basil Blackwell. Alier notes the contradiction in Jevons' work, that despite proposing a very physical view of economics in TCQ, his theory of political economy more generally was grounded in abstract theory.

Rather than thinking of economic value as something composed of the accumulation of things, Jevons believed value was the result of the 'circumstance of an object'. Accordingly, he argued 'a student of Economics has no hope of ever being clear and correct in his ideas of the science if he thinks of value as at all a *thing* or an *object*'[187]. In place of an understanding of value as a 'thing' such as labour or capital, in the opening statement of TOPE Jevons stated that 'value depends entirely on utility'[188], meaning the physiological or psychological satisfaction an individual could derive from consuming that thing[189]. Utility could be measured according to 'marginal' increments, 'infinitely small' fluctuations in use-value, both subjective and dynamic. The ratio of utility, or the difference between an additional unit of a good and the amount a consumer already possessed, could determine the quantity of that good, or similar, that an individual would purchase[190]. In effect, like Cassirer's definition of energy, in Jevons' scheme, economic value was the product of causal relations.

It followed, Jevons argued, that the individual's sense of utility were actualised in individual economic transactions. In each transaction utility was represented by the price accorded to goods or services, indications of the value that all buyers and sellers in the market accorded to that thing. Following Benthamite 'utilitarian' logic, Jevons believed that if a balance between supply and demand could be achieved across a market as a whole this would result in the most beneficial distribution of utility for that society in general[191]. This planted the idea of 'efficient' allocation' into economic thought, the idea that each unit of a commodity was allocated in such a way that the gain in utility achieved by transferring a commodity to

[187] Jevons, W. (1871) The Theory of Political Economy. London and Macmillan Company, p. 77. TOPE herein.

[188] TOPE., 1871, p. 1-2.

[189] TOPE., 1871, p. xxxiv.

[190] TOPE., 1871, p. 53.

[191] Jeremy Bentham's (1748-1832) utilitarian theory placed the maximisation of happiness at the centre of public life, likewise Jevons proposed 'the object of Economics is to maximise happiness by purchasing pleasure, as it were, at the lowest cost of pain' TOPE: 23.

another individual will equal the loss in utility involved in withdrawing it from another. In an efficient state, in which transactions between individuals were unobstructed, collective utility would be maximised; the idea that individuals' sense of utility could reach an equilibrated point of allocation implied the need for political liberalisation[192]. In line with Jevons' thinking, the idea that more value could be derived from the same amount of capital simply by reallocating it would become a cornerstone of the later science of ERC, as will be discussed in Chapter 4. But at this time, the idea that allocative efficiency *conserved* energy resources was definitely not an idea supported by Jevons' theory of political economy, as we shall see in the next section.

UTILITY MAXIMISATION AND ENERGY

In fact, in TCQ Jevons argued that the preservation of coal was impossible owing, counter intuitively, to *the* laws of energy and their effect on human behaviour. If it was truly a mathematical science, Jevons thought that political economy would be governed by 'general laws'[193] like any other science. Jevons also believed political economy could logically adopt analogies from other sciences[194]. On this epistemological basis, in TCQ Jevons came to accept that the conservation and dissipation of energy were fundamental laws that limited Britain's coal use[195]. In fact, later in his TOPE, as we shall see, Jevons explicitly stated that the law of the conservation of energy could explain the regularities of human behaviour: namely, the tendency economic actors had to maximise their utility: 'purchasing pleasure, as

[192] Hutchinson, T. (1978) On Revolutions and Progress in Economic Knowledge. Cambridge University Press., p. 86.

[193] Jevons, 1876*:* 198.

[194] Jevons, W. (1869) The Substitution of Similars, The True Principle of Reasoning, Derived from a Modification of Aristotle's Dictum. London: Macmillan.

[195] White, M. (2004) 'In the Lobby of the Energy Hotel: Jevons's Formulation of the Postclassical "Economic Problem', History of Political Economy, Vol. 36, Iss. 2.

it were, at the lowest cost of pain'[196]. Individuals acted to conserve their physiological energy, by minimising the painful labour they engaged in. Hence, curiously, and very importantly, Jevons' argued that the conservation of energy explained the laws of political economy. It was this belief in individuals will to conserve their own expenditure of energy that, as we shall see, underwrote his argument that coal could not be preserved by efficient use.

In order to understand how we arrive at this position, it I necessary to develop a greater understanding of the origins of Jevons' theory of human action. In TOPE Jevons stated that his 'theory presumes to investigate the condition of a mind, and bases upon this investigation the whole of economics'[197]. On this basis, historians have argued Jevons' utility maximisation drew on psychology[198]. But somewhat confusingly, Jevons also used analogies from mechanics to explain the 'mechanics of self-interest and utility'. He described how, if the owner of an amount of corn considered it as useful as an amount beef held by someone else, no exchange would take place; but if the corn's owner considers his corn less useful than the beef, and the owner of the beef considers the corn more useful than their beef, an exchange would take place: the metaphorical lever would pivot[199]. The motion of the levers was affected by mechanical force, and the exchange was like an 'equilibrium', or the dissipation of that force[200]. The amount of force needed to tip a lever would always be as

[196] TOPE, 1871., p. 23.

[197] TOPE, 1871., p. 14.

[198] Schabas, M. (1989) Alfred Marshall WS Jevons and the Mathematization of Economics', Isis, Vol. 80. Iss. 1. pp. 60-73.

[199] Maas (2005).

[200] Maas, H. (2001) 'An instrument can make a science: Jevons's Balancing Acts in Economics', History of Political Economy, Vol. 33, pp. 277-302.

minimal as mechanical operations conserved force[201]. Extending the analogy implied that individuals expended the minimum amount of utility possible to engage in an economic exchange, which meant they 'maximised' the scarce utility available to them, in a way which could equally be thought of as an act of conservation.

Jevons admitted that the 'real condition of industry' with its 'perpetual motion and change' and in 'all its natural complexity' would need some form of dynamic calculation to account for multiple, simultaneous and interrelated acts of exchange. In later systems of thought, dynamic modelling was achieved using computer simulations, which used sets of partial differential equations to imitate the complex dynamic relations of a given society[202]. We will return to this idea in Chapter 6, which shows how the advent of computers allowed the simulation of energy demand to be in a more dynamic way. In Chapter 8 it will be shown how computation also allowed the economic modelling to be carried out at a far higher level of system complexity. However, in the nineteenth-century given the technological limitations of calculation[203], as of 1871, he proposed that utility could be considered only as 'a purely statical problem'[204]. By which he meant an economic transaction could be formally analysed only like the action of a lone reciprocal lever.

The economic historian Philip Mirowski proposes a stronger relation between Jevons' principle of utility and physics. Specifically, he argued that 'utility was redefined as to be

[201] Grattan-Guinness, I. (2002) "In some parts rather rough": a recently discovered manuscript version of William Stanley Jevons's "General Mathematical Theory of Political Economy" (1862)', History of Political Economy, Vol. 34, Iss. 4.

[202] Schabas, M. (1984) 'The "Wordly Philosophy" of William Stanley Jevons', Victorian Studies, Vol. 28, No. 1. Pp. 129-147.

[203] On Jevons' work on computation see Maas (2005).

[204] TOPE: 93, See Schabas, M. (2014) A World Ruled by Number: William Stanley Jevons and the rise of Mathematical Economics. Princeton University Press.

identical with energy'[205]. Jevons was well aware of contemporary developments in energetics. Perhaps the strongest influence was his friendship with Balfour Stewart, a colleague at Owens College who wrote a popular account of the conservation of force[206]. In his posthumous *Principles of Economics* (1905), *pace* Mirowski, Jevons claimed 'the notion of value is to our science what that of energy is to mechanics'[207]. Mirowski's suggestion is that individuals act with a 'potential field' of utility, just as physicists described a field of potential energy, but they minimise their own energy expenditure (disutility) in attempting to exploit their personal availability of energy (maximisation of utility)[208]. Just as in mechanics, recasting economics as a problem of constrained maximisation assumed utility, like energy, was conserved. Whilst Mirowski's argument is well supported, Jevons limited his analysis to a single instance of exchange (the lever described above), and did not use the complex field formalism Mirowski himself proposed, so I would argue the strong analogy that Mirowski claims to exist between utility and energy in the history of Jevons' thought is overstated[209].

In fact, the most persuasive argument for Jevons' belief in an analogical relation between energy and utility combines psychology and physics. Based on extensive archival work, Harro Maas, proposes that Jevons' work on mechanical induction convinced him the mind was like a calculative mechanism, this idea helped 'Jevons to conceive of 'economic man' as similar to a machine'[210] which iteratively and logically calculated how to maximise its own utility. In developing this idea, Maas argues that Jevons drew on psychophysiology, the

[205] Mirowski, P. (1984) 'Physics and the 'marginalist revolution'', Cambridge Journal of Economics, Vol. 8. pp. 361-379.

[206] Mirowski, P. (1989) More Heat than Light: Economics as Social Physics, Physics as Nature's Economics. Cambridge: Cambridge University Press., p. 257

[207] Mirowski, 1989, p. 219.

[208] Mirowski 1984, p. 368.

[209] Mirowski, 1989, p. 257.

[210] Maas, 2005, p. 590.

Victorian science of the relation between consciousness and the environment[211]. Maas argues that developments in neurology and physiology had led some to explain human decision-making as if we were automata, mechanisms which responded to their environment according to pre-ordained natural laws. Maas' account of psychophysiological influence leans on the scholarship of economic historian Michael White, who identifies psychophysiologist Richard Jennings' *Natural Elements* (1855) as the text which gave Jevons a basis to establish a relation between marginality and labour. Drawing on physiological studies of labourer's fatigue, Jennings wrote that between 'incipient effort' and 'painful suffering' individuals calculated the 'toilsome sensations endured by the working classes'[212]. On this basis, Jevons argued individuals calculated their own willingness to engage in the disutility of work to amass future utility, or cease work for the pleasure of rest[213].

More generally, White's central argument is that Jevons' TCQ demonstrates a conceptual shift from a belief in utility as something determined by a theory of forces to one in which the idea of energy explained all. White compared the first and second edition of the book (1865; 1866), noting that Jevons's shift from an explanation of utility maximisation based on force to one on energy[214]. In doing so, White argued that the argument of TCQ did not change. But White's identification of an energetic basis for utility is important, in so far as it helps to explain why Jevons believed it was not possible for society to preserve coal, owing to the psychophysiological tendency for humans to want to conserve their own physiological energy, as we will see in the following paragraphs. In making the case for an energy-

[211] Daston, L. (1978) 'British Responses to Psycho-Physiology, 1860-1900', Isis, Vo. 69, No. 2, pp. 192-208,

[212] Jennings, 1855, p. 119.

[213] White, M (1994) 'The moment of Richard Jennings: The Production of Jevons's Marginalist Economic Agent', in Mirowski, P. ed. Natural Images in Economic Thought: "Markets Read in Tooth & Claw". Cambridge University Press.

[214] White, M. (2004) 'In the Lobby of the Energy Hotel: Jevons's Formulation of the Postclassical "Economic Problem', History of Political Economy, Vol. 36, Iss. 2.

determined theory of utility White warned that Jevons' arguments 'need to be placed in the rather confusing set of arguments on conservation principles in the early to mid-1860s'[215]. In his 1862 BAAS paper Jevons described behaviour as something determined by forces, like gravity. But by 1871, in his TOPE Jevons argued a marginal increment of utility, a psychological unit, was analogous to an 'indefinitely small amount of energy'. It followed that individuals entered into transactions to conserve utility, as if they were conserving their bodies' energy, in a thermodynamic sense.

White argues that Jevons became convinced of the importance of the conservation of energy for the science of political economy, and that this conviction stemmed from a particular argument, hinging on an understanding of 'muscular force'. Jevons argued that labour, or disutility, was fundamentally energetic, defined as the 'physiological limits of the rate at which people could work'[216]. Hence, in attempting to maximise the utility they received in recompense for work, it was as if individuals automatically acted to conserve their own bodily energy. Jevons would publish his own experiments on the relation between labour and work in *Nature* in 1870. In doing so, he built on Charles Babbage's experiments on labour and exhaustion carried out by his servants in the 1830s. In the second edition of TCQ, extending the analogy, Jevons described the human body as if it were an engine, and that like an engine, it conserved energy by converting it into a productive force, but in doing so other non-physiological forms of energy were consumed[217]. Hence, individuals seeking to maximise utility, units of psychological satisfaction, would maximise the use of energy found beyond the boundaries of their own bodies.

[215] Ibid, p. 229.

[216] Ibid p. 234.

[217] Ibid.

White claims Jevons' conversion to an energy-based theory was prompted by an argument put forward by the natural philosopher John Tyndall (1820-1893). In the second edition of CQ, Jevons quoted Tyndall's article 'The Constitution of the Universe' (1865)[218], which not only argued that coal was irreplaceable owing to the dissipation of potential energy that occurred in its use, but also that the language of forces was redundant. Owing to a growth in experimental evidence, and the development of a concept to explain these varied phenomena[219], Tyndall could argue that the term 'energy' could explain mechanics in terms of actual and potential energy and could also give an explanation for gravity, heat, magnetism, chemistry, and even 'muscular force'[220] that Jevons argued governed the subjectivity of the labourer.

The critical point to draw from White's thesis is that Jevons use of Tyndall's work explains how he was able to argue that individuals acted to minimise their individual expenditure of energy, but this would not, emphatically, preserve energy resources at the scale of the economy. The reason being that individuals would maximise the utility that they could derive from Earth's exceptionally useful energy resources, particularly as these resources obviated the need for human labour at an unparalleled rate. In a lecture at the Royal Institution in 1868, Jevons calculated that the amount of coal raised in 1866 was equivalent to the labour of 2650 million men, working for eight-hours a day, three-hundred days a year[221]. As such, Jevons argument in TCQ can be seen as part of a wider nineteenth-century concern with the

[218] Jevons, 1866, TCQ. Second Edition, Macmillan, London: xvi; xvii-xviii.

[219] Smith, C. (1998) The Science of Energy: A Cultural History of Energy Physics in Victorian Britain. Athalone Press: London.

[220] White, 2004, p. 248.

[221] WSJ Archive: Coal, GB 133 JA/6/9, 1867-1878, WSJ (1868) Royal Institution of Great Britain, Weekly Evening Meeting, March 13, 1868.

science of work, that is, the pursuit of the maximisation of economic output with the minimum of input of labour[222].

THE COAL QUESTION

Why should Jevons, given his interest in mathematical political economy, take a specific interest in coal, and in the significance of energy efficiency? In August 1863 armament manufacturer and engineer William Armstrong (1810-1900), one of Britain's most successful industrialists, assumed the Presidency of the British Association for the Advancement of Science (BAAS). In doing so, he addressed a large crowd of society's members in Newcastle. In a wide-ranging account of the achievements of British science and industry, advances which he suggested had 'no parallel in history', Armstrong proposed Britain's industrial supremacy might one day be threatened by the exhaustion of coal. Though abundant at the time, owing to the growing rate of use, scarcity was a real prospect. The recently discovered laws of thermodynamics were central to Armstrong's argument, as he stated 'The dynamical theory of heat is probably the most important discovery of the present century'. It had revealed two factors of great importance to the question of coal's duration. To Newcastle engineer George Stephenson (1781-1848), Armstrong noted, it had revealed that coal was formed over thousands of years. It was fossilised solar radiation irreplaceable in the timescale of human history. Whilst to Britain's engineers, thermodynamics revealed how many engines realised only a 'small part of the thermic effect of the fuel'[223]**.** Evidence of waste was suddenly evident wherever an engine was used. What had, before the discovery of thermodynamics, looked like unparalleled productivity, now looked like prolific waste of an

[222] Rabinbach, A. (1990) The Human Motor: Energy, Fatigue, and the Origins of Modernity. University of California Press.

[223] Armstrong, W. (1863) Report of the Thirty-Third Meeting of the BAAS. Newcastle Upon Tyne. John Murray London.

irreplaceable resource. As the philosopher Ivan Illich later suggested, thermodynamics recast all of nature under a 'regime of scarcity'.

It was no wonder that, alongside these unparalleled advances, Britain was consuming coal at a rapacious rate. Mining records showed that 86 million tons had been extracted in 1861, which Armstrong believed to be a tenfold increase since the beginning of the century. As a result, he asked his BAAS audience:

> *'The question is, not how long our coal will endure before absolute exhaustion is effected, but how long will those particular coal-seams last which yield coal of a quality and at a price to enable this country to maintain her present supremacy in manufacturing industry*'[224].

Armstrong was not the first to raise questions about the duration of Britain's coal production[225]. As early as 1789 John Williams, a Welsh mineral surveyor, had warned of Britain's limited quantity of coal, but he had done so from a position of professional experience rather than on an empirical basis[226].

Whereas Armstrong's question had been provoked by Irish geologist Edward Hull's (1829-1917) *Coal-Fields of Great Britain* (1861), a survey of Britain's coal reserves, notable for being the first government survey of natural resources[227]. Under the aegis of the Royal Geological Society (1835) Hull had estimated Britain possessed nearly eighty-thousand million tonnes of coal, which would last over a thousand years the rate of use in 1850[228]. Hull also pointed out that it was price and the unworkable temperature of deep mines that would

[224] Armstrong, 1863., p. 4.

[225] Williams, J. (1789) The Limited Quantity of Coal in Britain. Cited in MacDuffie, A. Victorian Literature, Energy, and the Ecological Imagination. Cambridge University Press.

[226] TCQ., p. 15.

[227] Armytage, W. (1969) The Rise of the Technocrats. Routledge, p. 96.

[228] TCQ, p. 23.

place a limit on Britain's supply, but in general he painted a picture of abundance[229]. But Armstrong claimed the duration of coal was more than a geological question. Increasing international trade, population growth, and the increasing efficiency of industry were all important factors in determining the rate of coal consumption. In contrast to Hull, Armstrong was hopeful that demand for coal could be satiated, in part, by developing increasingly economic (i.e. efficient) means for its consumption. He estimated that coal, if production remained unchecked, would last two-hundred years. As a result of its dramatic forecast, Armstrong's address provoked popular concern[230].

In pursuit of the recognition that had evaded him in 1862 Jevons' astutely decided to address the topical question of coal's 'duration' to promote his developing theory of political economy[231]. In response to Armstrong, and similarly using Hull's 'geological datum', Jevons' book outlined the scale, depth, and accessibility of Britain's known reserves[232]. Like Armstrong, Jevons agreed Britain's industrial supremacy was the result of its' abundant coal, which he described as *'our peculiar force*[233]. Unlike Armstrong, Jevons argued demand for coal could increase exponentially; he estimated an annual growth in demand of 3.7 per cent, at which rate Britain's mines would be practically exhausted within 110 years[234]. By practical exhaustion, he meant the 'cost of fuel must rise, perhaps *within a lifetime*, to a rate injurious to our commercial and manufacturing supremacy'[235]. Not only had Jevons almost halved

[229] White, M. (1991) 'A Biographical Puzzle: Why Did Jevons Write the Coal Question?', Journal of the History of Economic Thought, Vol. 13. Iss. 2, pp. 222-242.

[230] Heald, H. (2012) William Armstrong: Magician of the North. McNidder and Grace.

[231] White, 1991: 230. Nb. in TCQ Jevons refers to the preservation and duration of coal rather than its conservation., e.g. p. 3.

[232] TCQ, p. 7. As Jevons noted '*the progress of the geological survey, and the establishment of a mining record have placed* [the coal] *question on a new footing*'.

[233] TCQ., p. 5.

[234] TCQ., p. 269.

[235] TCQ., p. 274.

Armstrong's estimate of the duration of British coal reserves, he would also go on to criticise the industrialist's faith in technology as a means of averting coal's exhaustion. But before then, he outlined the various factors that accounted for his more severe forecast.

The liberalisation of Britain's trade was one important factor in Jevons' analysis of the societal dynamics of coal use. The Cobden-Chevalier treaty, signed with France 1860, allowed Britain to trade coal with France for the first time. Around the same time, it became apparent that other nations, particularly America, had vast coal reserves, which Jevons would note were thirty-seven times as extensive as Britain's[236]. In the decades preceding Jevons' book, concerns that further liberalisation of trade might mean Britain's coal would be purchased by foreigners or superseded by cheaper coal from elsewhere were raised in Parliament[237]. Jevons was an advocate of economic liberalism, and made numerous references to the flaws of protectionist policies in his text, such as the Morrill Tariff, an American tax on foreign trade introduced in 1861 to limit European competition[238]. He also discussed the Britain's Corn laws, introduced in 1815 to restrict foreign imports of grain, as an example of the supply-restricting and price-inflating effects of market intervention[239]. Liberalisation, Jevons acknowledged, would mean an 'indefinite increase of the consumption of coal'[240] as its' exceptional utility would be recognised by other nations. Jevons claimed that 'the coal question', in so far as it implied the need to conserve Britain's coal, appeared 'antithetical to that of free trade'[241].

[236] TCQ., p. 19.

[237] White, M. (1991) Frightening the 'Landed Fogies': Parliamentary Politics and The Coal Question', Utilitas, Vol.3, Iss.2, pp. 289-302.

[238] TCQ., p. 135.

[239] TCQ., p. 227.

[240] TCQ., p. 5.

[241] TCQ., p. 12.

But Jevons antithesis was rhetorical. In fact, one objective of TCQ was to outline his belief in the damaging effects of a tax on coal. Prime Minister Sir Robert Peel (1788-1850) had unsuccessfully proposed a coal export tax in 1842[242]. Whig politician Samuel Overstone, an influential Parliamentarian on financial matters at the time, had reinstated calls for a tax on exporting coal during the Cobden-Chevalier negotiations[243]. But Jevons advised such a 'tax would be paid by ourselves as entirely as the tax on dogs or men servants'. A reference to taxes imposed on non-essential goods by Prime Minister William Pitt (1759-1806) in the 1790s[244]. Jevons' reference was, we can assume, intended to appeal to the wealthy industrialists who could afford such things. Jevons went on to suggest a tax on coal would have 'the further disadvantage that we should pay it through the discouragement of our navigation. It would be equivalent to a duty on outward tonnage'[245]. A coal tax, he argued, would almost equivalent to a tax on industry in general due to the fuel's ubiquity and importance, particularly in sea-borne trade, where coal was often used as a valuable ballast on outward journeys from Britain.

Despite Jevons' demonstrative concern over the contradiction between scarce coal and increasing economic liberalism, the central argument of *TCQ* ran counter to this concern. In fact, he argued that the coal trade must be liberalised, not despite, but because coal was a scarce and diminishing resource. How did he arrive at this conclusion? Jevons wrote in the concluding page of *TCQ*, given the dissipative nature of coal, 'We have to make the

[242] Hansard (1842) 'Financial Statement – Ways and Means', Vol. 61, cc. 422-467. 11 March.

[243] Knaflo, S. (2013) The Making of Modern Finance: Liberal Governance and the Gold Standard. Routledge.

[244] This odd reference suggests Jevons considered a tax on coal equivalent to a tax paid by a member of the capital owning classes rather than the poorer classes, who were unlike to own a dog. On Jevons' view on Dog Taxation see Black, R. ed. (1977) Papers and Correspondence of William Stanley Jevons: Volume VI. Lectures on Political Economy, 1875-1876. Macmillan.

[245] TCQ, p. 226.

momentous choice between brief but true greatness and longer continued mediocrity'[246]. Britain should exploit the 'rising tide of prosperity' that the nation's prodigious coal consumption allowed, and permit a system of economic liberalism to continue so that maximum utility could be derived from this abundant but exhaustible source of wealth[247]. The resulting economic prosperity could be saved for posterity, Jevons believed, if, via general taxation rather than a tax on coal specifically, government revenue was used to settle the national debt, the product of periodic engagement in wars with France, which stood at eight hundred million pounds[248].

Put simply, Jevons argued the physical limits of Britain's coal placed a limit on British commercial supremacy, but in a brief period of abundance, the maximisation of coal's value was vital for future prosperity. Whereas Armstrong had raised the prospect of government intervention to stop the wasteful extraction of coal, as 'Although coal is private property, its duration is a national question, and Government interference would be justified to enforce such modes of working as the national interests demand'[249]. The two authors presented quite different political solutions to the problem of coal, with Jevons' economically liberal paternalist argument seen as a counter to Armstrong's proposed government led interventions in the coal industry.

If geology and political economy were two aspects of the coal question, population was a third. As Jevons noted 'the exact quantity of coal existing is a less important point in this question than the rate at which our consumption increases, and the *natural laws that govern*

[246] TCQ, p. 460.

[247] Mirowski, P. (1984) 'Physics and the 'Marginalist revolution', Cambridge Journal of Economics, Vol. 8. pp. 361-379.

[248] TCQ: 448, White 1991.

[249] Armstrong, 1863.

that consumption'[250]. Drawing on the work of Thomas Malthus (1766-1834), whose 1798 *Essay on the Principle of Population* had demonstrated how population growth, given sufficient agricultural land, proceeded at a geometric rate of growth, Jevons developed his own 'Law of Social Growth'[251]. In Malthus's scheme, the supply of food would constrain population, but in Jevons' time, subsistence no longer depended upon corn but coal[252]. Jevons believed the law of social growth altered dramatically in the coal age, as he illustrated with a diagram showing a sweeping exponential curve in the book's frontispiece, which illustrated his forecasted increase in demand for coal up to the year 2000 (Fig. 1). Owing to coal's exceptional utility, its consumption would increase at four-times the rate of population, and would continue to increase, because - critically - he believed 'new applications of coal are of an *unlimited* character'[253]. Aside from more obvious applications, coal contributed to everything from the manufacture of dyes, to the development of flavourings and synthesis chemicals[254]. So, unlike breadfruit, demand for coal could not be satiated.

[250] TCQ: 25, my emphasis.

[251] For a geographic take on Malthus, see Chapter 5. Peart, 1990: 38, TCQ, p. 194

[252] Mayhew, R. (2014) Malthus: The Life and Legacies of an Untimely Prophet. Harvard University Press.

[253] TCQ, p. 196-7, TCQ, p. 187.

[254] In a public lecture Jevons described how even '*beautiful mauve and majenta colors are derived from coal-tar, as well as the pine apple and other flavours that are used in the manufacture of sweetmeats'*. JRL, Coal, GB 133 JA/6/9, 1867-1878, WSJ (1867: 131). For more on the use of coal for synthetic dyes, see Leslie, E. (2005) Synthetic Worlds: Nature. Art and the Chemical industry. Reaktion Books

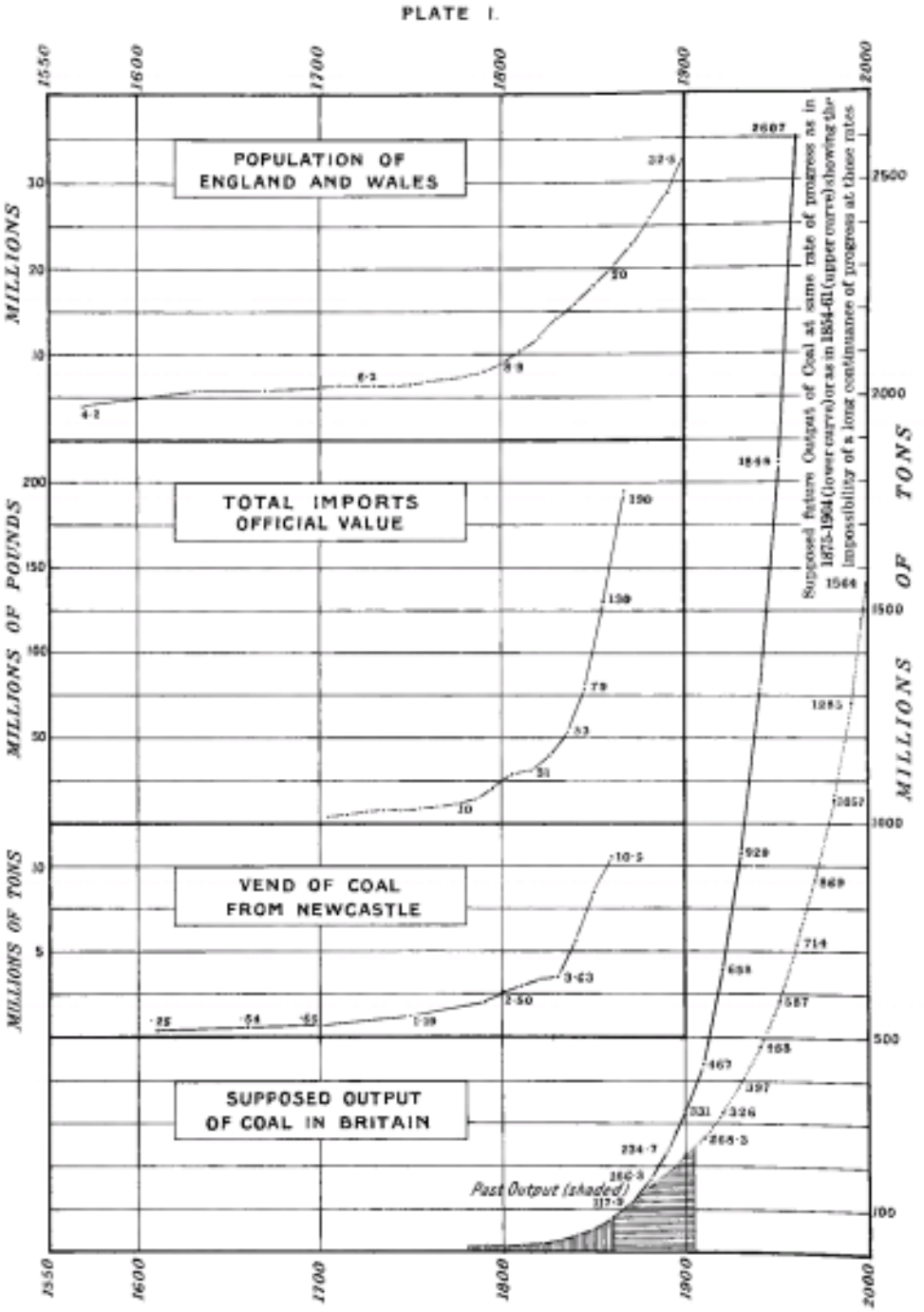

Figure 1.1. Frontispiece
Jevons, W. (1866: 12).

JEVONS' PARADOX

A paradox is a statement that runs contrary to received opinion, which can be either counterintuitive but true or intuitive but false[255]. Famously, Adam Smith used the disparity between the price given to diamonds and water as a means of illustrating how value was attributed according to acts of exchange, rather than according to the usefulness of goods[256]. Elsewhere, Smith wrote of the 'paradox of commercial society' as 'an outcome of unintended consequences – the subsistence of the need of the poor being served through a machine kept in motion by the blind cupidity of the rich'[257]. This reiterated Bernard Mandeville's paradoxical *Fable of the Bees* (1714), with its idea that private vice led to public benefit. Not forgetting the first work of political economy Jevons was known to have read, Whatley's *Lessons on Money Matters* (1836) described some of the outcomes of commerce as 'revolting paradoxes'. Jevons' interest in paradoxes was no doubt encouraged by his favourite lecturer at UCL, Augustus De Morgan (1806-1871)[258]. Though best known for his contributions to logic, De Morgan had also published short essays about 'paradoxers', individuals who 'used 'exact science' to attack preconceived ideas to produce and solve 'paradoxes', defined as 'something which is apart from general opinion'[259].

Twentieth-century German social theorist Niklas Luhmann argues that from the eighteenth century onward many political economists made use of paradox to describe the 'difference

[255] Quine, W.V. (1962) 'Paradox', Scientific American, Vol. 206., Iss. 4, pp. 84-96.

[256] Stephenson, M. (1972) 'The Paradox of Value: A Suggested Interpretation', History of Political Economy, Vol. 4, Iss. 1., pp. 127-139.

[257] Hont, I., Ignatieff, M. (1983) Wealth and Virtue: The Shaping of Political Economy in the Scottish Enlightenment. Cambridge University Press.

[258] Black, 1972, p. 129.

[259] De Morgan. A. (1872) A Budget of Paradoxes. Open Court Publishing, New York and London., p. 2.

between individual and social rationality[260]. Jevons himself had voiced a similar idea, that 'Political economy teaches us to look beyond the immediate and apparent effects of what we do, and to see the good of the whole community, and even of the whole of mankind'[261]. Jevons belief in the exceptional utility of coal was central to his paradox, as it combined with another important determinant of coal use: technology. Taking the example of an engine, Jevons argued that increased efficiency lowered the costs of that engine's use, increasing the utility that could be derived from a given amount of coal and a given amount of expenditure, thereby increasing the number of applications that engine could be economically applied to. Hence more rather than less coal would be consumed[262]. Evidence of such an effect abounded in industrial Britain. Alongside steam engines, Jevons noted such acceleration in smelting furnaces, 'manufactories', and now, thanks to the steel-making 'Bessemer process'[263], an abundance of the tensile material would enable ever greater industrial efficiency, owing to its durability, conductivity, and formability, the use of which meant most other forms of 'machine power' would soon reach 'apparent maximum in efficiency, economy, and elegance'[264].

Jevons argued that, as the efficiency of industry increased, Hull's datum on rates of coal extraction and surveys of coal sales showed the nation's coal consumption had increased rather than diminished[265]. Given this quantitative evidence, Jevons advised that it was the

[260] Luhmann, N. (1990) 'The paradox of system differentiation and the evolution of society', in Differentiation Theory and Social Change. Alexander, J., Colomy, P. eds. Columbia University Press.

[261] WSJ Archive, Political Economy, General, GB 133 JA/6/6/1, 1866-1878. WSJ (1878) Political Economy, Science Primers, Macmillan and Co. [handwritten manuscript]., p. 14

[262] TCQ, p. 78. See also Chapter 6.

[263] A process for producing steel from pig-iron by removing the impurities with hot air, patented by Henry Bessemer in 1856.

[264] TCQ, p. 130.

[265] Ibid.

'very economy' of coal use that was responsible for its 'extensive consumption'[266]. He termed this counterintuitive effect as *paradoxical*, perhaps reflecting his early interest in Whately's work, and stated that 'Nor is it difficult to see how this paradox arises'[267].

Jevons noted there were many 'parallel instances' of such unintended outcomes in political economy. The introduction of new machinery into a factory might initially lead to unemployment, owing to lowered costs of production, but eventually, as a result of lowered costs 'the sphere of employment is greatly widened'[268]. This was not a new idea, in 1776 Smith had argued machinery complimented rather than replaced human labour by dismantling old manufacturing techniques and creating more prosperity and opportunities for employment[269]. Jevons also described a 'familiar rule of finance': that a decrease in taxation would cause an increase rather than a decrease in total tax yield. Again, this was an old idea. In 1817 the political economist David Ricardo had argued higher taxes limited company profits, which meant total tax revenue would be greater had taxes not be raised[270]. JP, in the case of coal, simply described how increased economy was the same, in terms of its outcome, as a reduction in cost: it induced increased rates of demand. As such, despite its current heretical status in the fields of energy and environmental policy, at the time JP provided an unexceptional demonstration of a fairly common idea in political economy; lowered costs could increase the rate and scale of consumption.

[266] TCQ, p. 141.

[267] Ibid.

[268] O'Brien, D. (1975) The Classical Economists Revisited. Princeton University Press.

[269] O'Brien, 1975, p. 269; Berg, M. (1980) The Machinery Question and the Making of Political Economy, 1815-1848. Cambridge University Press.

[270] Ricardo, D. (1817) On The Principles of Political Economy and Taxation. John Murray, London., p, 18.

Whatever its novelty, this counter-intuitive dynamic of induced demand was all the more dramatic in the case of coal, an increasingly dominant form of capital, owing to the substance's unparalleled energetic value. If the cost of using coal went down, more coal would be consumed, with little or no likelihood of satiety. Because, as Jevons noted, the power that could be derived from coal was 'almost incredible': a small lump contained enough power, theoretically, to raise 'a million times its own weight a foot high'[271]. Moreover, unlike other 'rude forces of nature' such as sunlight or wind, coal was 'under perfect control'[272]. Control, like measurement, was central to realising the full motive power of coal. The more perfect control of coal been achieved thanks to engineer James Watt (1736-1819), who Jevons termed 'the immortal Watt'. His 1776 engine contained a crank, flywheel, and 'governor' – a mechanical control mechanism – which could automatically control the rate of fuel use according to the demands of the engine operator[273]. The Watt engine enabled engineers to 'communicate equable circular motion directly from a steam-engine to a machine' rather than, as in older, less efficient, 'Newcomen' engines using a boiler to pump water, which was then used to power a wheel[274]. By 'control' it is clear that Jevons meant efficiency. By developing ever more efficient control technologies, engineers were able to render material nature into productive force with increasing economy, and also at an ever greater scale. As he noted, the Watt engine allowed the constancy of water-driven power to be emulated even where such 'local circumstances' were unavailable[275]. The geography of motive power was vastly expanded by Watt's engine, and the efficiency of its use greatly amplified[276].

[271] TCQ, p. 186.

[272] TCQ, p. 163-4.

[273] TCQ, p. 160; 170. Mayr, O. (1971) 'Maxwell and the Origins of Cybernetics', Isis, Vol. 62, No. 4, pp. 424-444.

[274] TCQ, p. 176.

[275] TCQ, p. 171.

[276] One aspect of control, perhaps the most important, missed by Jevons was the external condenser. Watt discovered that as much as 80 per cent of the steam generated in a Newcomen engine was wasted in heating

Jevons was well aware that whatever the level of control coal consumption was irreversible[277]. He was familiar with the work of leading scientists Thomson and Joule on the conversion of heat and mechanical work, and later in his life he discussed Fourier's heat theory with James Clerk Maxwell[278]. Jevons had even developed his own theory of heat in 1853, in which he argued heat as the result of the vibratory motion of atoms[279]. He had also studied the history of steam engines, and their growing efficiency[280]. In TCQ, Jevons poetically described the implications of thermodynamics for a country that relied upon coal for its power: 'whilst other countries mostly subsist upon the annual and ceaseless income of the harvest, we are drawing more and more upon an capital which yields no annual interest, but once turned in to light heat and force is gone forever into space'[281]. In his posthumous *Principles of Economics* (1905) Jevons' pointed to this general tendency in more stark language, 'To consume is literally to destroy by fire – to make an end of a thing, as coal is burnt in the furnace, or food oxidised in the animal body.'[282]

Coal's exceptional utility, its geological limits, and irreversible consumption were problems for those who considered technology a means of preserving Britain's coal, particularly when these properties were considered alongside Jevons' theory of utility maximisation, itself based on the principle of energy conservation.

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and reheating the integral condenser. By creating an external condenser, the efficiency of steam engines was greatly increased. Glancey, J. (2012) Giants of Steam. Atlantic Books.

[277] WSJ Archive, JA 6/4/12, July 1861 'Light and sunlight', National Review.

[278] Mirowski, P. (1984) 'Physics and the 'Marginalist revolution'', Cambridge Journal of Economics, Vol. 8. pp. 361-379.

[279] WSJ Archive, JA 6/32/3, Theory of Heat, March 24 th 1853

[280] WSJ Archive, JA 6/31/1-4, Steam Engines Steam engine [history of]

[281] TCQ, p. xi.

[282] WSJ Archive, Political Economy, General, GB 133 JA/6/6/1, 1866-1878, see

REGENERATORS AND OTHER MOTIVE AGENTS

If JP was addressed towards the idea that Britain's coal could be preserved via increased efficiency of use, we should ask who held this opinion. Armstrong's 1863 BAAS address had described how the 'discovery of the dynamical theory of heat' allowed engineers to quantify the inefficiency with which energy was used in industry. Thermodynamics, as noted, revealed a world riven with inefficiencies. As he stated 'much as we are in the habit of admiring the powers of the steam-engine, our present knowledge of the mechanical energy of heat shows that we realise in that engine only a small part of the thermic effect of the fuel'[283]. Addressing the BAAS, Armstrong implored that it 'remains for mechanicians, guided by the light they have thus received, to devise improved practical methods of converting the heat of combustion into available power'[284]. This call for improved methods of energy conversion was part of a wider movement, informed by the newly developed principles of thermodynamics, which sought to maximise the conservation of useful energy and minimise waste through heat loss and friction. The maximisation of work and minimisation of waste had become a central concern in both engineering and political economy[285].

Historians Norton Wise and Crosbie Smith have noted that owing to the discovery of the laws of thermodynamics, both engineers and natural philosophers became increasingly concerned with the principles of 'work and waste', which were analogous to the physical laws of conservation and dissipation[286]. Conservation, in this sense, did not imply saving of fuel from use so much as converting energy, according to the first law of thermodynamics, in a productive manner. Already there was an ambiguity to this type of conservation. Energy was

[283] Armstrong, 1863, p. 4-5.

[284] Ibid, p. 5.

[285] Wise, N., Smith, C. (1989) 'Work and Waste I: Political Economy and Natural Philosophy in Nineteenth Century Britain', History of Science, Vol. 27, Iss. 3, pp. 263-301.

[286] Ibid p. 421.

always conserved, but the question was whether it was conserved productively. As William Thomson wrote, in 1851, during the act of combustion 'work is lost to man irrecoverably; but not lost to the material world'[287]. Hence the principles of work and waste were cast in distinctly utilitarian terms when it came to theories of political economy, how could work be maximised and waste minimised?[288] For example, given an individual engine, with a task to fulfil, increased efficiency could clearly conserve a given quantity of coal, in so far as it would keep it from combustion. But, if the engine's owner decided to carry out more work using the same amount of coal, conservation would not occur. The outcome of one individually efficient engine and the outcome of the operation of such an engine within society at large was uncertain. This was part of the 'machinery question', the uncertainties regarding the impact of the introduction of new labour-saving technologies[289]. It was uncertainty about the societal consequences of increased engine efficiency, in light of thermodynamics, which both Armstrong and Jevons' work addressed. The question of machinery had rightfully to be considered alongside the question of thermodynamics, and the exhaustion of coal.

In this vein, Armstrong, having outlined the coal question and called upon engineers to improve the efficiency of coal's consumption, he used the second section of his BAAS speech to outline the latest technologies in this domain. Three engineers, he lauded, 'Stirling, Ericson, and Siemens' had recently produced 'engines in which the motive power is excited by the communication of heat to fluids'[290], as opposed to the conventional steam combustion

[287] Wise, N., Smith, C. (1989) 'Work and Waste II: Political Economy and Natural Philosophy in Nineteenth Century Britain', History of Science, Vol. 27, Iss. 4, pp. 391-449.

[288] Smith, 1998.

[289] Berg, 1980, p. 9.

[290] Armstrong, 1863, p. 5.

engine, which since Watt had passed steam into a condenser to create a piston action. These new devices were referred to as 'regenerator', 'economiser' or 'air' engines[291].

In 1814 French engineer Sadi Carnot (1796-1832) had proposed that engines worked via the transfer of the motive power of heat substance ('caloric') from high-temperature to low; in a steam engine this meant the transfer of heat from a boiler to a condenser. Carnot had demonstrated that *theoretically,* an optimally efficient engine would be able to transfer caloric with no loss, from hot to cold, and back again if the process of cooling condensation could be avoided[292]. Some interpreted Carnot's theoretical point as an assertion that perpetual power might be possible[293] as if an engine could store and restore the heat produced by combustion in a fluid or gas with no waste, the differential in temperature could be used as a perpetual source of work[294].

More prosaically, by considering the conservation of heat within an engine as a potential resource, engineers began exploring the possibility of producing highly efficient engines which could regenerate motive power by re-using the heat produced by their own operation. For example, in 1827 Scottish engineer Robert Stirling (1790-1878) created the first engine of this kind. Stirling's engine consisted of a set of tubes through which fluid or gas could pass, conducting heat into the tubing, where it was temporarily stored. When a fluid or gas was passed through the engine in the other direction, this heat was conducted back into the substance. The process did not conserved all the waste heat produced in combustion, but by raising the temperature, less fuel was needed to achieve combustion, allowing the engine to

[291] Daub, E. (1974) 'The Regenerator Principle in the Stirling and Ericsson Hot Air Engines', British Journal for the History of Science, Vol. 7, Iss. 3, pp. 259-277.

[292] A significant improvement had been made in this regard by Watt engines, see note 329.

[293] Smith, 1998.

[294] Mirowski, 1989, p. 25.

operate with greater efficiency than it would have done at a lower temperature[295]. Stirling called his engine an 'economiser' as it minimised wasted heat and implied lower operating costs[296].

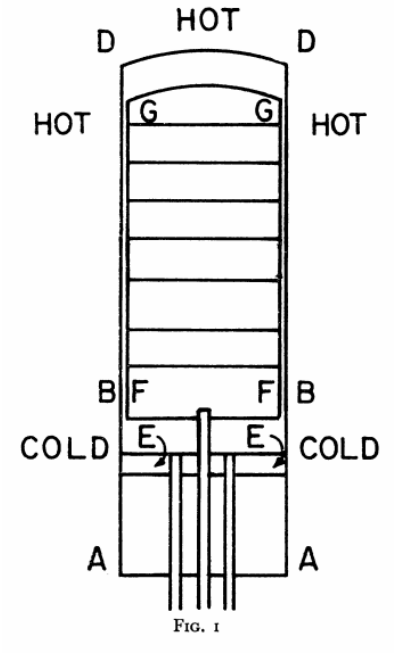

Figure 1.2. Stirling Engine
Daub (1974)

Along similar lines, German engineer Friedrich Siemens' (1823-1883) designed a gas economiser around 1856. His patent detailed a system of ducts, a 'checker-work', through which hot flue exhausts from a furnace could pass. Hot air could then be mixed with a gas, and burnt. In effect, the waste heat was used to raise the temperature of the system for further combustion, meaning glass-making and other types of furnace work could be carried out more efficiently.

[295] Ewing, J. (1926) The Steam Engine and Other Heat Engines. Cambridge University Press
[296] Daub, 1974.

However, some took the efficiency gains achieved by these engines as something of greater cosmological significance. In 1861 Friedrich's brother William Siemens had successfully applied the economiser system to steel manufacture in Britain. Supposedly obsessed with the problem of waste, William took his invention as an indication that energy was regenerated at a planetary level, and that the laws of thermodynamics would be eventually contravened[297]. In 1881 William would present a paper 'On the Conservation of Solar Energy' to the Royal Society[298], in which he outlined the belief that solar energy was conserved, as despite initial dissipation, in the vastness of space cool regions 'recombine to stream again towards the Sun, where the process is renewed'[299]. Such arguments, inferred from technological examples, indicated that the laws of thermodynamics were far from fully established in the period in which Jevons wrote[300]. In their increasingly efficient use of fuel, economizer engines somewhat unsettled the idea that the second law might not always apply. This meant that later in his career, even Jevons – a theorist who's lifework had been informed by energy's dissipative qualities - in his unpublished *Principles of Science* (1905) speculated on the possible 'reconcentration of energy' at the universe's edge[301].

[297] Schaeffer, S. (1995) 'Where experiments end. Tabletop trials in Victorian Astronomy; J. Buchwald, J. ed. Scientific Practice: Theories and Stories of Doing Physics, Chicago, University of Chicago Press.

[298] I thank Gabriele Gramelsberger for bringing Siemens work on thermodynamics to my attention. On Friedrich Siemens's contribution to meteorology see Gramelsberger, G. (2016) 'Calculating the Weather: Emerging Cultures of Prediction in the late 19th and early 20th century Europe', in Heymann, M., Gramelsberger, G., Mahony, M. eds. Cultures of Prediction in Atmospheric and Climate Science. Taylor and Francis.

[299] Siemens, W. (1881) 'On the Conservation of Solar Energy,' Proceedings, of the Royal Society of London, Vol. 33, pp. 389-398.

[300] Smith and Wise refer to this as the 'years of uncertainty' regarding thermodynamics. Smith, C., Norton, W. (1989) Energy and Empire: A Biographical Study of Lord Kelvin, Cambridge University Press.

[301] Jevons, W. S. (1905) The Principles of Science: A Treatise on Logic and Scientific Method. Macmillan and Company.

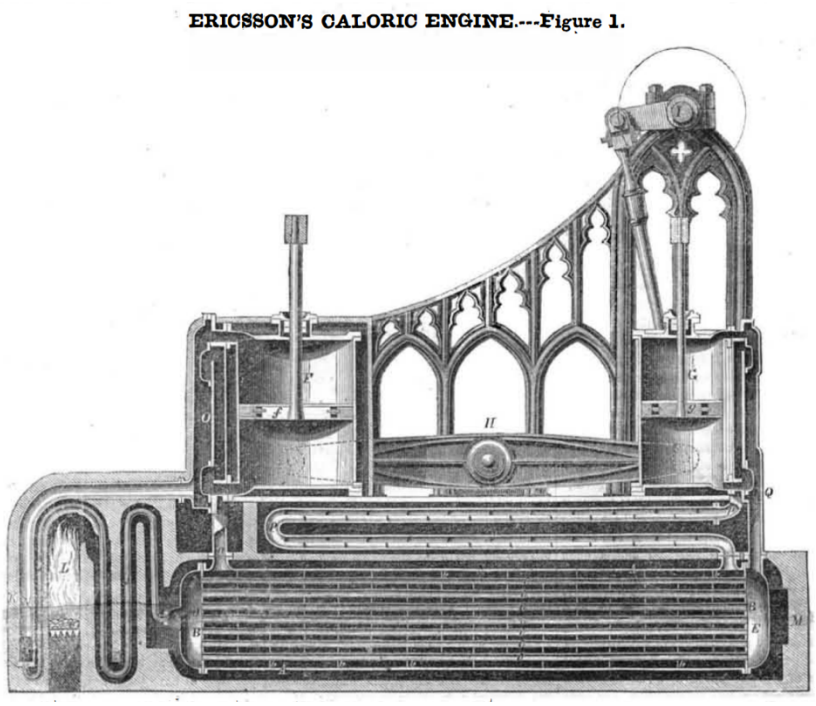

Figure 1.3. Ericsson's Caloric Engine
Scientific American, Vol. VIII, No. 2 1853: 1.

Alongside cosmological claims, others sought to influence public opinion with regard to thermodynamics. Swedish naval engineer John Ericsson (1803-1889) was the most hubristic public advocate of economising engines. In the 1830s, he developed a device to convey hot-air through a dense wire mesh, which allowed heat to be stored over its large surface area. This warmed surface could then be used to heat air or gas for combustion, as in Stirling or Siemens engine, but which could, in a sealed chamber, increase the efficiency still further by subjecting the air or gas to increased levels of pressure[302]. With greater ambition than his competitors, Ericsson argued the motive power of heat, or 'caloric', a kind-of weightless gas Carnot had believed determined the properties of heat before the discovery of energy, could even be re-used if combustion and took place at high pressure, hence he termed his device a 'regenerator' owing to its touted ability to regenerate the motive potential of caloric[303].

[302] Daub, 1974.
[303] Ibid.

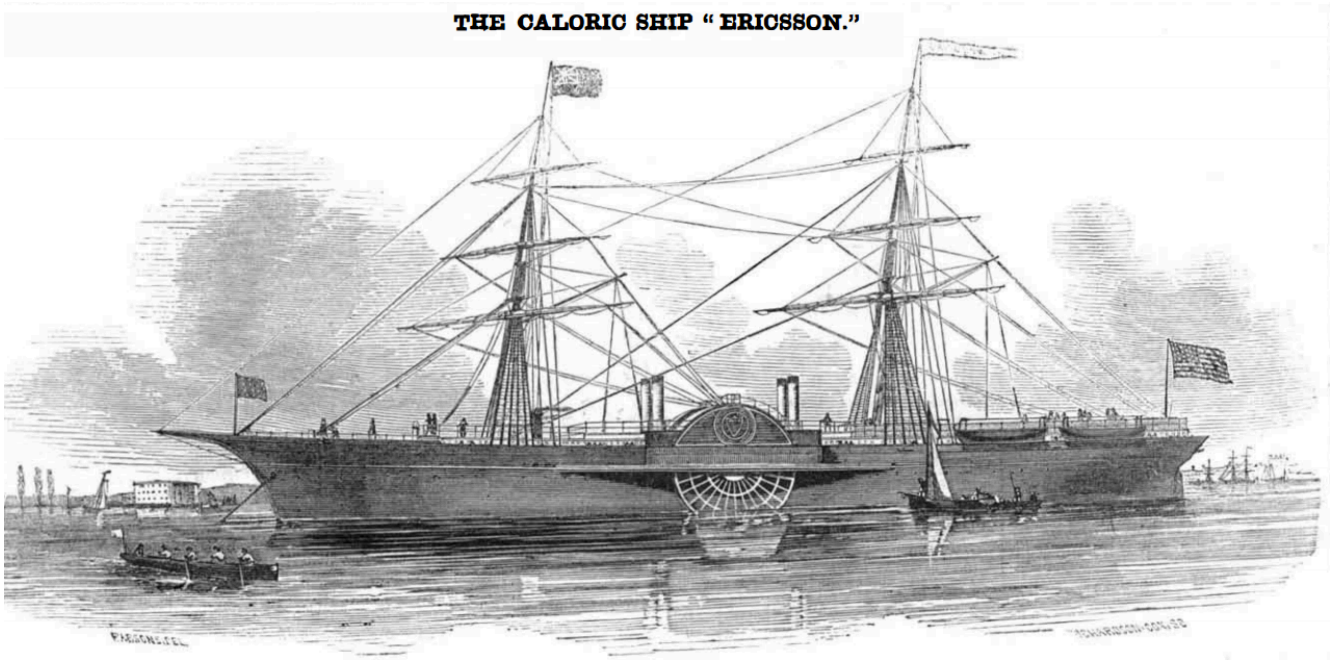

Figure 1.4. Illustration of the caloric ship 'Ericsson'
'She is now lying at 'Green Point,' there being something not complete about her machinery'
Scientific American, Vol, VIII, No. 2 1853: 160.

In 1850 Ericsson oversaw the installation of four fourteen-foot diameter regenerators on-board a paddleboat eponymously titled the *Ericsson*[304]. This 'caloric' ship created a flurry of journalistic interest, with reporters invited to ride its six-foot pistons, and newspapers relaying its supposed ability circumnavigate the globe without refuelling[305]. The editors of the *Athenaeum* even opined that the ship's successful voyage might mean 'the mathematical theory of heat-force must undergo a complete revision'[306]. Another headline declared the beginning of a new stage of industrialisation with the headline, as 'The Age of Steam closes, the Age of Caloric opens'[307]. Unlike steam, which dissipated in an engine, if motive power was believed to be a kind of substance, it could – it was assumed – be conserved in some way, leading journalists to assume, encouraged by Ericsson, that unparalleled efficiencies

[304] Cardwell, D. (1989) James Joule: A Biography. Manchester University Press, p. 117.

[305] Marsden, B. (1998) 'Blowing Hot and Cold: Reports and Retorts on the Status of the Air-Engine as Success or Failure, 1830-1855', History of Science, Vol. 36, pp. 373-420.

[306] Daub, 1974, citing Anon, 1853: 232.

[307] Daub 1974, p. 274.

were possible. Caloric was conserved via the engine's pressurised seal. However, the *Ericsson's* first voyage, as the world's press watched, one of the ship's engines exploded under pressure. Two years later, another expedition ended with the ship sinking. Despite these failures, Ericsson's claim about the 'absolute reproduction of mechanical force' remained in popular discourse, in part thanks to a concerted American lecture series[308].

Engineer Robert Stephenson (1803-1859) and Architect Isambard Kingdom Brunel (1806-1859) were among the contemporary experts who seriously considered the claims made by Ericsson when he had presented his regenerator engine to the Institute of Civil Engineers (ICE) in 1852. It was only when relatively unknown Bristolian engineer Benjamin Cheverton[309] (1796-1876) demonstrated that the heat stored and transferred in an Ericsson engine was at far too low a temperature to carry out most useful tasks[310], that the idea was challenged empirically. Cheverton's calculations showed that the estimated speed of Ericsson's ship was patently false, and that his touted fuel efficiencies were only possible at prohibitively low speed. The Institute concluded that Ericsson's engine did produce some effect, but one 'no greater than would be produced without the regenerator'[311]. In his paper Cheverton explained that the 'reiterated use of the same caloric, in the production of power' disagreed with the 'best established laws of nature'[312]. As though 'caloric' was always in a

[308] Daub, 1974, p. 273

[309] Cheverton that was famed for creating a device for creating miniature facsimiles of marble busts, alongside James Watt, later his partner in mechanical sculptural reproduction. See Insley, J. (2013) 'James Watt and the Reproduction of Sculpture', The Sculpture Journal, Vol. 22, No. 1, pp. 46-47.

[310] Hills, R. (1989) Power from Steam: A History of the Stationary Steam Engine. Cambridge University Press., p. 171.

[311] Cheverton, B. (1853) 'On the use of heated air as a motive power', Minutes of the Proceedings of the ICE, Session 12., pp. 312-324.

[312] Cheverton, 1853, p. 365.

sense conserved as heat, he claimed in achieving motion some caloric ceased to be caloric as it changed into force[313].

Armstrong had been amongst those discussing regenerator engines at the ICE[314]. He seemed to have accepted Cheverton's criticisms, as by the time of his 1863 BAAS address he noted that 'the regenerative principle' was a term that 'has, with reason, been objected to, as implying a restoration of unutilized heat'[315]. Recognising that regenerators were certainly not means of perpetual power, but that they could possibly increase fuel efficiency, Armstrong went on to tell the BAAS audience that the 'so called 'regenerator' did not regenerate fuel but such devices could cause a 'consequent reduction of fuel'[316]. This was certainly true in the case of an individual engine, but whether it was true at the scale of a national political economy was unproven. So whilst Armstrong understood the potential of individual engine efficiency, he asserted that regenerative engines might offer some means of addressing Britain's wasteful fuel expenditure and conserving coal, though without clear evidence as to why[317].

Irrespective of Armstrong's caution, it was clear the public took regenerative engines seriously. Reporting on the BAAS meeting, *The Times* for example, noted that though Armstrong's coal question had created a 'small sensation' it could be 'hoped that before the meeting is over some practical measures will be for preventing the waste and staving off the future deficiency toward which he points'[318].

[313] Cardwell, 1989, p. 118.

[314] Cardwell, 1989, p. 119.

[315] Armstrong, 1863, p. 5.

[316] Ibid.

[317] Ibid, p. 7

[318] Cardwell, 1989: 404, ft. 29.

Here was where Jevons' his treatment of the coal question deviated from Armstrong's. Whilst similarly discussed the inventions of Stirling, Siemens, and Ericsson[319], Jevons disagreed with Armstrong and the public's optimism with regard to the potential coal conservative outcome of using such technologies. Jevons' paradox ordained that increased efficiency might lead an individual engine to use less energy but that at a societal level more coal would be used: collective demand for coal would increase, induced by the lowered cost of using coal efficiency increases dictated. As Jevons wrote in TCQ, after reviewing the possible fuel economies of these new kinds of engines: 'every such improvement of the engine, when effected, does but accelerate anew the consumption of coal'[320]. Jevons also disagreed with Armstrong's assertion that, as railways, steam navigation, and the use of engines in factories had now been firmly established in Britain, a certain amount of Britain's demand for coal had been satiated[321]. Jevons instead argued that, again owing to coal's exceptional utility, demand for coal was effectively insatiable and there was no point at which new uses for coal would not be found.

Referring to Armstrong's address, Jevons tactfully described the BAAS Chairman's comments as 'excellent', particularly his observation that 'the entire quantity of coal may be considered as practically inexhaustible'[322]. But this Victorian gentility served only to soften the fact that Jevons' explanation for coal's effective inexhaustibility was significantly different to that of Armstrong. Armstrong believed coal was inexhaustible, firstly because of its global abundance, and secondly, because increasingly efficient engines could reduce fuel

[319] TCQ, p. 150. for example, for a comparison of the fuel economy of Stirling and Ericsson's engines.

[320] TCQ, p. 152-153.

[321] 'it would be too much to assume that [demand for coal] will continue to advance with equal rapidity' as it had in the past'., Armstrong, 1863.

[322] TCQ, p. 32.

use, and thirdly, because demand for coal could be satiated. As a result, he believed coal *could* be conserved, and Britain's prosperity maintained indefinitely. Whereas Jevons argued the increasing efficiency of coal use would accelerate consumption for a commodity whose demand could not be satiated. This would accelerate coal use, leading to coal scarcity at a national level. Scarcity would raise prices, prohibiting coal's literal exhaustion, but costly British coal would be ruinous to British prosperity[323]. Here were two very different visions of the outcome of Britain's increasing industrial efficiency.

Not only did they disagree about the benefits of technology. In his address, Armstrong mentioned that many believed before coal was exhausted 'some other motive agent will be discovered'. He was particularly enthusiastic about 'the power of water descending from heights to which it has been lifted by the evaporative action of the sun'. He hoped this source of power, energy derived hydrological cycles, would in time 'become the means of economizing the precious stores of motive power' stored in mineral coal[324]. But here again Jevons tactfully disagreed with Armstrong.

In TCQ Jevons commended Armstrong's 'beautiful apparatus' for carrying out mechanical work with hydraulic power, perhaps referring to the hydraulic engines Armstrong had installed at a lead mine in the Pennines which he had invited the BAAS meeting's attendees to visit[325]. Armstrong had developed a number of hydropower machines, including an improved waterwheel, a hydraulic crane at Birkenhead docks, and the outline of a vast hydro-power system making use of Greenock reservoir[326] . Mirroring Armstrong's enthusiasm, in

[323] TCQ, p. 460 'We have to make the momentous choice between brief but true greatness and longer continued mediocrity'.

[324] Armstrong, 1863.

[325] TCQ, p. 172.

[326] Heald, 2012, p. 121.

TCQ Jevons even speculated that 'the most perfect conceivable system of machine labour might be founded on hydraulic power', and he reiterated Armstrong's claim, made in his BAAS address, that a waterpower system might one day run factories and homes[327].

However, Jevons went on to suggest that, though impressive, hydropower was a poor substitute for steam, as coal offered a more concentrated source of energy that was also far easier to control than water power, thanks to newly developed control mechanisms, such as Watt's engine and its governor component mentioned above[328]. Again, coal's exceptional utility was vital to his argument, as if greater utility could be more easily derived from coal than other sources of power, then on aggregate society would consume coal-power before other forms of energy.

Elsewhere in TCQ Jevons' described the opinions of Irishman Dionysius Lardner (1793-1859), who had argued that 'more powerful mechanical agents will supersede the use of coal'[329], as 'inexcusable'[330]. In the second edition of TCQ Jevons compared Lardner's claim, with a less-than-subtle dig at Ericsson, as opinions 'worthy only of a savant who proved that a steam-vessel could not cross the Atlantic'[331]. Jevons refused to consider that other fuels may supersede coal on the basis that 'to think of getting energy except from some natural source is as absurd as to think of making iron or gold out of vacant space'[332]. In doing so, he echoed the words of Scottish engineer William Rankine (1820-1872), who had presented a

[327] TCQ, p. 172.

[328] TCQ. p. 164.

[329] Lardner, D. (1840: 8) The Steam Engine Explained and Illustrated; with an historical sketch of its invention and progressive improvement; its applications to navigation and railways, 7th ed. London. cited in TCQ, p. 158.

[330] TCQ, p. 158.

[331] TCQ, 2nd ed., p. 160, ft. 1.

[332] TCQ, p. 161-2.

paper to the BAAS in 1855 which had addressed the 'popular delusion' that regenerators were a means of producing 'power created out of nothing'[333].

Coal, Jevons noted, underwrote all other forms of power, even electromagnetic engines or the use of hydrogen as a fuel would require steel components, which would need to be smelted by coal-fired furnaces[334]. As to the possible alternative sources of motive power: water, wind, light, heat, chemicals and magnetism. Jevons described them as 'rude forces of nature' whose power was either 'too great for us, as well as too slight'[335]. Energy abounded in nature, but it was either in too concentrated a form to be useful, such as the sun, or too diffuse, such as sunlight. Whereas coal power was, thanks to its concentrated material form and thanks to the development of engines of increasing control and efficiency, was 'wholly at our command, to be exerted when and where and in what degree we desire'[336].

Armstrong, by contrast, was an advocate and developer of alternative sources of power. In 1822, his friend William Siemens had visited Armstrong's imposing Northumberland home 'Cragside', and saw the source of his electricity supply, a large dynamo powered by a waterfall[337]. Alongside his hydraulic inventions, in the 1840s he had developed a hydroelectric machine which produced electricity via the friction produced by steam forced through a number of small nozzles[338]. Later in life, in 1881, during a speech to the BAAS in York, he speculated the use of solar power as a means of generating electricity, with no fear

[333] Cited in Daub 1974.

[334] TCQ. p. 180.

[335] TCQ, p. 164.

[336] Ibid.

[337] Ibid. p. 192.

[338] Morus, I. (2011) Shocking Bodies: Life, Death & Electricity in Victorian England. The History Press., p. 81.

of waste as 'the sun's heat is poured on the earth in endless profusion'[339]. As such, this coterie of industrial engineers, Armstrong and Siemens, and – with less credibility - Ericsson could be characterised as technological optimists, in so far as they believed either the increased efficiency of coal use or alternative sources of power might conserve Britain's coal supplies, if not obviating the need for coal entirely[340]. If one wanted evidence of Armstrong's faith in technological salvation we can return to his BAAS address, where he stated 'the seeds of invention exist, as it were, in the air, ready to germinate whenever suitable conditions arise'[341]. Jevons, by contrast, whilst lauding the value new technologies could produce, denied that any invention could preserve Britain's coal, nor did he believe other sources of power could replace coal without a loss to the nation's industrial supremacy.

THEORIES OF COAL'S DURATION IN CLASSICAL POLITICAL ECONOMY

Jevons' TCQ can clearly be seen as a refutation of what were the two principle technological means of 'preserving' energy in the nineteenth century: either using coal more efficiently or even in a regenerative way; or substituting coal with another less scarce source of motive power. Jevons' refutation of both the technological and substitutive means of conserving coal was not his only attack on nineteenth century principles of coal husbandry. Jevons also used the principles of political economy to attack the idea of coal conservation. He did so by clearly identifying a specific example of this argument within political economy[342]. At the beginning of Chapter VII Jevons noted:

[339] Heald, 2012, p. 190.

[340] Far from 'cranks' or 'incurable optimisits' it was clear that advocates of regenerator engines were credible engineers, and though their inventions did not meet the more expansive claims certain advocates made of them, they would go on to play a substantive role in later developments. See Marsden, 1988; Chapter 3.

[341] Armstrong, 1863., p. 2.

[342] Though the term conservation was not used.

> '*It is very commonly urged, that the failing supply of coal will be met by new modes of using it efficiently and economically. The amount of useful work got out of the coal may be made to increase manifold, while the amount of coal consumed is stationary or diminishing*'[343].

As a result, Jevons wrote that some mistakenly considered increasing efficiency and economy a '*means of completely neutralising the evils of scarce and costly fuel*'[344].

So Jevons not only disagreed with the technological and substitutive basis of coal conservation, he would also criticise the idea of coal preservation from the perspective of political economy. In exemplifying this wrongheaded view Jevons had cited[345] William Waterston's 1846 *Cyclopaedia of Commerce*, a digest of mercantile law, finance, commercial geography, and navigation for the use of merchants. The *Cyclopaedia's* entry on the 'Duration of Coal' noted that the author had grounds to:

> *'hope that the present waste of coal in the mine and on the bank cannot always continue, for in the progress of knowledge we have an assurance, that every year, as it increases the necessity, will also increase the means of economising our resources*'[346].

Like Armstrong's technological optimists, the authors here assumed the necessities of scarcity would encourage economy. If coal did become scarce, the entry went on, then 'a general rise in the price of coal would stimulate ingenuity'[347].

This meant, at least according to this author, that the question of coal's duration was unproblematic as:

> *'the only legitimate end to be aimed at by speculators on the duration of coal, is the prevention of all waste. If, to the best of our power, we husband our resources, we may safely leave to prosperity the management of their own interest, - the task of compensating for a*

[343] TCQ, p. 137.

[344] Ibid.

[345] Ibid, ft. 1.

[346] Waterston, W. (1846) A Cyclopædia of Commerce, Mercantile law, Finance, Commercial Geography, and Navigation. London, H.G. Bohn., p. 163.

[347] Ibid.

diminution of mineral resource' [could be achieved] *'by an increase of mechanical skill and ingenuity'*[348].

In nineteenth century Britain, clearly a form of coal conservation was believed possible according to the principles of political economy: a scarcity-driven increase in skill and ingenuity could preserve coal by minimising waste.

Who held this opinion? Waterston was the name of the *Cyclopaedia's* publisher rather than its author. The name referred to the son of George Waterston, a stationer from Edinburgh[349]. The book's preface stated that entries were attributed to individual authors where possible, though some could not be identified[350]. But the introductory chapter, 'A Treatise on the Principles, Practice, and History of Commerce', which gave an outline of the state-of-the-art in nineteenth century political economy, noted that the treatise 'although published without his name, is well known to be from the able pen of J. R. M'Culloch, Esq.'[351].

John Ramsay McCulloch (1789-1864) was a Scottish political economist and journalist, born in Galloway, who had studied mathematics at Edinburgh University. Though now widely forgotten, he was arguably the best known economist of the period. Described as Britain's first professional economist as he was able to make a living from publishing and lecturing.[352]. McCulloch regularly contributed articles to the *Edinburgh Review* and *Scotsman*, and it is not farfetched to imagine some more of the *Cyclopaedia's* articles were written by him[353].

[348] Waterston, 1846, p. 164.

[349] George Waterston and Sons (1952) Bi-Centenary History: George Waterston and Sons, ltd. 1752-1952. Edinburgh.

[350] Waterston, 1846, p. iv.

[351] Ibid.

[352] O'Brien, D. (1970) J.R. McCulloch, A Study in Classical Economics. Allen & Unwin.

[353] O'Brien, D. (2004) The Classical Economists Revisited. Princeton University Press. p. 17

McCulloch wrote on political economy and published 'statistical' studies, which at this time meant the collation of quantitative data on aspects of the economy rather than probabilistic mathematical analysis[354]. But McCulloch could also claim some expertise on the subject of coal. In 1830 he had published *Observations on the duty on sea-borne coal; and on the peculiar duties and charges on coal, in the Port of London,* a response to concerns raised by a Parliamentary Committee regarding the abuse of 'sea coal' duty. The term sea coal referred not to coal washed ashore, as it had in earlier times, but to coal transported by ship from the North of England. London, uniquely, had imposed a duty on coal since the Great Fire of London[355].

McCulloch began this book by asserting that 'fuel is one of the articles most indispensable to existence' and that Britain had 'the good fortune to possess inexhaustible supplies of the very best coal'[356]. McCulloch noted, two geologists 'Dr Buckland and Mr Taylor'[357] had estimated Britain's coal would last, at the present rate of use, between seventeen hundred and two thousand years[358]. Given this duration McCulloch argued London's coal tariffs should be removed, as 'a free trade in coal would be followed by reduction in price, much beyond the mere amount of duty'[359]. Reiterating that familiar liberal idea about the beneficial outcomes of reduced taxation, McCulloch argued that a reduction in coal duty would encourage trade, increasing general prosperity far beyond that achieved by taxation. To those who, as a result

[354] For more on McCulloch's statistics see Wise and Smith 1989.

[355] Nef, J. (1932) The Rise of the British Coal Industry. London, Routledge. p. 452.

[356] McCulloch, J.R. (1830) Observations On The Duty On Sea-Borne Coal; And On The Peculiar Duties And Charges On Coal, In The Port Of London. Longman, London., p. 4.

[357] William Buckland (1784-1856) and Richard Cowling Taylor (1789-1851), two leading English geologists Rudwick. M. (2008) Worlds Before Adam: The Reconstruction of Geohistory in the Age of Reform. University of Chicago Press.

[358] McCulloch, J., 1830, p. 22-23.

[359] Accordingly, 'coal duty ought to be immediately repealed' Ibid, p .20.

of the removal of duties, feared the exhaustion of Britain's coal, McCulloch comforted by stating that 'national debt will be every shilling paid off many centuries before posterity begins to feel any serious falling off in the supply'[360]. Already, McCulloch's book was seemed to have introduced many ideas that both Armstrong and Jevons would discuss in their work on the question of coal's duration.

Other evidence adds to the idea that the *Cyclopaedia* article on the duration of coal drew on or was written by McCulloch. In *A Descriptive and Statistical Account of the British Empire* (1847) McCulloch noted the 'good deal of attention' recently given to the question of coal's exhaustion[361]. In a similar formulation to that in the *Cyclopaedia,* McCulloch noted that 'apprehensions of the speedy exhaustion of our coal mines' were misplaced owing to both the 'untouched coal beds of immense magnitude' and given that current mining methods were 'slovenly' more than two-thirds of coal was left behind in most mines. But signs of scarcity would encourage more efficient mining, 'so that for all practical purposes, and in relation to such periods of time as may be supposed to come within the scope of the remotest schemes and combinations, our supply of coal may be considered inexhaustible'[362]. Given obvious similarities, though the *Cyclopaedia* entry was unsigned, it could be presumed to have either been written by, or strongly reflect the arguments of, McCulloch, an author well-known for self-plagiarism[363].

[360] McCulloch, J., 1830, p. 21

[361] Ibid, p. 599.

[362] Ibid, p. 600.

[363] O'Brien self-plagiarism is apparent in Waterston's *Cyclopaedia*, many entries from which can found in McCulloch's *Commercial Dictionary.* Creedy, J. (2001) 'D.P O'Brien and the History of Economic Analysis' in Historians of Economics and Economic Thought: The Construction of Disciplinary Memory. Routledge. Medema, S., Samuels, W. eds, p. 18.

McCulloch's suggestion was that coal was inexhaustible thanks to the effect of raised prices in increasing the efficiency of mining. This raises the suggestion that in some sense, he believed coal could be preserved by the actions of the economy. On what basis did McCulloch make this claim? Historians of economic thought often class McCulloch as a follower of David Ricardo, who, as we saw in the discussion of the marginal theory of value, proposed a theory of value in which value was determined by the application of labour to other forms of capital, such as land or technology. But McCulloch's biographer, historian of economics Dennis O'Brien, derides the idea that McCulloch was a doctrinaire Ricardian, suggesting such a view misleading, as he had in fact developed an alternative value theory to Ricardo[364]. In place of labour or capital as determinants of value, McCulloch proposed a more complex 'cost of production' theory of value, in which various forms of capital contributed to the calculation of value in different ways. O'Brien acknowledges that this distinction has been obscured, as McCulloch willingly simplified his value theory, which involved complex calculations, in order to popularise his ideas to a non-scientific reader[365]. So, in his popular writings McCulloch could be considered essentially a Ricardian. As was evident in his publications on coal, McCulloch proposed that the value that could be derived from mines could be increased via the operation of the market, as increased competition would encourage an increase in efficiency, human labour, and ingenuity.

How did competition act against scarcity in Ricardian political economy? In *Principles of Political Economy and Taxation* (1817) Ricardo wrote 'when the wealth and population of a country are increased, if that increase is accompanied by such marked improvements in agriculture, as shall have the same effects of diminishing the necessity of cultivating the

[364] O'Brien, 1970; O'Brien, D. (1966) 'J.R McCulloch and the Theory of value', Scottish Journal of Political Economy, Vol. 13, Iss. 3, p. 332.

[365] Ibid, p 333. See also Smith and Wise 1989.

poorer lands, or of expanding the same amount of capital on the cultivation of the more fertile portions'[366]. In effect, as agricultural methods improved, he claimed the amount of capital, in this case land, needed to produce a given amount of output would decrease. Scarce forms of capital could be supplemented by improved methods of cultivation. Or, more simply, technology could supplement scarcity. In related optimistic claim, Ricardo also argued that competition would drive improvements in cultivation. As population and affluence grew, more efficient machinery would be created, which would *increase* the availability of all forms of capital, rather than as Jevons would argue in the case of scarce coal, *reducing* availability. As historian Maxine Berg has proposed - and in stark contrast to Jevons' TCQ - 'Ricardo's *Principles* put forward a new ideology of economic and technological improvement – if not of limitless growth, then of growth to which an empirical limit could not yet be set.'[367].

This technological optimism was reflected in Ricardo's views on the economics of coal. Elsewhere in *Principles* he wrote, just as in agriculture, that:

> '*If the old mines are insufficient to supply the quantity of coal required, the price of coal will rise, and will continue rising till the owner of a new and inferior mine finds that he can obtain the usual profits of stock by working his mine*'[368].

Revealing his application of agricultural reasoning, Ricardo considered the 'fertility' of mines as something regulated by technological improvement, competition, and the price of coal. Ricardo wrote in a period in which spatial limits to the expansion of industry were not

[366] Ricardo, D. (1817) On The Principles of Political Economy and Taxation. John Murray, London; Berg, M. (1980) The Machinery Question and the Making of Political Economy, 1815-1848. Cambridge University Press., p. 49.

[367] Berg, 1980, p. 65. It is worth noting that Ricardo is more commonly understood to be a political economist concerned with constraint and limits, see Wrigley 2010 for example. Hence Berg's argument is somewhat unconventional. However, given its focus on the emancipatory potential of technology, rather the constraints of declining return on capital (in Wrigley) this author is more sympathetic to Berg's more optimistic reading of Ricardo's work. This optimism is also reinforced by Ricardo's somewhat cornucopian view of coal scarcity.

[368] Ricardo, 1817, p. 24.

yet apparent, which may go some way in accounting for his somewhat cornucopian prospect. Unsurprisingly, Ricardo's view on coal scarcity mirrors that of McCulloch. In Ricardian theory, it was entirely possible to preserve coal by using it more efficiently, as scarcity could be averted by incremental, price-driven, technological improvements. Alongside Jevons' attack on the engineer's technological optimism, articulated by Armstrong and others, JP can be read as a rhetorical challenge to Ricardo and McCulloch's optimistic idea that coal preservation was possible via an increase in the availability of complementary forms of capital.

THE ROYAL COMMISSION OF 1866

The Royal Commission provoked by Jevons' TCQ first met at the House of Lords in July 1866. Jevons, Siemens, and William Armstrong were called to give evidence. The stated aim of the investigation was, in part, to investigate, amongst other things 'whether there is reason to believe that coal is wasted, by bad working, or by carelessness, or neglect of proper appliances for its economical consumption'. The Commission noted that in most of Britain's engines, 'not more than one thirtieth of the whole theoretical value of coal is present realized in Power'[369]. The Commission therefore warned of the enormous waste of heat and fuel that was occurring across Britain, the inefficient use of energy had become a political concern, and would remain so throughout the twentieth century.

The Commission's final report, published in 1871, reached a more comforting conclusion than TCQ. The report noted Jevons' inference that 'economies would have no effect in diminishing consumption' was demonstrably correct, according to the rate of coal use in

[369] HMSO (1871) Report of the Commissioners Appointed to Inquire into the Several Matters relating to Coal in the United Kingdom. Vol. 1. HMSO, London.

subsequent years, which agreed with Jevons' forecast growth rate (3.7 per cent per annum). It was argued that Jevons' forecasted rate of exhaustion (110 years) was exaggerated. He had failed to account for the declining growth rate of Britain's population, which was just becoming evident and the exceptionalism of industrialisation, which would mean that per capita energy-use would begin to level out. On this basis the Institute of Civil Engineer's statistician Price Williams provided range of alternative 'modes of seeing the question', scenarios which forecast a significantly lower population growth rate than Jevons, and in which coal was accordingly predicted to last anywhere from 360 to 1695 years[370]. Following this more moderate warning, no government action would be taken to use coal with greater efficiency until the outbreak of World War One, as will be discussed in Chapter 3.

CONCLUSION

I began this chapter by suggesting that Jevons' paradox had often been divorced from the historical and intellectual contexts from which Jevons had both formulated and directed his argument. His argument was that efficiency could cause an increase in the rate of resource use. In reassembling this context, I have suggested that Jevons' paradox did three things. First, within the history of economics it can be seen as a demonstration of the emerging concept of marginal utility, though a somewhat idiosyncratic example, as Jevons believed that coal had an almost infinite number of uses, and as a result, it was almost impossible to satiate its demand.

I have proposed that the paradox was directed toward the pronouncements of William Armstrong regarding the possible prolongation of coal's use via the use of increasingly

[370] HMSO (1871) and Clapp, B. (1994) An Environmental History of Britain Since the Industrial Revolution. Routledge.

efficient technology, and the more sensationalist discussion of technological progress in the popular press. In particular, regenerative engines, and engineers such as Ericsson had created the idea that exceptions to the still yet uncertain laws of energy might be possible. The final target of Jevons' paradox, I have argued, were the also popular theories of political economy put forward by McCulloch, which drew on Ricardian principles, to suggest that coal scarcity could be avoided almost indefinitely if other factors of production such as land, labour, or their extension via technology, could be achieved. It appeared as if in classical ('Ricardian') economic theory, ERC of some kind was considered possible. But by drawing on his knowledge of thermodynamics, and allying this to his theory of utility maximisation, Jevons' paradox was intended to refute the idea that fuel could be conserved via technological or economic ingenuity. Jevons' work can be understood as an attempt, as Wise and Norton have suggested elsewhere, to explain how energy could be harnessed for economic growth, and what the limits of this usage were[371].

Hypothetical links can be made for the intellectual 'effect' of the contemporary claim that regenerator engines could preserve fuel on the equally optimistic notion of coal's duration proposed by Ricardian theory, and vice-a-versa, just as historian of technology Otto Mayr has done for the steam-engine governor and Adam Smith's notion of self-regulating market,[372]. Though they remain hypothetical, both the technology and theory manifest the same belief in the prolongation of the use of scarce resources via the increased efficiency of their use. Such relations, it should be re-asserted, remain wholly hypothetical, but such ideas could be credibly made during what Smith and Wise termed, 'years of uncertainty' with regard to the scientific and social implications of thermodynamics.

[371] Wise & Smith, 1989, p. 392.

[372] Mayr, O. (1971) 'Adam Smith and Concept of the Feedback System: Economic Thought and Technology in 18th Century Britain', Technology and Culture, Vol. 12, No. 1, pp. 1-22.

This leads to the slightly odd conclusion that Armstrong and McCulloch, as figureheads for a belief we can assume was more widespread, seemed to suggest fuel could be conserved as they acted in ignorance of, what Jevons believed to be, the societal consequences of thermodynamics. Whereas Jevons believed, contra Armstrong and McCulloch, that coal could emphatically not be conserved owing to its unparalleled utility, and according to the principle of energy conservation, manifest in individual's attempts to conserve their own physiological energy by using other labour-saving forms of energy. And yet, without renouncing either the laws of neoclassical political economy or thermodynamics, in the following chapters we will see how a science of ERC emerged which would overturn Jevons' position.

CHAPTER. 3. HERBERT STANLEY JEVONS AND THE EFFICIENT USE OF FUEL IN BRITAIN.

This Chapter describes the early decades of fuel efficiency policy in pre- and post-war Britain drawing on the work of Jevons' son, Herbert Stanley Jevons. In documenting his work it is shown how the notion of fuel efficiency intersected with profound shifts in the politics and administration of fuel use. For much of the nineteenth and twentieth century attempts had been made to use fuel with increased efficiency in order to minimise waste. Jevons senior's paradox, stated in 1865, had claimed that increased efficiency of fuel use counterintuitively *increased* the rate and scale of fuel use by lowering the cost of use. Minimising wasteful coal consumption, he argued, caused an increase in coal consumption, rather than its conservation. But the Royal Commission of 1866, discussed in the previous chapter, had suggested fuel economies should still be sought for reasons of economic productivity, and to extend the duration of Britain's coal supply. For much of the early history of twentieth century Britain, particularly following the First and Second World Wars the British Government actively promoted the efficient use of fuel. This approach stood in contrast to the science of energy conservation that would emerge in the 1970s for a number of reasons. First, the emphasis was on the conservation of distinct fuels rather than energy as a more all-encompassing concept which described the properties of different fuels in abstract terms. Second, efficient fuel use was rarely discussed in terms of 'conservation', and when it was, it referred to in the sense of conserving 'national capital', the economic value that could be derived from fuel. Third, owing to the regulation of fuel prices and the nationalisation of many aspects of the fuel industries after Second World War, calls for restructuring fuel markets in pursuit of efficiency could not be sensibly made.

HERBERT STANLEY JEVONS

As suggested in this thesis' introduction, one aspect of this thesis' approach to intellectual genealogy is to follow the literal genealogy of the Jevons' family, in accordance with Michel Foucault's historical approach, that even within a generation, the history of ideas is not a process of accumulation, but of change[373]. So let us turn to William's son. Herbert Jevons was born in 1875, ten years after the publication of his father's book *The Coal Question*. That year, William's diary noted that Herbert 'has not yet shown any consciousness of his relation to me'[374]. It would not remain this way. Once an adult, and also an economist, much of Herbert's writing would address his father's work, to whom his achievements were often compared. Herbert was seven-years-old when his father died, and a decade later, like his father, he began to study at UCL. He went on to Trinity College Cambridge, and then to study geology to the Geological Institute in Heidelberg. Once graduated, Herbert returned to Cambridge briefly as a 'demonstrator' in petrology before lecturing for two years in geology and mineralogy at Sydney University, an antipodean period similar to his father's years at the Sydney mint. In 1905, he gained an appointment as a lecturer in economics and political science at Cardiff University, where he combined his knowledge of geology and economics in a study of the local coal industry. In 1914, leaving Cardiff, Herbert worked in Allahabad, in Uttar Pradesh, India and Rangoon (now 'Yangon') in Myanmar, Burma, for over fifteen years, during which time he taught economics at a number of universities[375].

[373] Foucault, M (1987) 'Nietzsche, Genealogy, History', in Rabinow, P. ed. The Foucault Reader. London.

[374] Jevons, W. (1886) Letters and Journal of W. Stanley Jevons. Macmillan London.

[375] Anon. (1955) 'Obituary: Stanley Jevons', Journal of the Royal Statistical Society, Series A. Vol. 118, No. 4., pp. 498-499.

Herbert's contributions to economics, and specifically resource economics, have gone relatively unremarked upon[376], despite his publishing widely. His books include *Essays on Economics* (1905,) a summary of contemporary economics; the *Foreign Trade in Coal* (1909); *The Causes of Unemployment* (1909), which addressed the effect of trade cycles on employment; *The Sun's Heat and Trade Activity* (1910), an analysis mirroring his father's work on the relationship between sunspots and trade cycles; and *The British Coal Trade* (1915), a rejoinder to his father's book on coal which emphasised the geological and working conditions of coal-mining; his time in India resulted in *The Future of Exchange and the Indian Currency* (1922); and later in life he published *Economic Equality in the Co-Operative Commonwealth* (1933), a manifesto for a socialist economy . Alongside his own work, Herbert edited the fourth-edition of his father's *Theory of Political Economy* (1875 [1911])[377]. He also wrote pamphlets and journal articles, on subjects as diverse as petrology, steel, mineralogy, economics, politics, housing reform, co-operatives, war, and utopianism[378]. Herbert was also a frequent letter writer, corresponding with British economist John Maynard Keynes (1883-1946), Japanese economist Shinzo Koizumi[379] (1888-1964), geographer and town planner Patrick Geddes (1854-1932), and the classicist Margaret Ensor (1908-2006), with whom he worked on an unpublished adaptation of Thomas More's (1516) *Utopia*[380].

[376] Tomlinson, T. (2004) 'Herbert Stanley Jevons', The Biographical Dictionary of British Economists, Vol. 1, Thoemmes, Bristol. Rutherford, D. ed., Missemer, A. (2015) 'La peur du déclin économique face à l'épuisement des ressources naturelles, de W. Stanley Jevons à Herbert S. Jevons (1865-1915)', Revue Économique, Vol. 66, pp. 825-842., are exceptions.

[377] Collison Black, R. (1892) 'The Papers and Correspondence of William Stanley Jevons: a supplementary note', The Manchester School, 50, IV, pp. 417-428.

[378] OUP (2014) 'Jevons, Herbert Stanley', Who was Who, A & C, Bloomsbury Publishing. In fact, on this last subject, HSJ was working on a translation and modernisation of Thomas More's Utopia () with the help of Margaret Ensor (1908-2006), a British Classicist residing in America. See Unpublished Manuscript - 1962 and 1965 donation 9: 'Utopia' - typescripts, correspondence, etc., 1935.

[379] Koizumi would go on to translate WSJ's Theory of Political Economy and also tutor future Emperor. Ikeda, K. (2007) 'Shinzo Koizumi (1888-1966): A Japanese Economist's Encounter with the West', History of Economics Review, Vol. 44, Iss. 1, pp. 39-49.

[380] In fact, at the time of their correspondence, Olivia Coolidge used her birth name Margaret Ensor. See HSJ Archive, Unpublished Manuscript - 1962 and 1965 donation 9.: 'Utopia' - typescripts, correspondence, etc., 1935.

Herbert's life was more cosmopolitan than his father's. In 1914 he established the first chair of economics at the University of Allahabad, which he held until 1923. There, in 1916, he founded the *Indian Journal of Economics*, and met Indian Nationalist Mahatma Gandhi (1869-1948), who attended a lecture. Gandhi took exception to Herbert's view that economics must be scientifically true but morally neutral, but the two remained cordial, if critical, correspondents[381]. In later life Jevons' cosmopolitanism extended to Africa. When Benito Mussolini (1883-1945) invaded Ethiopia in October 1935, Jevons responded by founding the Abyssinian Association to coordinate voluntary British assistance on behalf of Emperor Haile Selassie (1892-1975). In a pamphlet he accused Mussolini of 'total disregard of moral principles'[382], and he accompanied Selassie to Geneva in 1936 to appeal to the League of Nations. After the unsuccessful appeal, Selassie lived intermittently in Bath, Southwest England, and the two remained friends.[383]. Herbert would continue to campaign on behalf of Selassie, who was eventually restored to power in 1942[384].

Herbert was also distinguished by his socialism. A year after the First World War ended he had written of a 'constitutional, bloodless revolution' in which the middle classes of Britain would be converted to believing in socialist principles[385]. His belief would develop in a particular direction, when he joined the Common Wealth Party. Founded by Liberal MP Richard Acland in 1941, during and immediately after the Second World War, Common

[381] Lindley, M. (2007) J.C. Kumarappa: Mahatma Gandhi's Economist. Popular Prakashan, Pvt. Ltd.

[382] Jevons, H. (1937) Italian Military Secrets; three years' preparation for the Abyssinian war, astonishing official revelations by General de Bono. A paper read before the Abyssinia association by Professor H. Stanley Jevons. Self-Published.

[383] Anon. (1955) 'Obituary: Stanley Jevons', Journal of the Royal Statistical Society, Series A. Vol. 118, No. 4., pp. 498-499.

[384] Jevons, H. (1942) 'The New Era in Ethiopia', The Contemporary Review, Iss. 161., p. 213.

[385] HSJ Archive, Unpublished Manuscript- 1962 and 1965 donation 6.: 'The Social Revolution'. Chapter V missing, 1919.

Wealth proved a briefly popular party, advocating a moderate form of Christian socialism. At its 1944 peak, the party had four-hundred branches and fifteen-thousand members, including novelist J.B. Priestley and two members of Parliament. Acland had argued, in outlining the party's position, that war had led to the 'complete breakdown of the existing order'; an order based solely on the principle of self-interest and in 'diametric opposition to the teachings of Jesus Christ'. In its place, Acland wanted a new order where the 'motive of service transcends the motive of individual gain'[386]. As such, members of Common Wealth hoped the economic depression of the nineteen-thirties, which they believed to be the result of a liberalised economics of self-interest, would be replaced by a rationalised approach to industry, as the war had shown possible[387].

The Second World War had involved an unprecedented effort to mobilise industrial output in support of the war effort. For each of the 4.8 million Britain's in combat, each had a corresponding industrial worker producing goods for them. As a result, Britain had becoming what historian of technology David Edgerton has termed a 'warfare' state[388]. Common Wealth's aim was to use this technological base to form a modern, technocratic form of socialism, including full public ownership of industry, in contrast to the compromised 'state-capitalism' Labour Party Prime Minister Clement Attlee would achieve from 1945 onward[389]. Common Wealth were largely critical of Attlee's post-war policies, regarding them as 'pale

[386] Callaghan, J. (1995) 'Common wealth and the communist party and the 1945 general election', Contemporary Record, Vol. 9, Iss. 1, pp. 62-79.

[387] Prynn, D. (1972) 'Common Wealth – A British 'Third Party' of the 1940s', Journal of Contemporary History, Vol. 7, No. 1., pp. 169-179.

[388] Edgerton, D. (2006) Warfare State: Britain, 1920-1970. Cambridge University Press, p. 75.

[389] Conservative Harold Macmillan termed it "state capitalism" and nationalisation was noted for the degree to which captains of industry remained in place, and worker participation was marginal. Pearce, R. (2006) Attlee's Labour Governments, 1945-1951. Routledge, London.

pink' rather than socialist red, it was argued that capitalism needed to be abolished rather than becoming state-managed[390].

In the last years of the Second World War, writing on behalf of Common Wealth, Herbert produced a pamphlet titled 'Abundance for all, through Common Ownership' which stated that 'competition involves wasteful expenditure'. In a capitalist system, he believed money was spent needlessly to advertisers, shareholders, or was held in banks rather than being used productively. Critically, fuel was also wasted. Herbert noted the 'supposedly good management of private industry has been well shown up in England during the war'. When coal mines were government-run, and various industries co-opted by government for the war effort, productivity had markedly increased. Particularly in new government-owned armament plants, which enjoyed £1 billion in government investment between 1936 and 1945[391]. Not only that, Herbert also claimed war had shown 'The great majority of manufacturing firms were found to be wasting coal, burning from 15 to 50 per cent more than was needed'[392].

Such evidence of industrial waste had been documented by the Fuel Research Board (FRB), established during the war in 1917, to investigate the use of coal and other fuels 'in the broad national interest'[393]. The FRB was a branch of a larger research organisation, the Department of Scientific and Industrial Research (DSIR) which had been established a year earlier to

[390] Callaghan (1995).

[391] Edgerton, 2006, p. 77.

[392] HSJ Archive, Abundance for all through Common Ownership'. MS and typescript, 1962 and 1965 donation 14 (*undated*), p. 3.

[393] Monkhouse, A. 'Forty Years of Fuel Research', Journal of the Royal Institute of Chemistry, and Stranges, A. (1985) 'From Birmingham to Billingham: High Pressure Coal Hydrogenation in Great Britain', Technology and Culture, Vol. 26, No. 5, pp. 726-757.

carry out long-range industrial research to support industry during the war[394]. Edgerton uses the term 'research corps' to describe these new government-funded research bodies, which acted as a supplement to existing university and industry based research organisations, and extended government intervention in public life beyond the civil service in a diffuse range of scientific and industrial settings affiliated by their collective contribution to the war effort[395].

In his Commonwealth manifesto, building on this wartime state-led industrial research, Herbert outlined a future in which engineers, 'combining new mechanical and electrical devices', would begin 'securing abundance and cheapness of the necessities and conveniences of life'. Abundance, he suggested, would be achieved partly via automation[396], not to replace labour, but to ensure workers acted with increased productivity. As an example Jevons mentioned the recently invented Japanese **'**Toyada automatic loom'[397] which allowed one operative to tend thirty or fifty looms rather than the six to eight a skilled Lancashire weaver could manage. Suitably technologized, Herbert believed Britain could replicate the productivity increases that an increasingly scientific approach to industrial management were achieving in Japan and America.[398]. Common Wealth would eventually be subsumed by the increasingly popular post-war Labour party, but Jevons' enthusiasm for scientific rationalisation of production was in step with a more general faith in progress through industry held by the British labour movement after the Second World War[399].

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[394] Edgerton, 2006, p. 106.

[395] Edgerton, 2006, p. 115.

[396] A term used to describe the mechanisation of task that previously required human's physical or cognitive labour cf. Noble. D. (1986) Forces of Production: A Social History of Industrial Automation. Oxford University Press.

[397] Named after its inventor Japanese industrialist Sakocho Toyada (1867-1930) who would go on to apply the same industrial principles to automobile manufacture, resulting in the anglicised 'Toyota' automobile company in 1957. Toyata, J. (1988) Toyata: A History of the First 50 Years. Toyata Motor Corporation.

[398] Ibid., on the Scientific Management of Resources, see Chapter 4.

[399] Whitson, K. (1995) Scientific Management Practice in Britain, A History, Unpublished PhD. Warwick University.

THE SECOND INDUSTRIAL REVOLUTION

Herbert had long been interested in the management and automation of industrial processes. In 1931 he had published an article in the British Journal *Economic Review* titled 'The Second Industrial Revolution', in which he described 'a sweeping change of the methods and organisation of the secondary industries' that he saw occurring in many industrialised countries. Exactitude and planning, Herbert believed, would increase the nation's productivity to an extent comparable only to the Industrial Revolution that marked his father's lifetime. This idea was not new. In 1927 British journalist Walter Meakin had described Germany's post-war regeneration as a 'New Industrial Revolution'[400]. Similarly, in 1939 Marxist scientist J.D. Bernal would write of an ongoing 'second industrial revolution' in which 'science is playing a much larger and more conscious part than the first'[401]. For Herbert 'The essence of the new industrial revolution' was ' the search for exact knowledge, and the planning of processes: from the minutiae of manual operations (based on motion-study) to the lay-out of the machinery of a gigantic plant – even of a whole industry throughout the country'[402]. This second industrial revolution, Herbert believed, was the result from three developments: the increasing sophistication of accountancy, the growing precision of industrial engineering, and the emergence of 'continuous mass production'. All developments which he observed to have been accelerated by the First World War.

But these advances in the efficacy of industry had also involved a human component. the nineteenth-century, the actions of human physiology had been increasingly seen as the result of somatic thermodynamic processes. This view of the human body as a biological motor lent

[400] Bernard Cohen, I. (1987: 396) Revolution in Science. Harvard University Press.

[401] Bernal, J. (1939) The Social Function of Science. Routledge, London.

[402] Of course, the term industrial revolution was established much later cf. Toynbee. See Wilson, D. (2014) 'Arnold Toynbee and the Industrial Revolution: The Science of History, Political Economy and Machine Past', History and Memory, Vol. 26, No. 2, pp. 133-161.

support to an increasingly scientific approach to the management of labour, leading to what sociologist Anson Rabinbach termed a 'science of work', in which both labourer and machinery were cast as means for maximising the productive efficiency of energy use[403]. Such ideas would become increasingly sophisticated in the twentieth-century, principles of 'scientific management' were first formalised by American engineer Fredrick Winslow Taylor (1856-1915) in 1911. His work was encapsulated by his dictum: **'**Science, not rule of thumb. Harmony, not discord. Cooperation, not individualism. Maximum output, in place of restricted output. The development of each man to his greatest efficiency and prosperity'[404].

'Taylorism' was intended to increase productivity and overcome labour disputes by closely monitoring working practices, and formulating ways to improve the frequency, accuracy, or duration of labour, with the aim of increasing profits for the manager and increasing prosperity for the worker[405]. 'Fordism' was a related science of work developed by automobile engineer Henry Ford (1863-1947) in which production took place along assembly lines, and individual workers 'specialised' in a single, repetitious part of production. Both Taylorism and Fordism implied some degree of automation, the replacement of human labour by that of machines, but despite this scientific management was positively received by the labour movement in Britain[406]. Though Taylor had intended scientific management to be a means of overcoming class tensions, in Britain, scientific management seemed to excite

[403] Rabinbach, A. (1990) The Human Motor: Energy, Fatigue, and the Origins of Modernity. University of California Press.

[404] Taylor, F. (1911) Principles of Scientific Management. New York and Company.

[405] Karns Alexander, J. (2008) The Mantra of Efficiency: From Waterwheel to Social Control. Johns Hopkins University Press.

[406] Whitson, 1995: ix.

rather than quell such antagonisms, encouraging those who believed that production could be rationalised as part of a socialist redistributive system[407].

Principles of scientific management had become increasingly evident in British industry after World War One partly as an import introduced by American financiers who invested in or purchased British firms during the Great Depression[408]. Like the war, the effects of depression of the 1930s, had been instructive, monetary policies had contributed to deflation, and monetary policies were also considered the most orthodox solution to widespread unemployment and tepid economic growth[409]. In contrast to this orthodox solution, advocates of scientific management suggested it was improvements in technological and worker efficiency that could lead out of the depression. For example, Herbert's book *Economic Equality in the Co-Operative Commonwealth* (1933), outlined to achieve a system of co-operative socialism with technology used for welfare rather than competition, and with it a new and more efficient order established involving 'a system of industry planned and controlled throughout in accordance with scientific principles, many of which have yet to be discovered and formulated'[410].

Herbert's book drew parallels with the American engineer Howard Scott's (1890-1970) recent pronouncements on the implications of labour-saving technology, in *Harper's Magazine,* Published similarly in 1933, Scott had outlined the 'striking increases in industrial

[407] See Chapter 4, and Haber, S. (1964) Efficiency and Uplift: Scientific Management in the Progressive Era, 1890 to 1920. University of Chicago Press. And Maier, C. (1970) 'Between Taylorism and Technocracy: European Ideologies and the Vision of Industrial Productivity in the 1920s', Journal of Contemporary History, Vol. 5, pp. 27-61.

[408] Armytage, W. (1965) The Rise of the Technocrats: A Social History. Routledge and Kegan Paul ltd.

[409] On the 'great depression' in Britain see Temin, P. (1989) Lessons from the Great Depression. MIT Press. The idea being that government could print more money, or produce currency, as a spur to public and private investment. This investment, in turn, would increase employment, as investment projects would need workers.

[410] Jevons, H. (1933) Economic Equality in the Co-Operative Commonwealth. London, Methuen and Company.

productivity' that had been achieved in America in recent years[411]. In a further reference to Scott's thinking, Jevons suggest such productivity increases had been unfortunately offset 'by an equivalent commercial waste in the form of unemployment'[412]. Jevons believed competition between technology and labour was inherently wasteful, and he referred to Scott's 'group of engineers in America who have constituted themselves the pioneers of Technocracy' as those 'producing alternative statistics' which 'prove the impossibility of the continuance of the competitive price system'[413].

Scott's Technocracy movement had proposed an extreme form of scientific management. They claimed America should be ruled by a technical elite rather than democratic government. Their ideas provoked some enthusiasm given the apparent failure of government during the great depression, which Scott argued was the result of dramatic increases in technological productivity and automation, which had displaced demand for labour[414]. Earlier that year, again in *Harpers,* Scott described how 'technology smashes the price system'. His argument was that economic value was not determined by price, or utility, but by the use of energy. As technology allowed energy to be used more effectively, it displaced the need for human labour. But if America were run as 'a huge and intricate machine', in which labour and value were recognised as similarly energetic phenomena, full employment could be assured by the imposition of 'energos', a currency based on energetic value, which he believed would provide a consistent reward for the energy expenditure of work[415]. And whilst Herbert did not advocate an energy-theory of value, but he upheld the Technocrat's view that

[411] For more on Scott Chapter 9.

[412] Jevons, H. (1933) p. x.

[413] Ibid. p. 355.

[414] Akin, W. (1977) Technocracy and the American Dream: the technocracy movement, 1900-1941. University of California.

[415] Scott, H. (1933) Technology Smashes the Price System', Harpers Magazine, Vol. 166, p. 129-142.

the depression undermined the marginal theory of pricing his father had help develop, as the price system had led to widespread unemployment during the depression. In place of a liberalised market, Herbert proposed a 'stabilised system of production and distribution' that would involve which a 'central price fixing authority' which would seek 'the greatest good' in according prices 'relative to each other and in relation to the cost of production[416].

After the Second World War, the case for rationalisation had come alongside a growing critique of the wastefulness of competition, a point Herbert's book demonstrated[417]. Companies had become larger, and economies of scale were sought rather than economies generated by a large number of competing business. Sprawling industries required 'management', and expertise in maintaining control over the disparate components of a single industry became ever more prized[418]. Hence in Britain, Herbert argued that a second industrial revolution should not only driven by industry, but also by publicly owed 'management research groups' such as the National Physical Laboratory, certain universities, and - significantly - the Fuel Research Board, organisations which he suggested were 'characteristic of the new industrial revolution'[419] .

In fact, as David Edgerton's work attests to, over the course of the wars, Britain had developed one of the largest research and development capabilities of all the industrialised nations. The NPL and Fuel Research Board were part of a 'research corps', state-funded research establishments called on for advice by Government ministers, and with influence on

[416] Jevons, H. (1933) p. 139, 224.

[417] Ibid.

[418] Hannah, L. (1974) 'Managerial Innovation and the Rise of the Large Scale Company in Interwar Britain', Economic History Review, Vol. 27, No. 2, pp. 252-270

[419] Jevons, H. (1931) 'The Second Industrial Revolution', The Economic Journal, Vol. 41, No. 161, pp. 1-18.

policy[420]. In the light of this new industrial research landscape, Herbert believed industry's contribution under free competition had been shown to be 'irregular and uncoordinated', and that this revolution should be taken as an opportunity to expand government funded industrial expertise in order to develop a more efficient, publicly-owned and planned industrial economy[421]. Herbert's ideas suggested that if the first industrial revolution had been the work of private industry, the second should be a state-run affair.

Like Herbert, historians have acknowledged a discontinuity between early industrialism and a later period of intensified industrial precision and productivity, fuelled by electronics, chemical synthesis, automation, and the development of 'control engineering' techniques[422]. This last term described technologies which incorporated informational feedback to automatically fulfil a task without further human intervention. Such control devices had a long history, going back to Watt's Governor if not earlier[423]. But with widespread electrification, electrical control mechanisms become more common, allowing industrial operations to be carried out by electro-mechanical systems with unparalleled connectivity and consistency[424]. Historian James Beniger described this period as the latter half of the 'control revolution', the next step in a process first acknowledge by German sociologist Max Weber (1864-1920), who described how the growing use of 'informational' control had come to govern almost all aspects of society[425]. A range of increasingly popular technologies, such as

[420] Research Corps is the term used by Edgerton, to reflect their once removed martial status., 2006, p. 115.

[421] Jevons, H. (1931).

[422] Edgerton, D. (2008) 'Not Counting Chemistry', Distillations, Magazine of the Chemical Heritage Foundation, Spring., Edgerton Warfare State, p. 201, Bennett S. (1993) A History of Control Engineering, 1930-1955: IEE, Peter Peregrinus Ltd.

[423] Mayr, O. (1979) The origins of feedback control. MIT Press.

[424] Bennett, 1993., Mayr, O. (1971) 'Maxwell and the Origins of Cybernetics', Isis, Vol. 62, No. 4, pp. 424-444., Mindell, D., (2002) Between Human and Machine: Feedback, Control, and Computing Before Cybernetics. Johns Hopkins University.

[425] See Wilson (2014), Bernard Cohen (1987).

amplifiers, wireless telegraphy, radio, and servo-mechanisms, provided technologies of informational control. Such technologies, Beniger argued, provided an opportunity recentralisation of political control, which had been lost during the Victorian era of laissez faire industrialisation, in which significant amounts of sovereignty had been ceded from the state to industry[426].

Herbert articulated a similar idea, he believed control technologies could provide a means for political reorganisation. In his manifesto for Common Wealth he wrote of the benefits of wireless 'for broadcasting and remote control', of television, and fluorescent lighting, and 'magnetised wire' with 'a hundred industrial applications in controlling complex automatic machines'. Such devices had political potential, Herbert believed, they could help overturn the liberal system of private ownership, and centralise industrial control in a socialist way[427].

COAL AND LABOUR

Herbert's optimism about realising a socialist future through the use of new technologies predated the wars. Since his father's time, the politics of Britain had been transformed. The Second Reform Act of 1867 had granted the vote to working class men, and the 1871 Trade Union Act had legalised organised labour representation. Policymakers and political economists had become increasingly concerned with collective 'welfare', and the role of the economy and state as an instrument for redistributing wealth[428]. It was no surprise that a year after the *Coal Question* the ever prescient William Jevons begun to address labour rights,

[426] Beniger, J. (1986: 7) The Control Revolution: Technological and Economic Origins of the Information Society. Harvard University Press.

[427] HSJ Archive, Abundance for all through Common Ownership'. MS and typescript, 1962 and 1965 donation 14 (date? Post 1944), p. 6.

[428] Backhouse, R., Nishizawa, T. (2010) No Wealth But Life: Welfare Economics and the Welfare State in Britain, 1880-1045. Cambridge University Press.

organised labour, and working conditions in his book *The State in Relation to Labour* (1866), which outlined a role for government in mitigating tensions between classes[429]. Following in this vein, Herbert's *The British Coal Trade,* (1915), drew on his observations of the organisation of mining labour in the South Wales coal fields. In 1898, a widespread strike had begun in the areas in opposition to the variable 'sliding scale' payment of wages depending on the market price of coal. The strike was defeated after six-months, but the miner's would form one of the largest unions of the period, the South Wales Miners' Federation. As the productivity of mines faltered in the following years, and coal-owners imposed lower wages, the Federation became increasingly strike-prone[430].

As one reviewer of Herbert's book described it, the author was at the 'cockpit of industrial warfare'[431]. His intention was to document 'the lives and personality of the workers' rather than merely identifying facts and figures'[432]. His book combined conventional economics analysis, of his father's kind, with a detailed observational account of mineworkers lived existence, the circumstances of their communities, and leisure time, and, given Herbert's scientific training, the geological distribution of coal and its variable chemical composition.

In describing miners' lot, Herbert declared 'The collier's life is a monotonous one', and described arduous commutes, early starts, and descents into dark mine shafts where manually hewing coal, or using noisy, fume-emitting mechanical cutters created a dangerous and unhealthy working environment[433]. Herbert also described the small and insanitary housing in

[429] Hutchinson, T. (1978) On Revolution and Progress in Economic Knowledge. Cambridge University Press.

[430] Howell, D. Baber, C. 'Wales', in Thompson, F. (1990) The Cambridge Social History of Britain, 1750-1950. Vol. 1. Cambridge University Press.

[431] Carter, G. (1916) 'Review: The British Coal Trade', The Economic Journal, Vol. 26, No. 102, pp. 240-247.

[432] Jevons, H. (1915) The British Coal Trade. London: Kegan Paul, Trench, Trübner. *TBCT Herein*.

[433] TBCT, 1915, p. 608.

the Welsh coalfields of Methyr, Abedare, and lower Rhondda. And whilst writing the book Jevons was involved in establishing a cooperative housing project on the outskirts of Cardiff[434]. And given his political beliefs, his account of the rise of trade unionism was unsurprisingly sympathetic[435]. He considered the Miners' Federation of Great Britain, established in 1888, and its South Wales branch, as 'unique both in regard to the rapidity of its growth in recent decades and to its completeness and effectiveness'. The Federation united various regional unions that had formed early in the century. Herbert believed Unions 'growing power will be used for good'[436]. He applauded the National Coal Strike of 1912, when one-million mineworkers downed tools, and forced government to introduce the first minimum wage for miners[437]. Before this, miners were paid according to the market rate or according to the quality of the coal in their seam, which led to fluctuating and often unreasonable wages which, in Herbert's words, failed to acknowledge the 'abnormal places and other abnormal conditions of work' miners undertook[438].

Herbert's book also revisited his father's question about the duration of Britain's coal. William, Herbert noted, had argued that 'The crux of the question' regarding coal's duration was the price of coal. If coal was cheap it would be consumed rapidly, only scarcity driven price increases could control the rate of consumption. But Herbert disagreed, and argued that the scarcity and price of coal was 'mainly dependent on the cost of mining'[439]. Though he did not acknowledge this, Herbert's thinking marked a return to something more akin to

[434] HSJ Archive, NLW, 'A Third Garden City', *Typescript*, (Undated).

[435] TBCT, 1915, p. 135

[436] Ibid, p. 488.

[437] TBCT, 1915: p. 608, 126, 488,

[438] TBCT, 1915: p. 608; 126; 488; 520.

[439] TBCT, 1915: p. 718.

Ricardian notion of value as a factor of the costs of labour, as outlined in Chapter 2[440]. However, were clear differences in Herbert's approach. Close to ongoing industrial action, Herbert knew the costs of labour would increase and become more ambitious. Clearly his answer to the coal question diverged from his father's. Herbert argued that 'the Coal Question is in reality a labour question, for the price of coal depends more upon the cost of labour than upon anything else'. If labour was the ultimate determinant of coal's duration, it meant 'the attitude of labour, and […] the cost of meeting more stringent legislative requirements' would determine price to a greater degree than physical scarcity and its effect on price[441]. Labourers' attitude to the conditions in which they found themselves, and the degree to which this was reflected in legislation, were criteria wholly absent from William Jevons' quantitative answer to the coal question which had been based on his principle of utility maximisation and the assumption of a liberal Victorian economy.

Another distinction in Herbert's answer to the coal question was to portray the role of the technology in a more positive light than his father had. In accord with his later faith in scientific management, Herbert believed 'It is enterprise, science and organisation which will win the commercial race of the future'[442]. Herbert argued for a double-shift system, with mines worked continuously using the latest electrical machinery, but with individual miners working shorter and safer shifts. In return for increased productivity, they would receive better housing and higher wages. He suggested this would require considerable government investment but this would pay off in increased industrial productivity and an increased output of coal. Centrally planned, Herbert believed mining could benefit from an increase in

[440] Toynbee suggested Ricardianism was, in part, responsible for the emergence of socialism in Britain. See George, H. (1886) *Progress and Poverty*. London.

[441] TBCT, 1915, p. 760.

[442] TBCT, 1915, p. 767.

economies of scale and levels of investment, far greater than those possible under a competitive system[443].

But what of his father's paradox, did it still hold? In discussing the relation between labour and technology Herbert reiterated Jevons' paradox[444], though he did not make use that term:

> *'He* [WSJ] *demonstrated clearly also that economy in the use of coal, such as has been since achieved, whereby one ton will do the work done by two tons fifty years ago, is no means of delaying the exhaustion of coal, for the possibility of cheaper power, due to the more efficient use of coal, leads to the constant application of power to new uses, and an ever-growing demand for coal, which is added to the increased demand due to growth of population'*[445].

Considering Herbert's optimistic views of both the waste-minimising and labour-saving technologies, this reassertion of Jevons' paradox is intriguing, but not discordant with his general argument; elsewhere in the text Herbert argued that more efficient machinery would result in greater productivity, so labourers would be less numerous but of greater value. These economies would still result in the paradoxical affect his father had predicted, but at least the value that could be derived from coal could be used for collective good. In this respect, like his father, he accepted that the efficient exploitation of coal would accelerate its depletion. But like his father, he believed this brief opportunity should be exploited with optimal efficiency. However, whereas his father had believed an industry-led approach would best achieve this, Herbert argued that it was a nationally run coal industry that could best derive value from scarce and finite coal.

[443] TBCT, 1915, p. 771.

[444] Herbert mentions the paradox twice, again in discussing furnaces and gas stoves, he admitted that 'There is still great room for these economical appliances to be more widely used; but, on the other hand, with the increasing spending power of the working classes there will probably be an increase of their consumption. Hence one cannot assume any important decrease of consumption per head of population'. TBCT, 1915, p. 747.

[445] TBCT, 1915, p. 722.

Accordingly Herbert's book contained a reference to conservation, though not of coal but the 'Conservation of National Capital', which was explained in the following way: *'The wealth given to us in the bowels of the earth should not perish with the people who consume it, but rather should it be converted through the results of men's handiwork into a permanent possession for the good of all the people'*[446]. What did Herbert mean by conserving national capital? His suggestion was that the value of Britain's coal could be converted into new forms of capital via its efficient use, thereby conserving the nation's value in a new form. He proposed that the government should establish 'Inventions Commissions' to encourage novel technologies for fuel use and to make use of alternative sources of supply. He also argued that 'national ownership of the means of transport and production' and 'possibly by national ownership of mines', 'enormous economies' in coal use could be achieved. The conservation of capital meant using coal's 'immense utility in the present' to build up a 'great store of wealth for the future' from a resource that, over time, would inalienably diminish. Used to develop new industries, could ensure the 'welfare of our descendants'[447]. Herbert, like his father, did not suggest that efficient use of coal would conserve a physical resource. This was the crux of Herbert's notion of fuel conservation, the aim was to make best use of an irreplaceable fuel, not, as the later of science of energy conservation would claim, to save fuel from consumption by using it more efficiently.

NATIONAL EFFICIENCY AND THE CONSERVATION OF COAL

Hebert's views can rightly be seen as contributions to a wider, ongoing drive for increased efficiency at the national scale which predated the wars. This efficiency craze was not specifically related to the early enthusiasm for waste avoidance prompted by thermodynamics

[446] TBCT, 1915, p. 766.

[447] TBCT, 1915, p. 768.

(Chapter 2). In 1902 *The Spectator* magazine had noted a 'universal outcry for efficiency in all the departments of society, in all aspects of life'. Though presumably there had never been a drive for inefficiency, this call for efficiency, historian Gerald Searle has claimed, stemmed from Britain's defeat in the Boer War [1899-1902], where the British army had been defeated by a smaller, unprofessional, force. Ideologues on both the right, including Lord Roseberry the former Liberal Prime Minister, and journalist Arnold White, and on the left; the Fabians Beatrice and Sidney Webb, H.G. Wells, and George Bernard Shaw called for a cross-party kind of Edwardian technocracy, in which old, amateurish state institutions would be transformed by experts on a rational, scientific basis[448]. In 1902 the Webb's formed a club, the 'Co-Efficients', named at Beatrice's request, to develop ideas for achieving 'imperial efficiency at home and abroad'[449]. Various luminaries joined, including geographer Halford Mackinder, described elsewhere as a 'conservative collectivist' whose 'heartland' thesis would prove highly influential to geographic theories of imperialism, and most significantly, the Liberal politician and former Secretary of State for War Richard Burton Haldane (1856-1928), in whose home the first meeting was held[450]. Though the group never found direct political representation, the principles of efficiency began to permeate public life. In the first decade of the twentieth century, the founding of the London School of Economics, Imperial College, the National Physical Laboratory, and even the Eugenics Education Society, to some extent, institutionalised notions of national efficiency as advances on the perceived inefficiencies of Victorian liberalism[451].

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[448] Searle, G. (1971) 'The Quest for National Efficiency: A Study in British Political and Political Thought, 1899-1914.

[449] Searle, G. (2003) 'The Politics of National Efficiency', in Wrigley, C. Ed, A Companion to Early Twentieth Century Britain. Wiley Blackwell. And Hall, J.G., Martin, D. (1996) Haldane: Statesman, Lawyer, Philosopher. Barry Rose Law Publishers. England, p. 95.

[450] Knutsen, T. (2014) 'Halford J. Mackinder, Geopolitics, and the Heartland Thesis', The International History Review, Vol. 36, Iss. 5, pp. 835-857.; Green. E. (2004) Ideologies of Conservatism: Conservative Political Ideas in the Twentieth Century. Oxford University Press.

[451] Searle, 2003.

After the First World War, as part of national reconstruction efforts, Haldane was given the opportunity to turn concerns about national efficiency into specific recommendations for the reform of government in his position as Chair of the 'Machinery of Government Committee', established in 1917[452]. Joined by former Co-Efficient Beatrice Webb, amongst others, Haldane investigated how the functions of government might be rationalised. In doing so, he adopted what historian Jon Agar terms a 'comprehensive mechanical metaphor'[453] in describing government as a machine. Haldane's proposed reorganisation was based on the ideas of specialisation, informational control via statistics, and comprehensive financial bookkeeping. A similar formula to that of Herbert's Second Industrial Revolution. If these principles were applied to all levels of government, Haldane believed, the state could become a more efficient apparatus for administering to public need[454]. Of particular relevance was Haldane's work on behalf a subcommittee of the Reconstruction group, the Coal Conservation Committee[455], a body for ensuring the efficient use of all resources, especially for a 'wasting asset' as coal[456].

As noted earlier, state-funded research had become increasingly important in the interwar period. Government research organisations had become the centre of a British school of applied science. The Department of Scientific and Industrial Research (DSIR) was conceived of as a means of continuing the work of the War Cabinet's scientific advisory council on

[452] Agar, J. (2003) The Government Machine: A Revolutionary History of the Computer. Cambridge Massachusetts, p. 196.

[453] Agar, 2003, p. 67

[454] Agar, 2003, p. 69.

[455] Ministry of Reconstruction (1918) Report of the Machinery of Government Committee. London. HMSO. p. 30.

[456] Haldane, R. (1918) Great Britain. Ministry of Reconstruction. Coal Conservation Committee. London. HMSO.

industrial research[457]**.** It would carry out 'long-range' research into industrial problems that industries themselves would find uneconomical. Under this programme, the Greenwich-based Fuel Research Board (FRB), under the directorship of oil shale chemist George Beilby, would focus on improving fuel efficiency, developing new technologies, and carrying out surveys of the scale and chemical composition of Britain's coal[458]. The FRB's work was carried out at a six-acre site in Greenwich, with laboratories to study 'carbonisation, combustion, and gasification problems'[459]. Clearly, the measurement of combustive, thermodynamic processes had become a political concern, and a metrological project to be undertaken *by* government[460], rather than something documented by government as it had been during the Royal Commission of 1866 (Chapter 2).

Importantly, in discussing fuel efficiency between the wars, members of the FRB generally meant reductions in the fuel consumed in a given situation, such as the heating of a room, with the total potential heat that could be derived from a given amount of fuel in that room[461]. Put another way, the idea was to increase the value and potential that could be derived from fuel, rather than suggesting that fuel could be *conserved* from use via efficient consumption (as would later be the case). However, the notion of fuel *conservation* would soon enter British political thought.

[457] Cardwell, D. (1975) 'Science and World War I', Proceedings of the Royal Society of London, Series A. Mathematical and Physical Sciences, Vol. 342, No. 1631, pp. 447-456. Edgerton argues the Fuel Research Station emerged from NPL work, and focused on converting coal to oil. Edgerton, D. (1996) Science, Technology and the British Industrial 'Decline', 1870 to 1970. Cambridge University Press.

[458] Anon. (1927) 'Physical and Chemical Survey of the National Coal Resources', Journal of the Royal Society of Arts, Vol. 75. No. 38979, pp. 456-457.

[459] DSIR (1960) Fuel Research 1917-1958. A Review of the Work of the Fuel Research Organisation. HMSO.

[460] Barry, 2015.

[461] Anon. (1925) 'The Heating of Living-Rooms', The British Medical Journal, Vol. 2, No. 3366, pp. 27-28.



Figure 3.1 Site of the Fuel Research Board, Maze Hill Greenwich,
DSIR (1960) Research 1917-1958. A Review of the Work of the Fuel Research Organisation. HMSO

In 1918 a report by Haldane was published, titled *The Conservation of Coal*, reporting on the work of the Coal Conservation Committee, which had been formed in 1916 due to the shortages experienced during the war[462]. As noted, during wartime nationalisation the government had an unprecedented opportunity to assess the efficiency of the industry. But Haldane's report was also partly based on Herbert's work on coal's duration, which the report referred to as a 'remarkable book'[463]. On the basis of this evidence Haldane noted that current methods of coal extraction were remarkably wasteful. For example, in the Midlands, forty-per-cent of the 288 million tons of coal that had been surveyed was inaccessible with current technology. It was estimated that around half of this waste was the result of 'disorderly'

[462] Hall, J.G., Martin, D. (1996) Haldane: Statesman, Lawyer, Philosopher. Barry Rose Law Publishers. England, p. 345.

[463] Haldane, R. (1918), p. 10.

extraction, which meant acres of coal were left in place to form barriers 'to protect one colliery area from being inundated by water from another colliery'[464].

The Haldane report estimated that nearly four-thousand million tons of coal was at risk of being wasted as a result of such barriers, which were partly the result of coalfields split up into independent property holdings, rather than being centrally administered. The report suggested that if more power were granted to government, a number of steps could be taken, including nationalisation, to achieve the 'greatest possible economy in production and the most advantageous use of coal'. In fact, the report argued that the ministry of mines and minerals should have 'statutory power to take all necessary steps for the conservation of coal'[465]. In the event, rather than nationalisation, after the war the coal industry was handed back to private owners, which some suggest provoked a particularly large miners' strike in Yorkshire in 1919, which rapidly spread to other regions and industries[466]. But what explains the sudden use of the notion of 'conservation' which was absent from earlier discussions of Britain's coal? There was no mention of conservation in the Royal Commission report of 1866 for example[467].

It was apparent that in 1913 Haldane had travelled to Canada, where he had come to oversee a legal case regarding fisheries rights. Haldane had become somewhat of an expert on Canadian constitutional law having first attended cases there in the 1880s, and he had a significant role in shaping the Canadian Constitution[468]. The year of the fisheries case, the

[464] Brady, R. (1950) Crisis in Britain: Plans and Achievements of the Labour Government, University of California, Berkeley., p. 80-81.

[465] Ministry of Reconstruction: Coal Conservation Committee. (1918) Final Report, Presented to Parliament by Command of His Majesty. London. HMSO. p. 2; 63

[466] Hopkins, E. (2000) Industrialisation and Society: An Industrial History, 1830-1951. Routledge.

[467] Not forgetting that Herbert Jevons had used the term 'conservation of natural capital' in 1915.

[468] Hall, J., Douglas, M. (1996) Haldane: statesman, lawyer, philosopher. Barry Rose Law, Chichester. p.78.

Canadian mining engineer William Joseph Dick had published a survey of coal deposits and mining law titled *Conservation of Coal in Canada* on behalf of the Canadian Commission of Conservation, perhaps the earliest account of coal conservation[469]. The study was prompted by the Canadian *Conservation Act* of 1909, which following an invitation to a North American Conservation Conference that year, had been instated by the King in an attempt to emulate the 'conservationist' policies for the management of resources that were being implemented in America under President Roosevelt's Progressive government[470]. Whilst the American school of Conservationism will be discussed in Chapter 4, but for now, it appears that Haldane's experience of Canadian law may have been one means by which the idea entered the British political lexicon.

Haldane's main proposal in *The Conservation of Coal* had been that electrification could provide the primary means of conserving coal, by producing heat and power with greater efficiency than using coal at the point of use. Haldane was primarily a philosopher, his approach to electrification had largely been gleaned from the work of the British electrical engineer Charles Merz (1874-1940), who had attempted to reorganize London's electrical grid before the war[471]. Merz's advice would eventually result in the establishment of the Central Electricity Board in 1926, which connected private and municipal electricity generators to a four-thousand mile 'grid' for conveying current[472]. As Haldane's coal report had noted 'the question of the conservation of coal so far as it falls within the reference of that subcommittee is the question of economy in the use of coal through supplying electricity

[469] Dick, W.J. (1914) Conservation of Coal in Canada, with note on the principal coal mines. Commission of Conservation: Committee on Minerals.

[470] Colpitts, G. (2002) Game in the Garden: A human history of Wildlife in Western Canada to 1940. UBC Press.

[471] See Hughes Networks of Power, His nephew Graeme Haldane would create the first ground source heat pump. See Banks, D. (2015) 'Dr T.G.N. 'Graeme' Haldane – Scottish Heat Pump Pioneer', International Journal for the History of Engineering & Technology, Vol. 85, Iss. 2, pp. 250-259.

[472] Armytage, W. (1965) The Rise of the Technocrats: A Social History. Routledge., p. 267.

for power and other forms of energy'[473]. The development of a nationally owned grid, publicly-owned on the basis of the avoidance of duplicating infrastructure, would provoke its own controversy, with some Conservative Members of Parliament arguing that it marked a concession to socialism[474]. Irrespective of such criticisms, it was clear that Haldane, like Jevons, considered electrification as a means of conservation, understood as increasing the accumulation of national capital and using finite resources in a more reasoned way.

Haldane's approach to policy in general drew on German idealist philosophy. He believed in instituting a wider program of bureaucratic reform according to underlying principles of German idealism[475]. He had reputedly read Hegel's *The Phenomenology of the Mind* nineteen times, and he adopted Hegel's belief in the progress of human history, advancing not through material richness but mental acuity. The *Geist,* or reason, of societal development implied that rationalisation and control were instruments of freedom, making society less dependent upon the material and physical forces of nature[476]. This idealism was readily apparent in Haldane's approach to the government of coal, with its emphasis on the transcendent possibilities of efficiency, electrification, and centralised management. As one observer remarked, it was as if Haldane had invented the word efficiency, given the frequency with which he used the term[477]. However, his advocacy for Hegelian thought would become increasingly unpopular as opposition to German military mobilisation increased in the

[473] Ministry of Reconstruction: Coal Conservation Committee. (1918)

[474] Hannah, L. (1979) Electricity Before Nationalisation: A Study of the Development of the Electrical Supply Industry in Britain to 1948. London Macmillan., p. 330.

[475] Vincent, A. (2007) 'German Philosophy and British Public Policy: Ricard Burdon Haldane in Theory and Practice', Journal of the History of Ideas, Vol. 68, No. 1., pp. 157-179.

[476] Hall, J.G., Martin, D. (1996) Haldane: Statesman, Lawyer, Philosopher. Barry Rose Law Publishers. England, p. 39.

[477] Searle, R. (1971) 'The Quest for National Efficiency: A Study in British Politics and Political Thought, 1899-1914. University of California Press, Berkelely., p. 3.

interwar period[478]. However, whatever the long term significance of Haldane's idealist approach to policy, his work was of some significance to the subject of this thesis in so far as it helped enshrine the notion of coal conservation in British political thought[479].

FUEL DURING AND AFTER THE SECOND WORLD WAR

With the outbreak of a Second World War in 1939, effective fuel use would again become a military strategic problem. Control over the Ruhr coalfields had enabled Germany's re-armament, but the war was highly mobile, involving large numbers of ships, tanks, aeroplanes, and automobiles, all of which required liquid oil. Lacking domestic oil supplies, Germany was forced to convert coal into liquid fuel via the inefficient process of synthesis known as the 'Bergius Process'[480]. To supplement this meagre supply, Russia jad initially supplied Germany with oil from the Baku oilfields in Azerbaijan, but German attempts to reach the Caspian oil fields following the invasion of the Soviet Union in 1941 were unsuccessful. In contrast to this restricted energy flow, from 1941 onward the Allied forces would, in Winston Churchill's words 'float to victory on a sea of oil'[481]. Arriving mainly by convoy from the Caribbean or Middle East, Britain's oil tanker fleet was the world's largest.[482]. And almost at the outbreak of war, in September 1939, petroleum rationing, was swiftly introduced, but gas, coal, and electricity rationing were loosely enforced[483]. A 'black

[478] Searle, 1971, p. 103.

[479] Though not the notion of 'energy' conservation, which would not occur until around 150 years later. See Chapter 10.

[480] Stranges, A. (2001) 'Germany's Synthetic Fuel Industry, 1927-1945', Energia, Vol. 12, No. 5, pp. 2-6.

[481] Jensen, W. (1968) 'The importance of energy in the First and Second World Wars'. The Historical Journal, Vol. 11, Iss. 3, pp. 538-554. Though some credit Lord Curzon, head of the Admiralty with this memorable phrase, see for example, Yergin, D. (1991) The Prize: The Epic Quest for Oil, Money, and Power, Simon and Schuster., p. 166.

[482] Jensen (ibid).

[483] Hancock, W., Gowing, M. (1949) British War Economy. HMSO.

market' in petrol emerged in many places which the government sought to shame via publicity campaigns[484].

But Britain's coal supply was adversely affected by the war. Geological availability was not the problem so much as the supply of miners, who in the early years of the war were conscripted, many never returning[485]. Faced with shortages of labour, from 1943 onward, one-in-ten conscripts were sent to work in the mines[486]. Large stocks of coal meant rationing in the home was initially unnecessary, but by 1942, shortages became apparent. The productivity of mining fell markedly, as the percentage of miners working at the coal face had been reduced, and those left were older, and exhausted from working longer hours[487].

In 1942, a Ministry of Fuel and Power had been formed by the wartime government with the aim of increasing mining productivity, allocating fuel strategically, and exploring domestic fuel rationing[488]. Since 1941, domestic deliveries of coal had been restricted, to avoid excessive consumption. But by March 1942, the Mines Department began to discuss the possibility of rationing fuel[489].The Permanent Secretary of the Ministry of Food, William Beveridge, published a survey which indicated Britain could conserve 8 million tons of coal per year through various forms of rationing. Households were to be given a number of points, which could be exchanged for all types of fuel, depending on how many rooms their house

[484] Roodhouse, M. (2013) Black Market Britain: 1939-1955. Oxford University Press.

[485] Court notes a 9 percent decrease in colliers between 1939 and 1941, and a decrease in coal output of 12 per cent. See Court, W.H.B. (1951) History of the Second World War: Coal. HMSO Stationary Office.

[486] Edgerton, D. (2015) 'Controlling resources: coal, iron-ore and oil in the Second World War'. in M Geyer & A Tooze, eds., Cambridge History of World War II: Vol III, Total War: Economy, Society, Culture at War. vol. III, 4, Cambridge University Press, Cambridge, pp. 122-148

[487] Average weekly output fell by over 104,000 tons between November 1941 and March 1942. Hancock, W., Gowing, M. 1949, p. 470.

[488] The Ministry became permanent in 1945.

[489] Gowing & Hancock, 1949.

contained, where in Britain they lived, and the age of the occupants. However, the Conservative Party blocked the majority of Beveridge's plan, fearing it was a concession toward socialism and would be unpopular with their constituents. Instead, a range of voluntary fuel rationing measures were encouraged: baths were to be no deeper than five-inches deep*; The Times* began a column advising on home fuel efficiency, and Harrods department store in London opened an exhibition to encourage domestic fuel economy.[490] The only mandatory restriction remained that on deliveries of domestic coal, and nominal restrictions on gas and electricity purchases[491].

In place of strict regulation of individual economy, the government had pursued a programme of increased industrial productivity, placing mines under the control of the Ministry of Fuel and Power, mining was increasingly rationalised, and productivity increased[492]. In 1945, after peace had been called, the new Labour government sought to build on this effort, and to argue against the persistence of vested interests, monopolies, and a lack of investment in productivity improvements by private industry. Their manifesto had termed coal 'Britain's most precious national raw material'[493]. Mirroring Herbert Jevons' opinion, the Labour party argued that only full nationalisation of mines and mining industries would allow modernisation to continue and give an opportunity to transform a wasteful, dispute-ridden, and dangerous industry into an efficient, safe, and highly productive one[494].

[490] Calder, A. (1992) The People's War: Britain, 1939-1945. London. Pimlico.

[491] Hancock & Gowing, 1949, p. 472.

[492] Ibid.

[493] Chick, M. (1998) Industrial Policy in Britain, 1945-1951: economic planning, nationalisation, and the Labour governments. Cambridge University Press.; Edgerton, 2006, p. 95.

[494] Brady, R. (1950).

FUEL AND POSTWAR RECOVERY

Once peace was declared in 1945, the emergency Anglo-American administration almost immediately identified a European 'fuel gap' of three million tons of coal per month, which they believed threatened Europe's peaceful recovery. In response a 'European Coal Organisation' (ECO) was established, in cooperation with the United States, to oversee equitable allocation of fuel and return Europe's mines back to pre-war rates of productivity[495]. This agreement placed responsibility on national governments to increase the economy with which their economies used fuel. Given the scarcity, the intention was not to save fuel from use, but to ensure it was used productively. In order to do so, the ECO required that Fuel Advisory services should be established to give advice to industry, and 'thermal centres' established to demonstrate to industry how improvements in the efficiency of fuel use might be made[496].

The problem of scarce resources had become a global concern. In 1949 the United Nations (UN) would hold a large conference on the 'Conservation and Utilization of Resources', stemming from the traditions of the American conservation movement and pre- and post-war planning experience[497]. Faced with post-war dearth, seven-hundred attendees discussed how fuel, and other resources might be used with greater efficiency[498]. In doing so, the idea that finite resources could be scientifically managed found a new global audience, which then redoubled the message back to individual states. Harold Hartley was the British representative at the UN resource conservation meeting (as well as FRB Chairman at the

[495] Jensen, W. (1967) Energy in Europe, 1945-1980. Foulis, London.

[496] Anon. (1952) 'Europe's Coal Problems', The Engineer, Sept. 12, p.337.

[497] Goodrich, C. (1951) 'The United Nations Conference on Resources', International Organization, Vol. 5, No. 1, pp. 48-60.

[498] See Chapter 4. Anon. (1948) 'UN Conference on the Conservation and Utilization of Resources', Nature, Vol. 161, No. 4094, pp. 617-617.

time). On his return to Britain, he addressed the British Association for the Advancement of Science (BAAS), just as William Armstrong had done in 1863 (Chapter 2). Like Herbert's hope for productive gains through automation, Hartley told his audience that the latest chapter in man's use of energy' would involve the 'new science of auto-mechanisms', by which he meant the developments in 'control engineering', automated devices which replaced the 'drudgery of the human brain'. Such computers, he claimed, consumed negligible amounts of current, whilst saving 'man power' and adding 'greatly to the economy of production' and 'thus reducing the quantity of energy required'[499]. Like Armstrong, Hartley hoped energy might be saved from use by ever greater control in its use.

Britain's FRB had long provided advice on efficient fuel use, but in the context of post-war reconstruction, its efforts would intensify. New control mechanisms and computational devices would be used to improve the efficiency of appliances. The 'Egerton report', named after the chairman of the DSIR, Alfred Egerton, was titled *The Heating and Ventilation of Dwellings* (1945). The pamphlet came close to offering a clear definition of what was understood by fuel efficiency at this time: 'it is more important than ever to become efficient in the methods of heating our homes and factories, if the products of this country are to compete in world markets. Otherwise the cost becomes a perpetual drag, and the standard of living will drop. Energy used efficiently has been shown to be directly proportional to productivity'[500]. Just as in the nineteenth century, energy was considered to have been used

[499] Hartley, H. (1950) 'Man's Use of Energy', Bulletin of the Atomic Scientists, Vol. 6, Iss. 11, pp. 322-324. Hartley's enthusiasm for control engineering would persist, even after the FRB folded in 1947, he suggested the approach should be recognised as a 'primary technology', alongside other major forms of engineering. He called for a program of education in control engineering, and recommended that 'self-optimising systems' should be applied to fuel industries, such as oil refinement. Anon. (1958) 'Control Engineering, a New Technology', New Scientist, Vol. 4, Iss. 79, p. 11.

[500] Heating and Ventilation of Dwellings ('The Edgerton Report'), DSIR, Post-War Building Studies, No. 19. HMSO, 1945. See also Angus, T. (1956) 'Warming and Ventilation in British Living Rooms', Health Education Journal, Vol. 14, No. 3, pp. 134-138.

efficiently when it was consumed in an optimally productive way. In order to increase the productivity of fuel use, Egerton's conclusion was that homes should be heavily insulated, and minimum efficiency standards for heating technologies set by government. The Egerton study involved members of the FRB, and it marked the first attempt to address 'the economical use of the national fuel resources' via domestic appliances in an increasingly scientific way, which accounted for appliance performance, building design, and pollution[501].

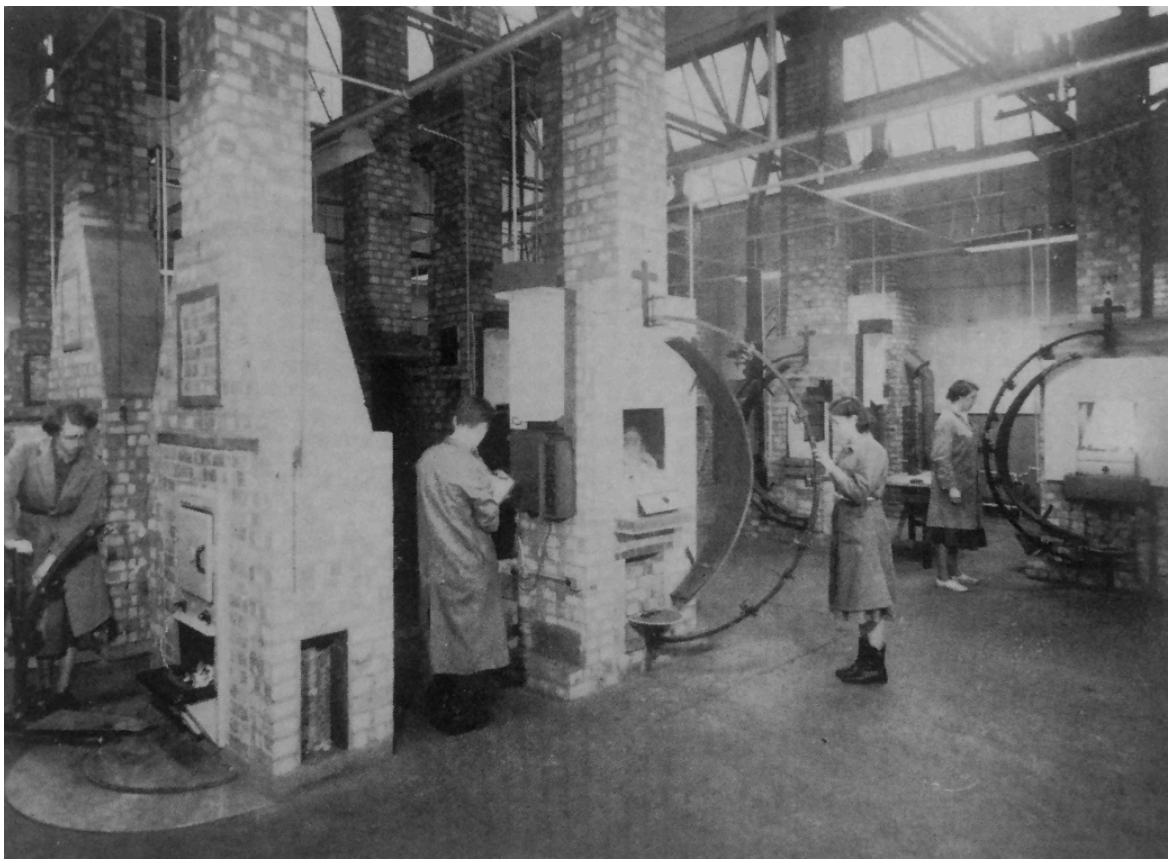

Figure 3.2. View of the Laboratory for Testing Domestic Heating Appliances
DSIR (1960) Research 1917-1958. A Review of the Work of the Fuel Research Organisation. HMSO.

[501] Monkhouse, A. (1948) 'Calorimeter building for domestic heating research at the Fuel Research Station, Greenwich', Nature, Vol. 162, Iss. 4108: 133. DSIR (1960) Research 1917-1958. A Review of the Work of the Fuel Research Organisation. HMSO.

The FRB's expertise would become highly significant during post-war reconstruction, as their advice on efficient appliances would be applied to large-scale reconstruction efforts. The government decided new houses erected after the war should have efficient grates and stoves, so the Ministry of Power sponsored the FRB to test appliances. In Greenwich a 'Calorimeter' building was built in 1946, which allowed chimney airflow and convection of heat onto surfaces to be measured, giving accurate information on the heat output to fuel consumption ratio of a range of appliances. The building was a vast four-story structure, covering 3000 square foot. In effect, a scaled-up version of the chemical laboratory calorimeter, with four room-sized cabinets in appliances could be tested.

As if realising Herbert's vision for precise control of industry in the national interest, and Hartley's hope for the role of automation in reducing energy use, by the end of the 1950s an analogue computer had been developed to automate some of the labour-intensive practices of heat radiation measurement over the six-hour testing period appliances were subject to[502]. Clearly a relation between measurement and evidence of fuel efficiency was central to the FRB's work, presaging the later claim of this thesis that ERC came to be considered as if it were a resource via metrological practices, which helped lend estimates of conserved energy a more ontologically present status.

THE RIDLEY COMMITTEE

The minimum efficiency standards proposed by the Egerton plan were never implemented, though government-built homes were fitted with efficient appliances, but the plan was notable for its almost total rejection of any kind of solution to the problem of inefficiency

[502] Penny, F., McHugo, J. (1959) 'An analogue computer for the solution of product integrals', Journal of Scientific Instrumentation, Vol. 36, Iss. 173.

based on market-mechanisms, instead, in line with nationalisation, the emphasis was on centralised government intervention and technological efficiency[503]. But the first blow to the Labour's newly nationalised coal industry came in the form of a three-week shortage of coal between the February and March 1947. As Britain froze in unusually incessant ice and snow, the recently formed National Union of Mineworkers (est. 1945) admitted they were unable to meet Britain's demand for coal. Shinwell was largely held responsible as he had continually taken the NUM's word that they would not let the government down. As a result, during this cold snap there was a deficit of eight million tons of coal. Shinwell was replaced by senior Labour politician Stafford Cripps[504], who was forced to impose cuts to industry's coal supplies, close factories, and limit household electricity use to five hours a day.[505]. This crisis led to two significant outcomes. First, the government committed to developing nuclear power[506]. Second, private industries that were able, increasingly turned to foreign oil supplies – particularly those in the Middle East - rather than coal as a more abundant and reliable fuel source. As we will see in Chapter 10, this move would prove a strategic vulnerability in the nineteen-seventies[507].

Another effect was that the crisis shook the confidence of advocates for public ownership. In response to the crisis, in 1951, the Minister of Fuel and Power, Philip Noel Baker established

[503] Price, E. 'Energy Economics 1940-1960', in Tempest, P., ed. (1983) Energy Economics in Britain. British Institute of Energy Economics. Graham & Trotman, ltd.

[504] Thomas, W. (2015) Rational Action: The Sciences of Policy in Britain and America, 1940-1960. MIT Press.

[505] Shinwell, E. (1955) Conflict Without Malice. London Oldhams Press.

[506] The AEA would be formed in 1954. As early as 1921 in his book The Reign of Relativity Haldane had promoted the idea of atomic energy. See Hall, J.G., Martin, D. (1996). American advocates of nuclear power, not least mathematician Jon von Neumann believed nuclear power would be 'too cheap to meter' and presumably therefore, too cheap to bother conserving! Von Neumann, J. (1955) 'Can We Survive Technology?', Fortune Magazine, republished in Development Review, Vol. 12, Iss. 1, pp. 117-126. See also Cohn, S. (1997) Too Cheap to Meter: An Economic and Philosophical Analysis of the Nuclear Dream. State University of New York Press, New York.

[507] Robertson, A. (1989) The Bleak Midwinter, 1947. Manchester University Press. See Chapter 10 for an account of the risks of oil dependency in Britain.

a Committee to develop a 'National Policy for the Use of Fuel and Power'[508]. As rationing came to an end in the early 1950s, policy makers had become increasingly concerned with the idea that the fuel industries could benefit from the reintroduction of aspects of competition in their administration whilst still remaining nationalised. The Ridley Committee, named after its Chair, Viscount Ridley, was established to address this question. Set up by Geoffrey Lloyd MP in 1951, at the request of Baker, the committee was set the following question: 'In view of the growing demands for all forms of fuel and power arising from full employment and the re-armament programmed, to consider whether any further steps can be taken to promote the best use of our fuel and power resources'[509].

This term, 'best use', invited debate, given the composition of the committee. Alongside a number of civil servants, the Ridley Committee contained disciplinary viewpoints as divergent as those of William Hawthorne (1913-2011), professor of thermodynamics from Cambridge and Professor Arthur Lewis (1915-1991), the Stanley Jevons Professor of Political Economy at Manchester University[510]. This mix of expertise was suited to the uncertainties of administering technologically complex and publicly owned utilities. As a result, before the war the economics of energy had largely centred on the 'energy coefficient', the quantitative relation between energy use and economic growth[511]. And after the war, attention had been focused upon the political feasibility of developing suitable technological infrastructure to meet the energy gap rather than on any economic principle. For most of the 1950s the cost of energy had increased alongside demand and income increases, which meant price rises had been alleviated by income increases. As a result, most

[508] Ibid.

[509] Price, 1983, p. 344.

[510] Chick, 1998, p. 119.

[511] Hartley, 1950. For more on the energy coefficient see Chapters 4 and 8.

studies argued price had little effect on fuel demand[512]. In economic language, fuel was considered price inelastic: demand did not respond to fluctuations in price. But post-war rationing meant there was no clear idea as to what the characteristics of a non-interventionist market for fuel would look like. As historian Martin Chick has suggested 'many of the early post-war discussion of average/marginal cost pricing look curiously academic in an economy in which the control of excess demand was the dominant problem'[513]. In a period of fuel scarcity, in which coal allocation was administered by the state, debates about marginal pricing could only exist in an academic sense.

Irrespective of the contemporary relevance of its deliberations, the Ridley Committee marked the first government attempt since the 1866 Royal Commission (Chapter 2) to identify the role the market could play in regulating the nation's demand for fuels. Within the Committee the main disagreement was between those grouped around Hawthorne who promoted 'average cost pricing', or 'cost-based pricing', they asserted ''Coal is so important to the economy that it should be sold at the lowest possible price which is consistent with the National Coal Board's covering its costs.'[514]; and those grouped around Lewis who supported 'marginal cost pricing', and did so largely along neoclassical Jevonian lines. "Marginalists" argued that 'the price of coal should correspond not to the average cost producing all the coal mined, but to the cost of producing additional supplies' and so 'the present price of coal in this country is in general *at least* fifteen shillings a ton too low'. Half of the committee

[512] A point discussed in Chapter 8, but for now, see Price, 1983, 343.

[513] Chick, M. (1991) 'Competition, Competitiveness, and Nationalisation, 1945-51', in Jones, G. ed. Competitiveness and the State: Government and Business in Twentieth Century. Manchester University Press.

[514] Ridley, V. (1952) Report for the Ridley Committee on National Policy for the Use of Fuel and Power Resources, London HMSO. p. 17

supported average cost pricing and half marginal. Ridley, the chair, decided the report should endorse average cost pricing[515].

In the course of decision-making, there was some debate as to whether average cost pricing or marginal pricing would be a greater spur to fuel efficiency. Average cost pricing, marginalists argued, encouraged profligate use of cheap coal, as it was below the rate a competitive market would impose. Marginally priced coal would be more expensive, and used with greater economy. But the opponents of marginalism believed higher priced fuel would discourage nationalised industries from investing in productivity increasing technologies, and would raise costs for other nationalised industries such as the railways: a position upheld by James Callaghan, the Secretary for the Ministry for Transport[516]. Whereas marginalists countered that in a state owned monopoly, the absence of competition would mean investment in productivity increases was unlikely to occur in any case. There was also a counter-argument to this position: high coal prices, owing to its ubiquity, would lead to inflation, meaning the overall economy would become less productive[517].

In a compromise the Ridley Committee proposed Parliament increase to the price of coal to £1 a ton. This price rise would help subsidise the deployment of efficient coal-burning appliances. The Committee also recognised the benefits of providing variable rates for electricity consumers which reflected periods in which industrial demand for electricity was low. All were measures believed to recognise 'The need for increased fuel efficiency and the duty of conserving our fuel resources'[518]. In total, the report presented forty

[515] Ibid, p. 15.

[516] Chick, M. (1998).

[517] Beacham, A. (1958) 'The Coal Industry', in Burn, D. ed. The Structure of British Industry: a symposium, Vol. 1. Cambridge University Press.

[518] Ridley, 1952, para. 293.

recommendations for increasing national fuel economy, ranging from minimum efficiency standards for solid fuel heating to improved methods for engine and furnace stoking[519]. Drawing on the work of the FRB, the Ridley report developed efficiency increasing interventions for myriad aspects of British fuel use, from the pithead, to railways, and homes. In doing so, it was estimated that 30 million tons of coal could be saved per year if more efficient plant were installed and boiler-men and traction engines were improved. Between 5 and 10 million tons of coal could be saved if more efficient space and water heating appliances were installed in homes[520]. What did it mean to estimate a total saving of around 45 million tons of coal in a system in which coal supply was nationalised and scarce? Labour considered coal Britain's most vital resource, and saving coal meant avoiding waste. This was not an act of ontologically constructing measurements of conserved energy as if they were a resource, so much as showing how extant living standards could be maintained or improved using less coal.

The Ridley Committee was notable for being the first serious attempt to consider the role of the price mechanism as a means of regulating the fuel industries. This argument would resurface in the nineteen-seventies. But for now, the Committee's work was somewhat forgotten. The 1947 crisis had prompted calls for a coordinated fuel policy and some members of the Committee had expressed that the best means of managing these industries would be to allow the free movement of prices to regulate supply and demand. Importantly, both sides agreed that price was an important means of avoiding waste in fuel use, as price rises saved fuel "by discouraging people from using coal for inferior purposes (e.g. as ballast in outgoing ships) and by stimulating users to burn coal more efficiently'[521]. As it was, the

[519] Ridley, V. (1952) 'National Policy for the use of Fuel and Power', The Engineer, September 12, p. 346-7.

[520] Anon. (1953) 'A fuel policy now', Spectator, 13 March, p. 8.

[521] Florence, P (1957) Industry and the State. Hutchinson, London.

Committee established an odd mix of intervention and liberalisation, as it concluded that 'the best pattern of fuel and power use will be promoted not by the direct intervention of the Government, but by the exercise of the consumer's free choice of his fuel and power services – provided that competition between the fuel industries is based on prices, tariffs, and terms of supply which closely correspond to the relevant costs of supply[522]'. As government was unwilling to upset the system of nationalised power provision, the pursuit of energy efficiency remained largely voluntary and encouraged by centralised advisory organisations like the FRB.

THE NATIONAL INDUSTRIAL FUEL EFFICIENCY SERVICE

One lasting contribution of the Ridley Committee was the establishment of a semi commercial fuel efficiency advisory service for industry. The National Industrial Fuel Efficiency Service (NIFES) was formed in 1953 with the aim of providing and promotion 'the provision of general advice to industry on efficiency and economy in the use of all forms of fuel, heat and power'[523]. Staffed by engineers from the Ministry of Fuel and Power, the organisation was an early example of a public-private enterprise, established because of ongoing coal shortages, and in the belief that industry only trusted advice it paid for[524]. The organisation captured the government's interstitial position in which the benefits of competition were well recognised, but the administration of competitive advantage was centralised[525]. Irrespective, as Britain's use of coal was increasingly supplemented by oil in the latter half of the 1950s, a national coal surplus became apparent, the organisation

[522] Ridley, 1952: para. 232.

[523] National Industrial Fuel Efficiency Service (1974) Fuel Economy Handbook. Graham Trotman Dudley Publishers.

[524] Ibid.

[525] Chick, M. (1998).

persisted in giving advice on economic grounds, as on their understanding 'Heat wasted is money wasted'[526].



Figure 3.3. £20 a Ton (1955) Stills
United Kingdom, 5 mins. Director: Lindsay Anderson.
Courtesy of the British Film Institute (BFI).

In the absence of scarcity, the idea of fuel efficiency as a means for economic advantage rather than as a means of conservation was readily apparent. In a film titled '£20 a ton' produced in 1955 on behalf of NIFES. Directed by Lindsay Anderson, to be viewed by for managers, the film depicts a business-owner handing over pound notes to his workers in recompense for the inefficiencies of his factory; which is using four or five times the amount of coal it should. Poorly lagged pipes, the failure to utilize waste heat or steam, and a lack of building insulation were presented all sources of financial waste and productive

[526] Anon. (1958) 'Guiding industry on fuel efficiency', New Scientist, Sept. 18, Vol. 4, Iss. 96., p. 841.

disadvantage. The implication was that some form of government intervention, even if only advisory, was necessary to overcome commercial inefficiency.

The same year as the NIFES film, Herbert, now in his late seventies, persistently attempted to persuade a number of engineering companies and the Fuel Research Board as to the potential efficiencies his self-designed space heater offered[527]. Herbert's device circulated the flue heat from a gas ring around his living room, via a looping pipe lagged with asbestos. The idea being that heat otherwise wasted up the chimney was propelled round the room, through the pipe, using the suction of a vacuum cleaner[528]. As he stated, the **'**purpose of the invention is to provide space heating with the lowest possible consumption of fuel, and thus at the lowest possible cost, by utilising the greatest possible amount of the heat generated by burning the fuel in a suitable stove'[529]. Over forty companies rejected the idea, which unfortunately produced a corrosive acid on the interior of the pipe[530], and the National Research Development Corporation, an organisation intended to commercialise war time research efforts, considered the idea technically unfeasible[531]. But the director of the Fuel Research Board invited Herbert to Maze Hill to see the work being done at the Fuel Research Station[532], and a patent was granted just before Herbert passed away in 1955[533].

[527] HSJ Archive, 'Space Heating', (undated).

[528] HSJ Archive, Letter to Madron Seligman, APV Company, 27th July 1953.

[529] HSJ Archive, Patent specification, Improvements in or relating to Space Heating, successfully completed, October 19th 1955, No, 738,584, application date July 2 1952

[530] HSJ Archive, HSJ to Bell's Abestos & Engineering Ltd, Slough, 21st March 1954

[531] HSJ Archive, National Research Development Corporation (Patent Office), 6 May 1953.

[532] HSJ Archive, Director of Fuel Research, 9 May 1954

[533] HSJ Archive, Patent specification, Improvements in or relating to Space Heating, successfully completed, October 19th 1955, No, 738,584, application date July 2 1952



Figure 3.4. 'Space Heating', Herbert Stanley Jevons' Efficient Heating Device
Space Heating', Patent specification, Improvements in or relating to Space Heating, successfully completed, October 19th 1955.
N.B portrait of William Stanley Jevons, on the right-hand side of the hearth.

Herbert's impractical invention is important for a number of reasons. First, it demonstrated the objectives of fuel efficiency in the post-war period: the aim was to derive the maximum utility from the minimal cost of fuel, in both pecuniary and material terms. Second, though home-spun, the device demonstrated how fuel efficiency was understood as a means of controlling conversions in state, heat, matter, synthesis, or even the flow of information, to increase the productivity of fuel expenditure. Third, it suggested that the pursuit of fuel efficiency was not something that conflicted with his father's argument about the paradoxical effect of efficiency increases. William's portrait can be seen in the top right of the photo, and as noted in Chapter 2, Jevons senior had not been opposed to efficiency, so much as the idea

that efficiency in some way perpetuated nature's provision of resources. A clear difference was that in the post-war period, coal was a nationalised resource. This raises the question as to what it meant to use fuel efficiently in a system where the rate of supply was largely determined by government? Coal was considered a form of national capital, and its' efficient use, was not only a good business proposition, but an obligation to the state.

CONCLUSION

The administration of fuel efficiency intensified by the mid-twentieth century, as temporary wartime nationalisation was followed by peacetime public ownership. Particularly following the 1954 *Ministry of Fuel and Power Act* which committed the British Government to 'promoting economy and efficiency in the supply, distribution, use and consumption of fuel and power, whether produced in Great Britain or not'[534]. With the growth of the Welfare state, this obligation marked a new role for British government, it was now tasked not only with regulating the power industries, but also promoting the economy and efficiency of fuel use within these industries, and within industrial and domestic settings more widely. The post-war period was marked by increasing attempts to persuade the fuel industries to provide heat, light, and force in a more efficient manner. The aim was economy rather than the conservation of fuel.

As the Ridley Committee had ordained, efficiency improvements should 'yield more than they cost' and should therefore appeal to the Chancellor of the Exchequer than the Minister of Fuel[535]. Conservation of fuel was not understood as the restriction of fuel use, nor the rationing of fuel. Instead, conservation was understood, as Haldane had stated, as actions

Chick, M. (1995) 'The political economy of nationalisation', in R. Millward and J. Singleton, eds., The Political Economy of Nationalisation in Britain, 1920-1950. Cambridge University Press, pp. 257-74.

[535] Chick, 1998: 124.

which achieved the 'greatest possible economy in production and the most advantageous use of coal'. This was conservation as the avoidance of waste, as it had been in the nineteenth century. To use energy efficiently meant the maximisation of the utility that could be derived from the combustion of fuel. This, as this thesis will go on to argue, was a distinct notion from the more contemporary, ontological, claims of ERC.

What did fuel efficiency mean in post-war Britain? Civil servant Eric Price, who would become head of economics and statistics at the Department of Energy (est. 1974)[536], later summarised the situation. As he succinctly put it, in the 1940s 'Coal was still allocated, the gas industry was still coal-based, and all oil was imported'[537], so management based on economic principles were rightly considered unsuitable. He noted the post-war years were marked by 'damaging fuel supply and capacity shortages. Particularly so for coal. In these conditions, the advice of industry and engineers were predominant, rather than those who proposed market solutions to the efficient use of fuel, who were 'beyond the pale – at least until the '50s'[538]. The Ridley Committee made some concessions to the allocative capacity of the market, but economists more generally did not play a dominant role in the civil service at this time[539]. Hence it was little surprise that fuel supply and demand was 'seen almost exclusively in physical terms; as the need to increase fuel supply to overcome scarcity, or to use fuel more productively.

[536] Est. in 1974, see Ch. 9.

[537] Price, E. 'Energy Economics 1940-1960', in Tempest, P., ed. (1983) Energy Economics in Britain. British Institute of Energy Economics. Graham & Trotman, ltd.

[538] Price, 1983, p. 340.

[539] Chick, 1998: 125-6. Chick writes that Keynes noted, within the Civil Service, 'Economics was not yet taken as a serious subject'.

There was no real market mechanism in the immediate post-war period, demand was regulated by increases in supply. For example, in response to the 1947 crisis, a 'crash programme' of electrical plant development meant electricity demand was dictated by the rate of new electricity connections and by power cuts, not by the level of market demand. Hence, in these years it was little surprise that economists proposing market based provision were, in Price's words, often 'laughed out of court by technical experts who *knew* their industry'[540]. In an era of industrial nationalisation, in which an engineer's rather than economists' notion of efficiency held sway, it was no surprise that interventionist fuel efficiency policies prospered. As it was, in post-war Britain, the idea that increased efficiency of fuel use *conserved* fuel from use was not a belief held by those implementing fuel efficiency policy. The aim of increased efficiency was increased productivity, lower cost, and survival in periods of scarcity, such as the 1947 crisis. Conservation, when discussed, was either meant in terms of conserving 'national capital', which could be seen as value maximisation for posterity. Or, in Haldane's work, the term conservation meant the avoidance of waste in production. It was this last definition that will be discussed in the next Chapter.

[540] Price, 1983, p. 340.

CHAPTER 4. THE ECONOMICS OF ENERGY RESOURCE CONSERVATION BEFORE THE CRISIS (PART ONE)

This chapter describes the emergence of petroleum conservation policy the United States. The prevention of waste in the production of oil and gas drew on the Progressive-era notion of the scientific management of resources for the benefit of future generations. In order conserve fuel both federal and state government developed interventionist policies in order to ensure waste was minimised during the extraction and production of petroleum (akin to Haldane's notion of coal conservation in the previous chapter). Interventionist conservation policies, as we shall see, found intellectual support from economists of the institutionalist school, who believed the mathematical abstractions of nineteenth century theory were increasingly unhelpful in managing the complex realities of twentieth century economies, particularly in light of crises of the 1930s. The principles of interventionist petroleum conservation are introduced via the work of institutionalist economist Erich Zimmermann. In doing so, outlines the idea that conservation was something best achieved by regulation. In contrast, a number of economists including Harold Hotelling, Siegfried Ciriacy-Wantrup, and most importantly, Tjalling Koopmans, came to argue that exhaustible resources could better be conserved by the free operation of market forces rather than political intervention. These economists argued that the terms 'conservation' and 'economy' meant the same thing. In doing so, this chapter outlines how an alternative concept of fuel conservation emerged which encouraged a return to economic liberalism. This short chapter is intended to preface Chapter 8, and they can be read in turn, though for reasons of chronology they are split.

THE CONSERVATION MOVEMENT AND ECONOMIC THOUGHT

At the turn of the twentieth century, during a reformist period in American politics referred to as the 'Progressive' era (1890-1920), the term conservation was adopted by federal administrators, such as chief forester Gifford Pinchot (1865-1946), to mean the 'wise use' of

natural resources. The idea was that resources should be scientifically managed on behalf of the nation. Led by Presidents Theodore Roosevelt (1901-1909), the conservation movement, in the words of its historian Samuel Hays, aimed 'to replace competition with economic planning' in order to 'create new heights of prosperity and material abundance'[541]. The term conservation drew from its use in federal irrigation programmes, where it was used to describe the use of reservoirs, built to conserve spring floodwaters for use in the summer months. But when it came to exhaustible resources, conservationist reasoning echoed the Ricardian idea that increased ingenuity in the avoidance of waste could preserve the life of mines. As Pinchot had noted in the case of coal: 'If it can be preserved, if the life of the mines can be extended, if by preventing waste there can be more coal left in this country after we of this generation have made every needed use of this source of power, then we shall have deserved well of our descendants.'[542]

Conservationism, meaning the efficient use of resources, was distinct from *preservationist* thought, as proposed by naturalist John Muir (1838-1914), which sought to restrict areas of America's wilderness being transformed into resources. Muir would form the preservationist *Sierra Club* in 1892, and they would emphasise the aesthetic and spiritual value of nature. Conservationists, represented by Pinchot, by contrast, proposed the scientific management of economic activity in order to maximise the efficiency of natural resource use, so the denudation of nature could occur only in circumstances which would afford the greatest benefit over time, as in Roosevelt's words 'for the perpetuity of civilisation'[543]. In 1909

[541] Hays, S. (1959) Conservation and the Gospel of Efficiency. The Progressive Conservation Movement, 1890-1920. Pittsburgh University Press; Stradling, D. (2004) Conservation in the Progressive Era. University of Washington Press; Tyrrell, I. (2015) Crisis of the Wasteful Nation: Empire and Conservation in Theodore Roosevelt's America. University of Chicago Press, inter alia.

[542] Pinchot, G. (1910) The Fight for Conservation, Doubleday, Page & Company. p. 76.

[543] Hays, 1959.

Roosevelt established a Conservation Commission, consisting of Congressmen, scientists, and federal administrators, who would investigate the 'more careful conservation of the foundations of our national prosperity'[544]. The Progressive-Era Conservation movement deserves more attention than can be given in this Chapter. Here the aim is simply to illustrate the impact this political movement had on contemporary economic theory, in order to begin to understand how the conservation of natural resources would go on to inform the principles of conserving energy.

Roosevelt's Presidential successor Howard Taft (1909-1913) was less enamoured by the idea of federally administered conservation, he famously remarked that 'the subject of Conservation is rather abstruse, but there are a great many people in favour of conservation no matter what it means'[545]. His point was that conservationism allowed unwarranted seizure of public land and government interference in commerce, yet at the same time, businesses could criticise regulation on the basis that it impeded conservation, the rhetoric of conservation could be mobilised for different strategic purposes[546]. Given his scepticism, Taft suggested conservation policy should be implemented at the state level rather than by federal government, and Pinchot was fired. However, true to his dictum, Congress voted for conservation policies, his presidency fulfilled them[547]. Despite a decrease in federal activism, during Taft's administration the notion of 'National Conservation' was only affirmed thanks to the earlier efforts of Roosevelt's Commission in gaining states' acceptance for conservation policy. The idea was that the nation belonged to the people, but government has

[544] Roosevelt, T. (1908) 'The National Conservation Commission', Science, Vol. 27, No. 704, pp. 994-996.

[545] Anon. (1910) 'National Conservation', Outlook, May 14m Vol. 95, Iss. 2, pp. 57-59.

[546] Hays, p. 148.

[547] Richardson, E. (1962) The Politics of Conservation: Crusades and Controversies, 1897–1913. Berkeley.

a right to intervene in order to ensure the benefits of ownership are shared and not monopolised by 'special interests'[548].

In Chapter 3 we saw how the concept of the conservation of natural capital influenced Herbert Jevons and Haldane's proposals for scientific management of Britain's coal, suggesting it was an international intellectual movement. Just as in Britain, there was a widely-held fear America was squandering its resources, but Taft cancelled a World Congress on Conservation Roosevelt had planned because he seemed to suggest there was insignificant interest. Though in fact it seems Taft did not want America to take a leading role in any global conservation initiative[549]. Whatever his intention, our concern here is on the different ways in which Roosevelt's heavily interventionism and Taft's more laissez-faire approach to resource conservation found themselves reflected in the work of the succeeding generation of economists.

Of course William Jevons predated the conservation movement, but he had also explicitly disagreed with the idea of resource conservation via increased efficiency[550]. Instead, the impact of conservationism on British economics can be traced back to Cambridge welfare economist Arthur Pigou (1877-1959), who noted 'there is wide agreement that the state should protect the interests of the future *in some degree* against the effects of our irrational discounting and of our preference for ourselves over our descendants', and that 'the whole movement for "Conservation" in the United States is based on this conviction'[551]. Pigou

[548] Hays, p. 65.

[549] Tyrrell. I. (2015) Crisis of the Wasteful Nation: Empire and Conservation in Theodore Roosevelt's America. Chicago.

[550] Alonzo-Smith, G. (1982) 'Natural Resource Economic Theory of the First Conservation Movement, 1895-1927', History of Political Economy, Vol. 14, Iss. 4, pp. 483-495.

[551] Pigou, A.C. (1920) The Economics of Welfare: Macmillan., p. 29-30

believed government should become 'the trustee for unborn generations as well as for its present citizens'[552]. In reference to discussions in America, Pigou argued the efficient use of exhaustible resources in the present could be used to create other forms of capital for preceding generations, which he saw as reflecting a longstanding tradition in neoclassical economics going back to Jevons' *Coal Question* (1865), which argued revenue from coal should be used to pay off the national debt or for public education. Herbert iterated a similar argument in relation to the conservation of natural capital (Chapter 3). As economic historian David Collard has proposed, this idea of intergenerational equity 'constituted an awkward thread of immanent criticism within neoclassical economics' as it implied the need for state intervention whilst simultaneously advocating market liberalisation if resources were to be used efficiently[553]. Already a conflict between divergent theories of conservation, one interventionist and one liberal, was apparent.

In American economic thought of the nineteen-twenties, conservationism influenced Wisconsin economist Richard Ely (1854-1943), whose *The Foundations of National Prosperity* (1918) advocated public ownership of exhaustible resources on the basis that private industry was wasteful. His pupil Lewis Cecil Gray (1881-1952) identified the central conflict of conservationism as 'between the interest of the present and the future'. In a move of lasting influence, he claimed interest rates were critical to determining the rate at which a resource was used. High interest rates encouraged rapid exploitation of resources, whilst low encouraged resource owners to leave them in the ground. Kansas economist John Ise (1885-1969) followed, and is remembered for a paper which, in applying utility theory of value to the question of exhaustible resources, noted the need to develop some kind of indication of

[552] Ibid.

[553] Collard, D. (1996) 'Pigou and future generations: A Cambridge tradition', Cambridge Journal of Economics, Vol. 20, Iss. 5, pp. 587-597.

future value. He believed a system of resource speculation should be encouraged by government, as 'it is only by speculation, in one form or another, that resources are conserved for the future'. Ise also believed 'the first essential' of a conservation policy 'will be a far higher level of prices', but also that competition was inherently wasteful as it led to low prices, and encouraged profligacy and a lack of foresight[554]. It was clear the first American conservation economists, though not offering a complete theory of resource conservation, had established the central factors of conservation economics: temporality, price, and the disputed role of government intervention[555].

Just as in Britain, in the nineteenth century coal had been America's primary fossil fuel, with steamships and coal-powered industry contributing the nation's emergence as a great power[556]. But by the turn of the century, oil was becoming increasingly predominant. As the industry's hagiography liked to suggest, in 1859 Colonel Edwin Drake (1819-1880) had dug America's first petroleum well in Titusville, Pennsylvania. Modifying a method normally used for extracting salt, the lowering of a pounding chisel into the earth, Drake's driver contained an extractive pipe which would become known as 'well-casing'. In doing so, he achieved an efficient means of extracting petroleum from beneath the Earth's surface[557]. Petroleum referred to both oil and the gases that sat on top of or formed a solution within the liquid. Developments in petroleum refinement allowed a variety of different fuels, lubricants, and plastics to be extracted from this raw material over the course of the long twentieth

[554] Ise, J. (1925) 'The Theory of Value as Applied to Natural Resources', American Economic Review, Vol. 15, Iss. 2, pp. 284-291. p., 286-7.

[555] Smith, G.A. (1982) 'Natural resource economic theory of the first conservation movement', *History of Political Economy*, Vol. 14, No. 4., p. 483-495.

[556] Shulman, P. (2015) Coal and Empire: The Birth of Energy Security in Industrial America. Johns Hopkins University Press.

[557] Giddens, P. (1959) 'When the Oil Industry was Born', Our Sun. Sun Oil Public Relations Department. Vol. 24, No. 3, pp. 4-8.

century[558]. Despite apparent abundance, given the economic significance of oil, and geologists' understanding of its limits, those concerned with America's prosperity grew increasingly concerned with the distant spectre of petroleum scarcity.

PETROLEUM CONSERVATION POLICY

It is ironic that petroleum conservation policy emerged due to its abundance. After World War One, which expanded and professionalised the petroleum industries, America experience an oversupply of oil for much of the 1920s and early 1930s. Crude prices fell from $3 a barrel to $1 and supply increased from 200 million barrels per year to 700 between 1920 and 1929. Vast oil fields were discovered in California and New Mexico, and the largest field yet in East Texas. Alongside discoveries, the invention of the internal combustion engine, and subsequent popularisation of the motorcar, became a powerful determinant of increased demand[559]. Crude discoveries readily met this new source of demand. Between 1899 and 1929 gasoline production increased from 7.4 million barrels to 445 million by 1929[560]. But with the stock market crash, demand dipped considerably, further lowering prices. By 1931, a barrel of Texan oil cost just 12 cents[561]. As prices bottomed out, the fear was that this irreplaceable resource was being squandered, as priced cheaply there was little incentive to avoid waste.

Oil had proven itself such an important strategic resource in war, and wartime federal management, as in Britain, had revealed numerous inefficiencies and means of increasing

[558] Johnson, B. (2014) Carbon Nation: Fossil Fuels in the Making of American Culture. University of Kansas Press.

[559] Huber, T. (2013) Lifeblood: Oil, Freedom, and the Forces of Capital. Minnesota Press.

[560] Zimmermann, E. (1957) Conservation in the Production of Petroleum. Yale University Press. p. 118.

[561] Yergin, D. (1991) The Prize: The Epic Quest for Oil, Money, and Power, Simon and Schuster., p. 250

productivity[562]. Most notably, in 1924 President Coolidge was encouraged to create the Federal Oil Conservation Board (FOCB) to assess levels of waste in the industry, following the demands made on oil during World War One[563]. Two years later, as an oil glut became apparent, the FOCB's aim became 'retarding [oil] development whenever economic demand does not warrant', marking the beginning of attempts to control rates of oil extraction to avoid wasteful oversupply[564]. Though not advocating fuel nationalisation as in Britain, the Board pushed for the regulation of petroleum output[565]. Whilst industry, in the form of trade association the American Petroleum Institute (API), pushed for deregulation of exploration licenses to further increase supply. Fearing regulatory constraint, at a Congressional hearing in 1926, the API attempted to define petroleum conservation as 'economical use' by industry rather than the conservation of resources via federal regulation of production[566]. Much debate followed, with some oil companies and lawyers linking the proposed bill to socialism[567]. As the depression lowered prices further, even the API accepted the need for Federal oversight. The result was that productivity regulations would be introduced at a State level, and federal control of production would only be reinstated in situations of national defence[568].

Oil producing states developed their own conservation laws, leading to a diverse set of heterogeneous, interrelated policies across the nation. Texan output, for example, as the largest oil producer had an effect on other states' production and regulation. Texas had been acting conservatively since 1899, as legislation required the protection of wells from water

[562] Vietor 21

[563] Nordhauser, N. (1973) 'Origins of Federal Oil Regulation', Business History Review, Vol. 47, Iss. 1, pp. 53-71.

[564] Vietor R. (1984) Energy Policy in America since 1945. Cambridge University Press.

[565] Ibid,

[566] Zimmermann, 1957, p, 127.

[567] Weaver, J. (1986) Unitization of Oil and Gas Fields in Texas: A Study of Legislative, Administrative, and Judicial Policies. Resources for the Future. Johns Hopkins.

[568] Zimmermann, p, 128.

seepage, plugging of abandoned wells, and the banning the flaring of gas outlets[569]. The crash of 1929 changed things considerably, and Texas introduced a state-wide prohibition on the industry producing more than fifty-thousand barrels of oil a day. Other states followed their lead, Kansas and Oklahoma instituted production rationing in 1930, with a licensing system granting extraction quotas on the basis of the size of the company applying and the specific properties of the oil and gas reserves. California, on the other hand, was left largely unregulated, aside for gas, owing to successful lobbying against oil conservation law[570]. A lack of co-ordination between states was overcome by President Franklin Roosevelt, who in line with New Deal's National Industrial Recovery Act of 1933, began federal oversight of production rationing ('pro-rationing') policies, managed by the API. Central government would carry out annual demand forecasts, in order allow states to orchestrate their rates of supply for the coming year, which was largely adhered to for fear of another price crash[571]. This mesh of state and federal controls would stay in place until 1972[572].

The FOCB, now working with the API, even came to the conclusion that licensing oil imports was a good method of conserving domestic reserves[573]. From 1938 to 1955 oil imports increased from 150,000 barrels a day to a million and a quarter barrels[574]. The establishment of federal oil import quotas, in the name of conservation, would have serious implications later in the century, but for now it proved a boon, providing low cost oil which had to be sold at the market rate, thereby appearing both profitable and conservative[575]. To

[569] Ibid, p. 144.

[570] Sabin, P. (2004) Crude Politics: The California Oil Market: 1900-1940. University of California Press

[571] Yergin, p. 257.

[572] Chapter 5. Vietor, 23.

[573] Zimmermann, 1957, p. 130.

[574] Ibid. p. 350.

[575] Clo, A. (2000) Oil Economics and Policy, Springer. p. 74.

the oil industry's critics, production restriction looked like a means of assuring high prices for the oil companies and import licenses seemed to offer the opportunity for huge profits[576]. But government argued the prevention of waste was a more important concern. Conservation had shifted from a progressive federal policy of market intervention to bureaucratic form of industrial oversight, which created a market for negotiating import and pro-rationing licenses and lobbying government for preferential status[577]. The policy soon took effect, and the price of oil rose to over a dollar a barrel, allowing industry to accept the regulation as profits returned[578]. As the economist Erich Zimmermann, who will be discussed in the next section, noted in 1933: 'The old school looked on conservation as a governmental function; the new school believes in entrusting it to the hands of business men and engineers'.[579]

INSTITUTIONALIST CONSERVATION

Though now forgotten, in his lifetime, German emigre Erich Zimmermann (1888-1961) advised the United States government and published widely on the issue of resources[580]. He was most well-known for *World Resources and Industries* (1933) a vast encyclopaedia describing the patterns of world resource use, in which he outlined his 'functional' theory of resources:

> *'resources are highly dynamic functional concepts; they are not, they become, they evolve out of the triune interaction of nature, man, and culture, in which nature sets outer limits, but man and culture are largely responsible for the portion of physical totality that is made available for human use.'*[581]

[576] Sampson, A. (1975) The Seven Sisters: The Great Oil Companies and the World They Made. Hodder & Stoughton.

[577] Nordhauser, N. (1979), The Quest for Stability: Domestic Oil Regulation, 1917-1935. New York, Garland.

[578] Fiege, M. (2012) The Republic of Nature: An Environmental History of the United States. University of Washington Press.

[579] Zimmermann, E. (1933) World Resources and Industries. Harper and Row.

[580] Bradley, R. (2008) Capitalism at Work: Business, Government, and Energy. M & M Scrivener Press.

[581] Zimmermann, E. (1945) 'Resources - An Evolving Concept', Proceedings and Transactions of the Texas Academy of Science, 1944., Iss. 28, pp. 157-165.

Zimmermann believed resources evolved, and that they were both physical and conceptual, in so far as they reflected the 'subjective appraisal' of the resource user(s). Hence, he proposed that resources were a 'concept which legitimately belongs the social scientist'[582]. His functional theory supported the idea that conservation could be achieved by government led intervention. The aim of conservation, as outlined by Zimmermann, was to limit total oil production to the rate of market demand, even if this was less than the maximum rate of extractive efficiency.

To understand why intervention was necessary, Zimmermann suggested 'one must have some knowledge of petroleum chemistry'[583]. The molecular composition of gas within the oil was critical for conserving the productive capacity of oil wells. Once struck, pressure was released, which acted as a propellant, forcing the oil and gas out of the well. The expulsion rate of this gaseous force as critical to the efficient extraction of petroleum, as improperly tapped, as much as fifty percent of the oil could be left in the well[584]. Once the 'gas drive' was expelled, petroleum could only be extracted using a pump, at considerable cost[585]. If misused, this 'natural unit of production' was forever wasted[586]. For Zimmermann, this implied the oil industry needed external management, particularly when different well owners extracted from a single reservoir. Because petroleum could, naturally or insidiously, escape its legal owner, or misuse of gas drives could waste petroleum, it was a 'fugacious'

[582] Ibid.

[583] Zimmermann, 1957, p. 58.

[584] Vietor, p. 22.

[585] Zimmermann, 1957, Water, in certain oil 'traps' could similarly provide expulsive pressure, as could undissolved gas. (.63-4). Oil wells were often compared to soda or beer bottles (.121).

[586] Zimmermann, 1957 p. 67.

resource[587], its value tended to dissipate, and efficient extraction could only occur if the number, location and proximity of wells was controlled.

As reservoirs often pooled under the wells of multiple prospectors, whenever oil was struck, prospectors would cluster around to capitalise on the find, as property rights were assigned to the extractor[588]. Writing in 1931, Columbia University economist Harold Hotelling (1895-1973) described how 'great forests of tall derricks rise overnight at a cost of $50,000 or more each'[589]. For economists, not only did such rushes indicate wasteful investment in infrastructure, forests of wells meant that the tapped reservoir would likely be wastefully extracted, but 'over pumping' meant as much as thirty to forty percent of a field's potential was left in the well. Like Zimmermann, Hotelling advocated that 'a much smaller number and a slower exploitation would be more economic'[590]. But he fundamentally disagreed with Zimmerman about this should be achieved. Clearly protecting the productive capacity of oil wells as central to the early twentieth century notion of fuel conservation, but there was a persistent debate about how this protection should be achieved.

Working under economist Clarence Ayres (1891-1972) at the University of Texas, Zimmermann's work reflected the earlier ideas of Thorstein Veblen (1857-1929) who stressed the determinant role of specific institutional arrangements in shaping economic activity[591]. Institutionalists believed the solution to recent economic problems lay in, what economic historian Philip Mirowski later termed, 'rigorous re-examination of the foundations

[587] Ibid.

[588] Hotelling, H. (1931) 'The Economics of Exhaustible Resources', The Journal of Political Economy, Vol. 39, Iss. 2., pp. 137-175.

[589] Hotelling, H., 1931.

[590] Zimmermann, 1957 p. 144.

[591] Phillips, R. (1995) Economic Mavericks: The Texas Institutionalists. Greenwich, JAI Press.

of the utility maximisation-based theory of demand'[592], the kind of abstract law-based theory Jevons proposed sixty-years earlier. During the New Deal era, when conventional economic theory and its attendant liberal policies appeared to have failed to predict or resolve the depression, alongside more conventional Keynesian economists, even after Veblen's death institutionalists increasingly had the ear of policymakers[593]. As it was, in Zimmermann's work it was the accidents of geography and geology which had variably distributed petroleum below the earth's crust, and the various legal, commercial, and technological institutions which dictated the economics, and thus conservation, of petroleum[594].

For Zimmermann, the oil industry's 'conflict with classical economic doctrine is most dramatic and most clearly evident'[595]. Petroleum's fugacity meant that the 'the conditions found in the petroleum industry do not let these market forces perform their functions properly'[596]. It could not be assumed that petroleum demand would dictate supply, or that supply and demand would mechanically respond to the price mechanism as they did in economist's models. But for Hotelling pro-rationing amounted to 'publicly ordained inefficiency', as only 'under free competition in the absence of complicating factors' was there the possibility of 'maximizing the "total utility" of petroleum[597]. But it was he who went against the grain of increasingly institutionalist orthodox economics in the nineteen-

[592] Mirowski, P., Wade Hands, D. (1998) 'A Paradox of Budgets: The Post-war Stabilisation of American Neoclassical Demand Theory', History of Political Economy, Vol. 20, Supplement., pp. 260-292.

[593] Tilman, R. (1988) 'Thorstein Veblen and the New Deal: A Reappraisal', The Historian, Vol. 50, Iss. 2, pp. 155-172.

[594] Klein, P. (1994) Beyond Dissent: Essays in Institutional Economics. Taylor & Francis.

[595] Zimmermann, 1957 p. 111.

[596] Ibid, p. 113

[597] Ibid, p. 137, p.143.

thirties[598]. For Zimmermann, market intervention conserved fuel, whereas for Hotelling, intervention was inherently wasteful.

Hotelling had studied topology at Princeton, with Veblen's nephew, Oswald Veblen, which had required rigorous numeracy. Throughout the 1930s he argued for the validity of mathematical neoclassical models despite their apparent failure[599]. Famously Hotelling wrote six economics papers, four of which made a major contribution to the discipline[600]. He pioneered mathematical economics in an age of descriptive institutionalism[601]. In an early paper on the economics of food he applied the concept of entropy to marginal utility, suggesting a homology in so far as both energy and utility depreciated over time. Like Ise and Grey in the Progressive era, he argued that the maximisation of utility from a scarce resource required some indication of the future rate of supply[602]. Extending his argument, in 1931 he gave a formal account of how the price of an exhaustible resource must be allowed to rise, firstly above the cost of its extraction, and secondly, at the same rate as the economy's rate of interest in the market more generally, as if interest rose, petroleum prices would rise, and it would become more economic to leave oil in the ground, gaining value, rather than spending money on its extraction; if petroleum became scarce its extraction would become uneconomic, hence it would be conserved. If petroleum was abundant, prices fell below the

[598] White, L. (2012) The Clash of Economic Ideas: The Great Policy Debates and Experiments of the Last Hundred Years. Cambridge University Press.

[599] Wade Hands, D., Mirowksi, P. (1998) 'Harold Hotelling and the Neoclassical Dream', in Backhouse, R., Hausman, D., Maki, U., Salanti, A., Eds. Economics and Methodology: Crossing Boundaries. St Martin's Press.

[600] Arrow, L., Lehmann, E. (2005) Harold Hotelling, 1895-1973. A Biographical Memoir. National Academies Press.

[601] Darnell A. (1980) 'The life and economic thought of Harold Hotelling', in The Collected Economics Articles of Harold Hotelling. Springer University Press.

[602] Hotelling, H. (1925) 'A general mathematical theory of depreciation', Journal of the American Statistical Assication, Vol. 20, No. 151, pp. 340-353.

economy's interest rate and its value would depreciate, making it a better idea to sell oil in the ground[603].

In effect, Hotelling argued maximum utility could only be derived from an exhaustible resource if the rate of its extraction was matched to the economy's interest rate, as this would create a self-regulating mechanism for extracting and conserving petroleum according to demand[604]. In a situation where all information was known about a resource, according to conventional price theory, it would always be sold at a price which reflected information about forthcoming scarcity[605]. If the resource was likely to become scarce in the foreseeable future the resource could be left in the ground, accruing value in expectation of future profit. An economist could use differential calculus to derive the optimal rate of extraction of a given resource over time, but a freely operating market could carry out the same calculation[606]. Hence, in Hotelling's work, conservation regulations which impeded the market were counterproductive as they led to either wasteful or uneconomic rates of extraction. Owing to its complex mathematics the paper was initially rejected for publication, but just as the article went to press, prospectors in East Texas found the largest oil field yet, the National Guard were sent to shut down wells to avoid a complete price crash; as a result Texas would introduced the nation's first pro-rationing system[607]. Hotelling's vision of a market mechanism for resource conservation, avant la lettre, was put on hold.

[603] Hotelling, H. (1931) 'The Economics of Exhaustible Resources', The Journal of Political Economy, Vol. 39, Iss, 2., pp. 137-175.

[604] Mitchell, T. (2011) Carbon Democracy: Political Power in the Age of Oil. Verso. New York and London., p. 195.

[605] Hotelling, 1931: 174.

[606] Bradley, R. (2007) 'Resourceship: An Austrian theory of mineral resources', Revue of Austrian Economics, Vol. 20, pp. 63-90.

[607] Mitchell, T, 2011 and Mitchell, T. (2010) 'The Resources of Economics', Journal of Cultural Economy, Vol. 3, Iss. 2. pp. 189-204.

OPTIMAL ALLOCATION

Under the New Deal conservation had become a business opportunity, as petroleum companies wilfully restricted their output to maintain profitability, the restriction of petroleum output was recast as a commodity. Intervention escalated during the Second World War, as petroleum production and rationing handed over to federal government under the Petroleum Administration for War (PAW) who attended to the vast logistical problem of ensuring the supply of oil to Allied forces across the world; the PAW introduced a conservation program in California to improve the efficiency of the state's unregulated production[608] . The Bartlesville Fuel Research Centre, akin to Britain's Fuel Research Board, sought to increase fuel efficiency across wartime industries[609]. Immediately after the war, America continued to ramp up oil production to supply Western Europe with oil under the 'Marshall Plan' which, in consolidating American control, was partly intended to convert the region to oil-use, in an attempt to undermine coalminers' unions and support for socialist movements: control over the rate of production and importation of petroleum provided means for geopolitical hegemony[610]. Under this peacekeeping system, the United Nations organised the first global conference on the 'Conservation and Utilization of Resources' in 1949, (discussed briefly in Chapter 3), hosting six-hundred signatories in New York, President Truman claimed 'conservation can become a major basis of peace'[611].

[608] Ickes, H. (1943) Fightin' Oil. Alfred A. Knopf. p. 131.

[609] Carlisle, R., Giebelhas, A. (1985) Bartlesville Energy Research Center: The Federal Government in Petroleum Research, 1918-1983. Department of Energy.

[610] Mitchell, T., 2011, p. 30.

[611] UNESCO (1949) 'The Scientific Conference on Resource Conservation and Utilization', Memorandum By the Department of Exact and Natural Sciences. November 10 1948. N8/UNR/1. Long predating the normal periodisation of 'global environmentalism' circa. 1972. Gibboney, C. (1949) 'The United Nations Scientific Conference for the Conservation of Resources', Science, Vol. 110., pp. 675-678. Mizuno, S. (2017) 'Global Governance of Natural Resources and the British Empire: A Study on the United Nations Scientific Conference on the Conservation and Utilisation of Resources, 1949', in Melo, C., Vaz, E., Costa Pinto, L. Eds. Environmental History in the Making. Volume II. Acting. Springer.

However, the Cold War briefly ignited during the Korean War. This led to an intensification of concern with regard to resource geopolitics. Truman setup a 'Materials Policy Commission' in 1951 to forecast the role resources would play in maintaining the 'free world' in coming decades. Added to which, a spate of popular 'neo-Malthusian' arguments had raised fears of a resource crisis, as the West became increasingly aware of the scale of population growth in the developing world[612]. The 'Paley' Commission reported that America's demand for resources would grow substantially and it could prove ruinous if they continued supporting European recovery, but without this support Europe risked entering a 'new dark age'. The Commissions aim was to establish if 'the United States and its allies have enough fuels and other forms of energy to support full economic mobilisation and maximum fighting strength' should conflict break out again[613]. Increased efficiency of fuel use was seen as one contribution, and the report commended the 'great advances' made in the efficient use of oil through the 'State regulation of production'[614]. But in coming years, the ongoing conflict between communism and capitalism would create an intellectual climate that would radically alter the notion of conservation.

Dutch-American economist Tjalling Koopmans (1910-1985) would reinvigorate Hotelling's vision of the market as a resource conservative device[615]. In 1948 Koopmans had become director of the Cowles Commission, an economic research organisation founded in 1932, specialising in 'econometrics', defined by the Econometric Society (est. 1930) as 'theoretical-

[612] Ward Shepard's (1945) *Food or Famine: The Challenge of Erosion*; William Vogt's (1948) *Road to Survival*, and Fairfield Osborn's (1948) *Our Plundered Planet*. In part, this owed to an 'explosion' in population. The Western World's population grew from 1,618 million in 1930 to 2,396 million in 1959. Robertson, T. (2012) The Malthusian Moment: Population Growth and the Birth of Modern Environmentalism. Rutgers University Press.

[613] United States President's Materials Policy Commission (1952) Resoruces for Freedom: A Report to the President. USGPO: Vol. 3, p. 1.

[614] United States President's Materials Policy Commission, 1952, Vol. 3. p.2

[615] As we will see in Chapter 8, Koopmans would acknowledge his work's similarity to Hotelling's in 1973.

quantitative and the empirical-quantitative approach to economic problems'[616]. He had also just won a research contract with the RAND Corporation, a research organisation that developed from an Air Force initiative during the war. RAND would become known as the archetypal Cold War 'think tank' (Chapter 6). The contract was to develop an econometric 'Theory of Resource Allocation' for allocating military resources[617]. A year before Paley's report Koopmans published a paper outlining an econometric approach to the 'efficient allocation of resources', which he positioned as a contribution to ongoing 'debate on the merits of private or corporate enterprise versus a centrally directed economy'[618]. Koopmans was not just referring to Cold War ideologies but also a long-running economic debate as to whether a socialist or capitalist economy used resources more efficiently. The 'socialist calculation debate' had persisted for decades[619], but Koopmans believed he had reached a solution which could effectively end the ideological impasse.

Koopmans outlined an econometric method called 'activity analysis', later 'linear programming'[620]. The idea was that for a given industrial process, an *optimal* output could be demonstrated given limited commodities, and the constrained ratios with which they could be combined. Commodities were represented numerically, which could be combined in various productive 'activities', represented by coefficients of commodity values, from which variations in 'output' could be calculated. By calculating the output values of all possible ratios of inputs and activities involved at each stage of production, the optimal allocation of

[616] Louça, F. (2007) The Years of High Econometrics: A Short History of the Generation that Reinvented Economics. Routledge. p. 29.

[617] Düppe, T., Weintraub, R. (2014) Finding Equilibrium: Arrow, Debreu, McKenzie and the Problem of Scientific Credit. Princeton University Press.

[618] Koopmans, T. (1951) 'Efficient Allocation of Resources', Econometrica, Vol. 19. No. 4, pp. 455-465.

[619] Davies, W. (2015) 'The return of social government: from socialist calculation to social analytics', European Journal of Social Theory, Vol. 18, Iss. 4.

[620] Each stage of production was a linear sum of the others. Dorfman, R., Samuelson, P., Solow, R. (1958) Linear Programming and Economic Analysis. The RAND Series. McGraw and Company.

resources could be identified. In so far as there was one ratio of commodities and productive activities, which according to the criteria of the analyst, could either maximise a desired output or minimise an input[621]. This last possibility would prove critical to the later science of ERC, as it seemed to suggest fuel inputs could be reduced whilst economic output was maintained, simply by altering the ratios of other inputs into various activities. We will turn to this idea in Chapters 6 and 8.

Given the ongoing 'red scare', Koopmans had made a bold claim, suggesting efficient allocation was not reliant on the market, as neo-classical economists had claimed (Chapter 2)[622]. Like institutionalists, he suggested optimal allocation could be achieved simply by rejigging 'institutional arrangements'. Key to this was the 'decentralization of decisions concerning activity levels'[623]. In effect, Koopmans had reversed the logic of institutional economics by suggesting that institutions should be reformed according to abstract econometric principles, rather than economics accounting for institutional peculiarities[624]. So, for wheat production, the ratio of labour to land could be optimised, and below that, the optimal ratio of fertiliser to soil; of nitrogen to phosphorus, and so on. If all managers at each level of significant activity 'choose only from those sets of activity levels that correspond to an efficient point' optimal allocation could occur without the need for competition[625].

[621] Koopmans, T. (1953) 'Activity Analysis and its Applications', The American Economic Review, Vol. 43, Iss. 2, pp. 406-414.

[622] Düppe, T. Weintraub, R. (2012) 'Siting the New Economic Science: The Cowles Commission's Activity Analysis Conference of June 1949', Science in Context, Vol. 27, Iss 3, pp 453-483.

[623] Koopmans, 1951, p. 463.

[624] Koopmans, T. (1977) 'Concepts of optimality and their uses', The American Economic Review, Vol. 67. No. 3., pp. 261-274.

[625] Koopmans, 1951, p. 464.

Essentially the Dutch American economist had argued that an algorithm could simulate a competitive market, hence markets need not be capitalist or communist, but 'optimal'[626]. The concept of optimality will be expanded upon in Chapter 6. But at this time, his work had the opposite effect, it emboldened economists' belief in competitive markets as it provided mathematical proof that competitive markets were the best means of allocating resources[627]. By analogy, the market could carry out linear programming calculations at a scale and level of granularity that even the best econometricians using the latest in post-war computing could not come close. Hence, despite comparative developments in the Soviet Union, linear programming would reinforce the epistemic authority of free-market capitalism[628].

Linear programming had direct implications for the sciences of conservation. In 1963, economists Harold Barnett and Chandler Morse, working for *Resources for the Future* (RFF), a think tank set up in 1952 at the behest of Paley, noted two notions of conservation had been unhelpfully conflated: the Progressive-era idea of scientific resource management, which had led to the interventions of the nineteen-thirties; and the later economists' idea of maximising the value of a scarce resource by allowing untrammelled consumer choice[629]. Worse still, given the recent red scare, Barnett and Morse clearly implied that interventionist conservation had been part of a wider revolution against the 'philosophy of the self-regulating market', and that ''Marxism was another European part of that revolution in ideas'[630].

[626] Koopmans, T. (1979) 'Economics Amongst the Sciences - an address to the American Economics Society', The American Economic Review, Vol. 69, Iss, 1, pp. 1-13.

[627] Koopmans, T. (1953) 'Activity Analysis and its Applications', The American Economic Review, Vol. 43, Iss. 2, pp. 406-414.

[628] Mirowski, P. (2002) Machine Dreams: Economics as a Cyborg Science. Cambridge University Press, Cambridge.

[629] Barnett, H., Morse, C. (1963) Scarcity and Growth: The Economics of Natural Resource Availability. Resources for the Future. Johns Hopkins University Press, p. 96.

[630] Barnett & Morse, 1963, p. 74.

But against these ideological tensions, what implications did optimal resource allocation hold for petroleum conservation? In 1957 Zimmermann had noted the "semantics" of conservation had changed. Previously defined as state-administered 'reduction in the rate of speed at which reservoirs are exploited', it now meant the 'distribution of use rates that maximises the present value of the flow of (expected) net revenues'[631]. This second, newer definition came from Siegfried Ciriacy-Wantrup (1906-1980), German-American agronomist, and amongst the first to realise the applicability of Koopmans' analytical economics to the question of resource conservation[632]. Writing from the Agricultural Experiment Station at Berkeley, Ciriacy-Wantrup wrote that the institutions which determined resource-use rates could be rearranged in such a way that the value derived from a given resource could be maximised. Future scarcities could be accounted for, as the calculation could be made dynamically to optimise use in a way which acknowledged declining revenues over time[633]. Ciriacy-Wantrup had essentially combined Hotelling's dynamic approach to resource pricing with the optimal allocation principles of Koopmans[634]

By 1961 Ciriacy-Wantrup was suggesting 'resource programming', the calculation of optimal rates of resource use over time, was replacing the idea of resource planning, associated with the interventionist policies of the 1930s. But calculations of the 'optimum state of conservation', he claimed, would require 'commensurate indicators of value attach to all physical inputs and outputs of resource use'[635]. Ciriacy-Wantrup's thinking was directed

[631] Zimmermann, 1957 p. 27.

[632] Vaughn, G. (1997) 'Siegfried von Ciriacy-Wantrup and His Safe Minimum Standard of Conversation', Choices, Fourth Quarter, pp. 30-33

[633] Ciriacy-Wantrup, S. (1952), Resource Conservation: Economics and Policies, Berkeley, University of California.

[634] Both used Lagrangian multipliers to solve a sequence of optimisation problems sequentially, representing change over time. See Ciriacy-Wantrup, S. (1961) 'Conservation and Resource Programming', Land Economics, Vol. 37, No. 2, pp. 105-111., ft. 4.

[635] Ciriacy-Wantrup, S. (1961) 'Conservation and Resource Programming', Land Economics, Vol. 37, No. 2, pp. 105-111.

toward agricultural problems, and resources in general[636]. But for petroleum, indicators of value were not possible in a market where prices were controlled by pro-rationing and import quotas. Irrespective, by the decade's end, a number of petroleum economists had begun to conflate conservation with the idea of economic efficiency, the optimal resource allocation over time[637]. Within economic thought, this semantic shift had planted the idea that conservation was something best achieved by a liberalised market, as only then would decision-making be fully decentralised, as Koopmans had advised, though this idea would not come to fruition until the nineteen-seventies, as we will see in Chapter 8.

CONCLUSION

Just as in geography, the use of econometrics transformed post-war ERC from an ideographic to a nomothetic science[638]. Questions of geology, law, and the physicality of petroleum, which had been characteristic of post-war conservation economics, and of policy, had gradually been eroded, to be replaced by an abstract economic theory of optimal resource allocation. A theory which, in an act of conceptual appropriation, had been reframed as means for resource conservation. The term conservation had shifted from its Progressive-Era meaning, as the scientific management of resources, to now mean policies to intervene in industry to avoid waste in the production of petroleum. But in a final turn, economic theory now implied that the best means of conserving petroleum, and other energy resources, was to allow the market to allocate them efficiently over time. The problem, as it stood, was that the fuel markets were still heavily regulated, and without considerable reform to the political

[636] Martin, W. (1990) 'Retrospective Review: Resource Conservation: Economics and Policies, By S.V. Ciriacy-Wantrup', American Journal of Agricultural Economics, Vol. 72, No. 2, pp. 502-504.

[637] Lovejoy, W., Homan, P. (1967) Economic Aspects of Oil Conservation Regulation. Resources for the Future. Johns Hopkins University Press.

[638] Barnes, T. (1996) Logics of Dislocation: Models, Metaphors, and Meanings of Economics Space: Models, Metaphors and Meanings of Economic Space. Guilford Press.

economy of energy, such conservative measures would be impossible. In Chapter 8 we will see how the econometric case for ERC via liberalisation came to have greater credibility in policymaking, as a result of multiple crises in energy supply.

As we will see in the next Chapter, 5, manifold energy crises would lend credibility to Koopman's proposed decentralisation of decision-making regarding energy use. Under the New Deal era system of production regulation, the onus to conserve fuel had been on the producer, soon the responsibility would shift to the consumer. But in this period, as Zimmermann remarked, to suggest consumers should use less energy would interfere with the sovereignty of the American consumer, and with it, the 'American Dream'. But presciently, Zimmermann noted that 'sometime in the not too distant future the touchy problem of inter-fuel relations and the still tougher problem of end uses will have to be thrashed out thoroughly, with a view for finding the most effective over-all energy policy for the nation'[639]. It was the crises of the nineteen-seventies which would bring this task to the fore, and econometrics which would provide its underlying means of resolution.

[639] Zimmermann, 1957, p. 47, 388.

CHAPTER 5. APPLYING SCIENCE TO ENERGY CRISES

Around 1968 a shift occurred in how American science was funded which proved critical to the emergence of an increasingly scientific approach toward ERC. Since 1950, the United States' National Science Foundation (NSF) had been intended to act promote basic research, funding research without a direct application. In the late 1960s, basic science entered a state of crisis owing to federal budget cuts and a diverse opposition to the objectives of undirected research. As a result, in 1968 the NSF was partly recast as 'applied' science funding body for whom research should be task-led or problem oriented. The demonstrative reorientation of research objectives that took place in 1968 indicated a significant reconfiguration of the relation between science and the American state. A shift readily apparent in a new NSF programme, 'Research Applied to National Needs' (RANN). Begun in 1970, RANN was intended to support technological solutions to America's developmental problems. This call for applied science coincided with multiple energy crises, which predated the Middle Eastern oil embargo of 1973. As a result, RANN funding transformed disparate post-war approaches toward fuel conservation into, what I term, a *science of energy conservation*: a collection of practices, practitioners, conventions, and shared values that constituted a distinct research discipline, dedicated to elucidating the energy conservative capacity of society. It was at this time the term 'the conservation of energy', in a more all-encompassing sense, became unfettered from its distinct thermodynamic sense to describe a wide range of technologies and policies designed to save energy resources. The science of energy resource conservation (ERC) was necessarily interdisciplinary, and was proposed as a means of attending to a complex of problems caused by the growing demand for energy. These problems would encourage a new generation of researchers to develop a means for reducing energy use at no cost to economic growth, via individual acts of efficiency at the point of energy use. The

onus to conserve shifted from fuel producer to consumer, a move which emphasised an applied, utilitarian, and market led approach to reducing demand.

A NEW NOTION OF CONSERVATION

In 1956 historian of science Thomas Kuhn (1922-1996) published his landmark paper on the 'simultaneous discovery' of energy conservation in nineteenth-century Europe. The paper's title was admittedly disingenuous, as rather than being simultaneous discovered, he theorised that scientists had become aware of 'the rapid and disorderly emergence of the experimental and conceptual elements from which that theory was shortly to be compounded'[640]. In this and the following chapters, I outline how a science of ERC, though not strictly thermodynamic was, with similar disorder, "simultaneously" discovered in the 1970s. As the growing demand for energy became increasingly problematic, the idea that society could act collectively to conserve energy through myriad acts of individual efficient energy use developed: the antithesis of Jevons' paradox. But my title is similarly disingenuous, as I will argue that this idea was not so-much 'discovered', as a result of shifting prerogatives of federally funded science: a shift in scientific order indicated a more comprehensive reconfiguration of social order. This re-organisation occurred alongside manifold crises in the supply of various fuels that became characterised as a singular 'energy crisis'[641]. It was the co-occurrence of crisis and a drive for applied science that created the impression of simultaneity.

[640] Kuhn, T. (1977) 'Energy Conservation as an Example of Simultaneous Discovery', Essential Tension. Chicago University Press

[641] Mitchell, T. (2011) Carbon Democracy: Political Power in the Age of Oil. Verso. New York and London., .; Lifset, R (2014) 'A New Understanding of the American Energy Crisis of the 1970s', Historical Social Research, Vol. 39, No. 4, pp. 22-42.

In the 1970s a number of America's leading universities, national laboratories, and non- and for-profit research organisations began to develop centres, departments, student courses, text-books, computer software, publications, and advisory bodies in an attempt to develop and formalise a science of ERC. For those working in this field, it was apparent that their work constituted a significant transformation to the notion of conservation, of the kind outlined in the previous three chapters. For example, by 1974, the German émigré economist Hans Landsberg (1913-2001) and other researchers at the Washington based resource policy institute Resources for the Future (RFF)[642], in a publication outlining the role of the social sciences in helping America to conserve energy, remarked that:

> '*Until very recently it was taken for granted that the term 'conservation' when applied to energy referred to keeping primary sources in the ground or managing their extraction in ways to maximise their flow over time. Now a new usage has developed. It denotes efficiency in utilization, avoidance of waste in application. One conserves energy when using a 40-watt bulb in place of a 75-watt bulb; when buying a compact car or pedalling a bicycle; when insulating the attic or pushing the thermostat up a little in summer and down a little in the winter.*'[643]

Over the decade, RFF would be one of a number of organisations involved in redefining the notion of energy conservation. This new approach to ERC contrasted readily with the extant notions of fuel conservation discussed in Chapter 3 and 4. In post-war Britain, fuel efficiency had been pursued as a state science, in order to minimise wasteful business practices and to extract maximum value from the nation's scarce coal. In America, conservation of fuel, building on the Progressive era theories of the scientific management of resources, had become manifest in an interventionist and regulatory policy intended to restrict the wasteful excesses of resource capitalism. Conservation of fuel, in both countries implied the efficient management of the productive capacity of petroleum wells and coal mines. The newer notion

[642] Chapter 4.

[643] Landsberg, H., Schanz, J., Schurr, S., Thompson, G. (1974: 140) 'Conservation in Energy Use', in Energy and the social sciences: an examination of the research needs. Resources for the Future, Inc. Washington. Funded by the National Science Foundation.

of conservation that would emerge in the nineteen-seventies, as Landsberg noted, proposed that the increased efficiency of energy use at the point of use offered a new way to conserve energy resources. In the following three chapters, the scientific basis upon which this claim was made will be set out, though of course the relation between science and policy was not unidirectional. Importantly, as Landsberg quote makes clear, this new approach to ERC was largely *consumer-driven*, a move that came with clear political implications, which will be outlined in Chapters 9 and 10.

The objective of this Chapter is to demonstrate how disparate strands of research into the determinants of energy demand were united under a single funding program, and in the wake of the energy crisis coalesced into a cohesive body of federally funded ERC research. The three Chapters that follow this one outline the work of some of America's leading research organisations in developing this new science of ERC, including Oak Ridge National Laboratory (ORNL), California's Research and Development (RAND) Corporation, the Ford Foundation, and a number of universities. All these organisations received funding for their work on energy from the same source, the NSF's 'Research Applied to National Needs' (RANN) programme[644]. Accordingly, it is vital to understand the prerogatives of this applied research endeavour, in order to understand how ERC emerged from a shift in the American political economy of knowledge. Historians Esther Mirjam Sent and Philip Mirowski have characterised this as a move from a 'Cold War' regime of large-scale federal investment in basic research, to a 'Globalised Privatisation Regime' in which publicly funded science was increasingly privatised and treated as a political resource, to be applied to problems of

[644] The Ford Foundation's work was an exception in that it was not a recipient of RANN funding, but, following an agreement in 1972, it was treated as such by the NSF. See Chapter 8.

government, such as the maintenance of economic growth[645]. As we shall see, this characterisation, with qualification, seems applicable in the case of ERC.

I want to suggest that the reconceptualization of conservation occurred not so much as part of a 'paradigm shift', to use Kuhn's term for the emergence of a novel research tradition with its own models, theories, and research practices, so much as an outcome of the reorientation of the role of science in society[646]. Historian Paul Forman wrote that a culture of government-funded 'science' had been at the heart of the aspirations of modernity, and that the shift to sponsoring applied 'technological' science indicated a shift toward 'postmodernity', an era 'when science is subsumed by technology'[647]. Hence beyond the designations pure and applied, the technologizing of science was an indication of a new cultural epoch. In this chapter, these changing dynamics of scientific funding are outlined, in order that the science of ERC can be understood as a system of thought, which emerged from this new cultural understanding of the relation between science and the state, and from within which a new concept of what constituted a resource developed.

THE IDEOLOGY OF ENERGY RESOURCE CONSERVATION

Famously, as geographer David Harvey noted, in 1972 at the United Nation's Stockholm Conference on the Environment, the recent forecast of 'limits to growth' produced by the Club of Rome caused widespread concern about the material limits to societal expansion. But the Chinese delegation had asserted that 'there was no such thing as scarcity of resources and

[645] Mirowski, P., Sent, M. (2002) Science Bought and Sold: Essays in the Economics of Science. University of Chicago.

[646] Kuhn, T., 1977.

[647] Forman, P. (2007) 'The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology', History and Technology, Vol. 23, Iss. 1, pp. 1-152.

that it was meaningless to discuss environmental problems in such terms'[648]. More precisely, China's representative, Tang Ke, had argued limits were 'mainly the result of the development of capitalism into imperialism', and that his country were opposed to 'super powers subjecting other countries to their control and plunder on the pretext of improving the environment'[649]. Irrespective, Harvey used Communist China's opposition to the idea of resource limits to make the point that the notions of population, scarcity, and of resources were 'ideological', openly so in China, but not so in the West. By ideological he meant there was no politically neutral way of discussing these ideas. To claim otherwise, that subsistence could be subject to 'rational' analysis was itself ideological, in so far as assertions of neutrality could only come from outside of scientific decision-making, and in doing so this move would impose authority, which was itself a form of politics[650].

Harvey argued that Western 'Aristotelian' methods used to bring population, scarcity, resources into purview, were overly essentialist, presuming some kind of immutable essence to these categories. This resulted in overtly ideological conclusions. For example, considering resources as fixed quantities and population as something that should grow, as Thomas Malthus had in the eighteenth-century, cast scarcity as an inevitability rather than something which could be mitigated by political planning. In contrast, Harvey argued that population, resources, and scarcity were determined by social relations rather than environmentally determined. Resource limits, as China had shown, could be alleviated by approaching

[648] Harvey, 1974 originally published as a longer lecture delivered in 1973, the Norma Wilkinson Memorial Lecture at the University of Reading *'A Question of Method for a Matter of Survival',* see Paterson, J. (1984) David Harvey's Geography. Routledge.

[649] Sterling, C. (1972) 'Chinese Attack on US Endangers Declaration on Environment', The Washington Post, June 11.

[650] Harvey's lecture argued that the assertion that science was ideology free could not be made by science, but 'from a source external', and so would always be in the domain of politics. See Paterson, J. (1984) David Harvey's Geography. Routledge.

problems in a creative dialectical materialist way, in which the supposed 'essence' of population, resources and scarcity was instead considered a product of the structure of social relations. Of course Marx and Engels had made a similar argument in the nineteenth-century, suggesting that scarcity revealed the shortcomings of capitalism[651].

However, in making his argument, Harvey failed to identify the emergence of a similar ideological development with regard to resources in the West. In this chapter, and those that fellow, I will argue the emergence of a science of ERC marked a transformation in the notions of population, scarcity, and resources comparable to China's claim that there was no such thing as resource scarcity. Based on capitalist rather than communist reasoning, as we will see, the applied science of ERC would lead American scientists and politicians to develop their own theory of abundance, manifest in their claim that energy resources could be conserved by using fuel more efficiently. Like China, the American's claim would be based on the idea that the availability of resources was not something fixed by natural limits so much as the product of social relations. They came to argue that if the relations of societal energy-use could be re-structured then the limited availability of energy resources could be transcended. Like China, the idea that energy could be conserved at a societal level came with its own ideological implications, as the central idea was that the governance of energy should be decentralised, with authority ceded from government to the lowest possible level, the energy consumer.

BASIC AND APPLIED SCIENCE

The 'applied' science of ERC that developed in the nineteen-seventies contrasted with the idea of 'basic' science, which had been seen as central to the relation between science and the

[651] Perelman, M. (1993) 'Marx and Resource Scarcity', Capitalism, Nature, Socialism. Vol. 4, Iss. 2, p. 65-84.

state for most of the post-war period. Almost immediately after the cessation of World War Two the former head of America's wartime Office of Scientific Research and Development (OSRD), engineer Vannevar Bush (1890-1974) published *Science, The Endless Frontier,* a report for President Franklin Roosevelt [1933-1945] outlining how federal government could help to advance science in peacetime as it had in war. In wartime the OSRD had overseen an increasingly rationalised approach toward military logistics and initiated a program of largescale federal investment in scientific research, resulting in the atomic bomb, radar, and anti-biotics amongst other developments[652]. In peacetime Bush argued that military prerogatives should not direct research, but research should continue to be supported by large federal contracts. Instead of the OSRD, in which science had been 'on tap' to Generals, he suggested a tranche of federal funding for 'basic' science in universities and other research organisation should be made available. The government and industry's research organisations had grown in size and importance but their focus was on 'applied' research. Bush believed publicly funded basic research could provide a frontier or reservoir of disinterested knowledge which industry and government could draw upon.

After a period of Congressional disagreement, Bush's approach was broadly the model the NSF adopted when formally established in 1950. Though basic research would continue be sponsored by many other branches of government, such as the Department of Defence, the NSF were cast as the protector of basic research[653]. With establishment of the NSF, the pre-war *laissez-faire* approach to scientific funding, in which it was supported by industry,

[652] Wolfe, A. (2013) Competing with the Soviets: Science, Technology, and the State in Cold War America. Johns Hopkins University Press.

[653] Edgerton notes that even in the 1960s the NSF sponsored less than 10 per cent of all basic research. Edgerton, D. (2004) 'The linear model' did not exist: reflections on the history and historiography of science and research in industry in the twentieth century', in Grandin, K Wormbs, N. Eds. The Science Industry Nexus: History, Policy, Implications. New York Watson, 2004.

individuals, and, to a lesser extent, the state, was expanded by the addition of a system in which researchers, working within universities or national laboratories, the former development sites of the atomic bomb, could request considerable funds from government[654].

Despite the seemingly clear mandate, in practice the NSF's role was far from clear-cut[655]. In fact, in appealing for peacetime federal funding, Bush noted that basic research could lead to useful outcomes beyond the pursuit of knowledge for its own sake. He wrote that the advancement of science could lead to 'better health, to more jobs, to a higher standard of living, and to our cultural progress'[656]. At the same time, those on the political left, who hoped federal support for basic research might help shed military influence, soon found their hopes quashed by the exigencies of the Cold War[657]. In pursuit of funding, scientists began to stress the indirect military applications of basic research[658]. Similarly, the 'basic' moniker was occasionally adopted by scientists wanting to distance their work from its martial role[659]. From the outset it was clear the dichotomy between 'basic' and 'applied' science was imprecise, and often strategically so. As historian Jane Calvert has noted, drawing on the work of sociologist Thomas Gieryn, the terms 'basic' and 'applied' are best understood as acts of 'boundary work', terms used to designate legitimate and illegitimate practices within the research community[660].

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[654] Kelves, D. (1977) 'The National Science Foundation and the Debate over Postwar Research Policy, 1942-1945', Isis, Vol. 68, No. 1, pp. 4-26.

[655] Greenberg, D. (1999) The Politics of Pure Science. University of Chicago Press., p.145

[656] Krige, J. (2006: 11) American Hegemony and the Postwar Reconstruction of Science in Europe. MIT Press.

[657] Wolfe, A, (2013).

[658] Forman, cited in Wang, J. (1995) 'Liberals, the Progressive Left, and the Political Economy of Postwar American Science: The NSF Debate Revisited', Historical Studies in the Physical and Biological Sciences, Vol. 26, No. 1, pp. 139-166.

[659] Forman, P. (1987) 'Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940-1960', Historical Studies in the Physical and Biological Sciences, Vol. 18, No. 1, pp. 149-229.

[660] Gieryn, T. (1983) 'Boundary-work and the demarcation of science from non-science: strains and interests in professional ideologies if scientists', American Sociological Review, Vol. 48, No. 6, pp. 781-795.

The conflicting rhetorics of basic and applied research were further complicated by their entanglement with the notion of productivity. For most of the post-war period, the economy had grown steadily, and any decline in employment levels had been countered by increasing the money supply. Employment could be achieved at the expense of currency inflation. In 1970 inflation rose to 5.7 per cent and unemployment increased, in a phenomena economist Paul Samuelson later dubbed 'stagflation'. Businesses were forced to increase their prices, wages remained low, and the productivity of the economy as a whole faltered. Some hoped science might offer a means of reigniting the productive power of the economy[661]. This was an old idea. In 1970 Alvin Weinberg, head of ORNL, traced the idea back to seventeenth-century Britain, and philosopher Francis Bacon's (1561-1626) suggestion that the object of science should material productivity, 'to make two blades of grass grow where one grew before'. This, Weinberg noted, challenged another view of science; that the pursuit of knowledge should be done for its own sake[662]. Taking to the idea, Weinberg described applied research as 'research done to achieve a non-scientific end' versus basic research 'done to further science'. Clearly the 'non-scientific end' would be dictated by political considerations, the most pressing of which was the state of the American economy.

The assertion that science was 'basic' had also developed an ideological function during the Cold War years. In Communist doctrine, science was considered part of society's ideational superstructure, something determined by the material basis and means of production upon which society drew. In this epistemological scheme, scientific knowledge could be altered according to material requirements or the demands of the party. For example, in the 1930s the Soviet biologist Trofim Lysenko (1898-1976) had attacked the anti-cooperative concept of

[661] Olson, J. (1999) Historical Dictionary of the 1970s. Greenwood Press.

[662] Weinberg, A. (1970) 'The Axiology of Science', American Scientist, Vol. 58, No. 6, pp. 612-617.

natural selection in evolutionary theory. In response British chemist Michael Polanyi had founded the Society for Freedom in Science in 1940, to promote unplanned, positivist science. As a result, in earlier decades, the notion of applied science could not escape association to socialist centrally planned societal development. Equally, the assertion that research was 'basic', or unplanned, was taken as an instantiation of the superiority of liberal Western political organisation as compared to centralised Soviet countries[663].

In fact, the historian of science, Thomas Kuhn, introduced the notion of 'paradigms' in science as a means of describing a collective internal logic of scientific progress, without reference to an underlying economic base. Such an argument would lend credibility that science, applied or pure, was not significantly determined by social relations[664]. Harvey's argument in 1974 was that there was an ideological blind spot in the West's assertion that their science was objective, 'rational', and ideology free. This claim was itself ideological, he suggested, as it was a claim which conferred authority on Western science by denying its content was informed by political needs[665]. Though Harvey did not expand on this blind spot, the history of ERC helped demonstrate this propensity when it was claimed by both American policymakers and scientists that Western science could be directly 'applied' to societal needs.

Given the ideological as well as economic significance of the terms basic and applied, it is odd the federal government's shift toward 'applied' research in the late 1960s has not

[663] Roll-Hansen, N. (2008) 'Wishful science: the persistence of T.D. Lysenko's Agrobiology in the Politics of Science', Osiris, Vo. 23, pp. 166-188. And Mirowski, P. (2012) Best Served Cold

[664] Reisch, G. (2003) 'Anticommunism, the unity of science movement and Kuhn's *Structure'*, Social Epistemology, Vol. 17, No. 2, pp. 271-275.

[665] Harvey, 1974, on this point see Barry, A (2002) 'The Anti-political economy', Economy and Society, 31, 2, 268-84. On the politics of paradigm shifts see Fuller, S. (2000) Thomas Kuhn: A Philosophical History for Our Times. University of Chicago Press.

attracted more interest from historians of science. Perhaps part of the reason was that the move toward basic research was more demonstrative than transformative. In 1962, the NSF estimated 9.1 per cent of their research was 'basic', 22.6 'applied', and 68.3 'development', activities which could turn research outcomes into products and processes. Development could even be considered a type of applied research. However these figures were categorised, it was clear that a significant majority of NSF research could, in some sense, be classified as applied well before the stated shift in research prerogatives that occurred in 1970[666]. As historian of science David Edgerton points out, the bulk of post-war research was never 'basic', and he reminds us that Bush's *Endless Frontier* had only argued 'for a small space for fundamental research in a world of applied, directed, and controlled research', and that the majority of research has always been industrial ('non-research science) rather than 'academic'[667].

If the majority of federally funded science had always been in some sense applied, what was the significance of the NSF's asserted enthusiasm for applied science in 1970? Policy analyst Roger Pielke has recommended the term 'applied' can be read as a means by which science was 'marketed', promoted as if it were a product, both by scientists themselves and by those required to account for its cost[668]. In order to understand the science of ERC, it must be understood as an outcome of this marketing work.

[666] Godin, B. (2006) 'The Linear Model of Innovation: The Historical Construction of an Analytical Framework', Science, Technology and Human Values, Vol. 31, No. 6, pp. 639-667.

[667] Edgerton, D. (2004) 'The linear model' did not exist: reflections on the history and historiography of science and research in industry in the twentieth century', in Grandin, K., Worms, N. Eds. The Science Industry Nexus: History, Policy, Implications. New York Watson, 2004.

[668][668] Pielke, R. (2012) 'Basic Research as a Political Symbol', Minerva, Vol. 50. Iss. 3, pp. 339-361.

The definitions used for these categories of research support this idea of applied science as marketable science. Originally, these categories were formalised as accounting conventions, borrowed from the Organisation for Economic Cooperation and Development (OECD) after the War. The NSF adopted them in 1951, and by 1959 applied research was defined by the government as research that had 'specific commercial objectives with respect to either products or processes'[669]. In 1963, the OECD developed a new research accounting methodology called the 'Frascati Manual', a document which the NSF considerably influenced, enshrining the commercial orientation of applied research[670]. If during the 'high' Cold War generous federal funding had meant government and industry laboratories had been structured like universities, free to carry out exploratory research, in the latter quarter of the century, government and university laboratories would be reformed in the pragmatic mould of commercial industrial research[671]. In Britain, an analogous process was occurring, as during Edward Heath's rule [1970-1974] government funded science was increasingly provisioned according to a 'customer-contractor' principle in order to achieve more 'socio-economically relevant R&D'[672] (Chapter 10). This emphasis on marketing and the commercially-driven development of science and technology for public good, would prove central to the proposed solution to the problem of energy demand.

THE CRISIS IN SCIENCE

Federally funded science faced straightened circumstances in the late 1960s. The problem was primarily economic. As inflation slowly climbed from one to four percent in the second

[669] Godin, B. (2006) 'The Linear Model of Innovation: The Historical Construction of an Analytical Framework', Science, Technology, and Human Values, Vol. 31, Iss. 6, pp. 639-667.

[670] Godin, B. (2003) 'Measuring Science: is there "Basic Research" without statistics', Social Science Information, Vol. 42, Iss. 1, pp. 57-90.

[671] An extension of the argument made in Sent & MIrowski 2002.

[672] Williams, R. (1973) 'Some Political Aspects of the Rothschild Affiar', Science Studies, Vol. 3, No. 1, pp. 31-46.

half of the nineteen-sixties, the value of the dollar decreased, reducing the worth of government investment. The reasons for creeping inflation were manifold, but an important contributor was the end of the Bretton Woods agreement, a post-war United Nations compact that had attempted to stabilise world finance by fixing currency rates according to the value of gold. But in 1968 American financial institutions encouraged the end of the agreement, in part, to give nation states greater autonomy[673]. This led the value of the dollar to fall, which caused a rate of inflation at 5.5% according to the consumer price index. Despite a record-breaking NSF budget of $495 million in 1968, this fell to $400 million in 1969[674]. As a result of this combination of inflation and budget cuts, in real terms 1969 was the first year the NSF's budget fell since the organisation had been founded. After which the budget for federal science would remain stagnant until the mid-1970s[675].

In part, this budgetary freeze was politically driven. In August 1970, the newly elected President Richard Nixon signed in an 'Economic Stabilization Act' as an emergency power to control stagflation, the idea being that the government would be granted permission to control wages and prices. Though not imposed until August 1971, the legislation indicated the degree of crisis in the American economy. Nixon would try to control inflation by minimising government expenditure, including that of science[676]. This move was not solely dictated by macroeconomic considerations, it reflected a growing unease across the political spectrum, about continuing to increase the budget for federal science at a geometric rate. As

[673] Mitchell, 2011: 171, also argues that the end of Bretton Woods would encourage the end of oil import allowances in 1970, as America could attempt to control its own rate of inflation by printing currency with no reference to the value of gold.

[674] Abramson, R. (1971) 'Patron on the Potomac: The National Science Foundation', Change, Vol. 3, No. 3, pp. 38-43.

[675] Popp Berman, E. (2012) Creating the Market University: How Academic Science Became an Economic Engine. Princeton University Press, p. 37.

[676] Rockoff, H. (1984) Drastic Measures: A History of Wage and Price Controls in the United States. Cambridge University Press.

historian of physics Daniel Kevles has written, from its post-war high as a 'secular establishment' science would undergo a process of 'disestablishment' in the 1970s[677].

As science journalist Philip Boffey conjectured at the time, the public's 'nuclear and space-engendered excitement' was sated and the supposed achievements of science were increasingly provoking 'disenchantment'[678]. Policy makers were similarly experiencing buyer's remorse. In 1967, the Department of Defence (DOD) completed an eight-year analysis of the contribution of basic science to military objectives. As the costs of the Vietnam War escalated, and despite unprecedented levels of investment, *Project Hindsight* concluded that 'undirected' research had provided little of direct benefit to the military since the Second World War[679]. Two years later, in 1969, Senators Mike Mansfield and William Fulbright introduced an amendment which restricted the DOD from investing in research without an obvious military role[680]. Mansfield's amendment was not driven by anti-war sentiment so much as the idea that basic science, lacking obvious utility, was a dereliction of federal responsibility to the taxpayer[681]. This move was part of a wider review of the work of the 'mission oriented' agencies of government: Defence, the Atomic Energy Commission, the National Aeronautics and Space Administration (NASA), and the Departments of Agriculture and Health, amongst others. which dictated that they should only fund research directly relevant to their stated goal, 'mission-oriented basic research' was increasingly cancelled.

[677] Kevles, D. (1971 [1995) The Physicists: The History of a Scientific Community in Modern America. Harvard University Press. Cambridge Massachusetts.

[678] McElroy, W. (1971) 'Letter: McElroy defends NSF Budget', Physics Today, Vol. 24, Iss. 8, p. 9.

[679] Belanger, D. (1998) Enabling American Innovation: Engineering and the National Science Foundation. Purdue University, p. 81.

[680] Boffey, M. (1970) 'Mansfield Amendment not dead', Science, Vol. 170, Iss. 3958, pp. 613.

[681] Larsen

The review resulted in the termination of over four-hundred projects and a total budget cut of $10 million[682].

Owing to previously high levels of investment in scientific education, during federally funded science's 'boom years', an employment crisis loomed[683]. At the American Physical Society's (APS) annual meeting in 1968, a thousand applicants clambered for only two-hundred and fifty-three jobs. By 1970, nearly the same number competed for only sixty-three positions[684]. At the same time, younger scientists were becoming increasingly dissatisfied with the post-war relation between science and the state. Not only with the funding arrangements of scientific research, but also its direction. Both professional and campus-based radical science groups emerged in opposition to state-funded science, such as Scientists for Social and Political Action (SESPA), who collaborated with the Black Panther movement, feminist organisations, and Vietnamese researchers, in creating a heterogeneous oppositional approach to scientific work[685].

But even for establishment figures, given the straightened circumstances, basic research was increasingly tainted not only by its militarism but also its esotericism. As ORNL's Director Alvin Weinberg noted, there was a 'new cry of relevance within the universities' and a 'yearning for science that is relevant'[686]. The older forms of 'big science', most evidently particle physics, which required high levels of investment in technology and researchers in

[682] Nichols, R. (1971) 'Mission-Oriented R&D' Science, Vol, 172, No 3978, pp. 29-37.

[683] Kaiser, D. (2011) How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival: WW Norton.

[684] Kaiser, D. (2002) 'Cold War requisitions, scientific manpower, and the production of American Physicists after World War II', Historical Studies in the Physical and Biological Sciences, Vol. 33, Iss. 1, pp. 131-159.

[685] Moore, K. (2008) Disrupting Science: Social Movements, American Scientists, and the Politics of the Military, 1945-1975. Princeton University Press.

[686] Weinberg, A. (1970) 'The Axiology of Science: The urgent Question of Scientific Priorities has helped promote a growing concern with value in science', American Scientist, Vol. 58, No. 6., pp. 612-617.

order to unravel ever deeper knowledge about the constitution of the universe more were becoming increasingly unappealing to younger, more politically active scientists[687]. As we shall see, both here and in later Chapters, the energy crisis would provide this generation of researchers with a new sense of purpose.

INTERDISCIPLINARY RESEARCH

Given the ongoing sense of crisis in America science, in 1968 Congress passed an important amendment to the act upon which the NSF had been founded. This initiative was led by Connecticut Congressperson, Democrat lawyer Emilio Daddario, whose membership of the Committee on Science and Astronautics had led him to carry out a review of the NSF's work. By 1966, like others, Daddario was increasingly sceptical about ever-increasing federal investment in science, and an advocate of assessing the impact of new technologies before introducing them to the public. He reported that Congress should 'make the NSF more sensitive to the shifting winds of our national scientific climate and the government's role therein'. In 1968 his proposed amendments were voted in. 'Section 3.C' authorised the NSF to 'initiate and support scientific research, including applied research, at academic and other non-profit institutions'. As historian of post-war science Dian Belanger suggested 'with three small words […] the NSF took on a 'new character'[688]. Though a majority of the NSF research had always been of the applied kind, in legislative terms, the form and substance of the NSF had been altered in so far as an opportunity had opened for researchers to gain funding if they marketed their research as 'applied', and in so far as this they presented their work as economically productive[689].

[687] For more on this, see Chapter 7.

[688] Belanger, 1989, pp. 77-78.

[689] Smith, B. (1990) American Science Policy Since World War II. The Brookings Institution, Washington.

The first outcome of this re-orientation of scientific endeavour as a means of production was the establishment of an NSF sub-program, Interdisciplinary Research Relevant to the Problems of Society ('IRRPOS') in 1969, which as one journalist joked, was 'One of the least euphonious acronyms on the Washington Science scene'[690]. Accordingly IRRPOS was intended to promote 'the contribution of fundamental scientific research in resolving major national problems', a formulation which tactfully avoided a complete endorsement of applied research[691]. With a budget of $6 million in the first year, rising to $13 million in the second, the project's aim was to direct American science toward the resolution of major national problems, ranging from environmental pollution to regional development. IRRPOS was led by Joel Snow, a thirty-three-year-old theoretical physicist whose role was to steer pure research to applied ends with an 'interdisciplinary' approach. That is, an approach which transgressed the normal boundaries of established research disciplines in generative rather than imitative ways[692].

In outlining his agenda, Snow outlined how the Manhattan Project and the Apollo space program had demonstrated the scale of ambition that interdisciplinary projects could achieve. Research of this kind, he advised, required the analysis of a 'total system' rather than discrete elements[693]. 'Systems analysis' had been central to President Lyndon Johnson's administration [1963-1969], primarily as a means of systematically rendering the battlefields of Vietnam into an abstract set of options and interrelated variables that could be managed

[690] JBP (1970) 'IRRPOS looks for relevance to society's problems', *Physics Today*, Vol. 23, Iss. 11., pp. 61-2.

[691] Ibid.

[692] Barry. A., Born, G. (2013) Interdisciplinarity: Reconfigurations of the Social and Natural Sciences. and Frodeman et al 2010.; Frodeman, R. (2010) The Oxford Handbook of Interdisciplinarity. Oxford University Press.

[693] Schaffer notes the term interdisciplinary entered sociological discourse in interwar debates on education policy. 'Multidisciplinarity' appeared after the Second World War. Schaffer, S. (2013) 'How Disciplines Look', in Barry, A., Born, G. (2013).

from afar according to generalizable principles in order to achieve optimal outcomes[694]. In approaching problems systematically rather than according to a specific disciplinary perspective, systems analysis was at the forefront of interdisciplinarity. Vietnam was even described as an 'interdisciplinary war'[695]. Applying systems analysis to domestic problems marked a shift in policy-making akin to the development of civilian operations research (OR) immediately after the war, with the same principle being upheld: that policy-making could be increasingly rationalised via science[696].

Writing at the time, German philosopher Jürgen Habermas described such developments as part of an ongoing 'scientization of politics' in which the rationalisation of political decision-making was believed, wrongly in Habermas' view, to be a means of rendering ideological decision-making, based on political considerations rather than the principles of optimality, defunct[697]. It was this kind of assertion of ideology free science that Harvey also railed against, on the basis that all science had a social objective[698]. But it was from this increasingly technocratic belief in the ideological purity of systems analysis that the new science of ERC would emerge.

[694] Edwards. P. (1996) The Closed World: Computers and the Politics of Discourse in Cold War America. MIT Press.

[695] Amron Katz, RAND reconnaissance expert, cited in Light, J. (2003) From Warfare to Welfare: Defence Intellectuals and Urban Problems in Cold War America. Johns Hopkins University Press.

[696] See Chapter 3, and Hughes, T., Hughes, A. (2000) Systems, Experts, and Computers: the systems approach in managing and engineering, World War II and after. MIT Press.

[697] Habermas, J. (1971) 'The Scientization of Politics and Public Opinion' in Toward a Rational Society, Boston, MA: Beacon Press

[698] Harvey, 1974, p. 256. See also 'Mannheim's Paradox', an idea developed by Karl Mannheim which asserts that any attempt to identify ideological reasoning in others must come from one's own sense of reality, which was itself an ideological position. See Breiner, P. (2013) 'Karl Mannheim and Political Ideology', in Freeden, M., Stears, M. eds. The Oxford Handbook of Political Ideologies. Oxford University Press. Given that Mannheim's work was intended to defuse Marxism as just another ideology, it is unsurprising Harvey made no reference to his work.

This new systemic style of research was different to the statist sciences of policy that emerged in the wake of World War Two[699]. Rather than positioning the state as provider of a reservoir of knowledge, this new research agenda increasingly required that the state should act less state-like. For example, in a 1970 editorial in *Science*, Cornell University's Vice President for Research, the chemist Franklin Long proposed 'The environment' posed 'thorny problems' which 'more often than not demand the *simultaneous* and *interactive* efforts of a wide spectrum of talented professionals'. Long went on to suggest that post-war research organisations like California's RAND Corporation had long been engaged in systemic, interdisciplinary research, and that there had been a recent 'realization', no more so than the RANN programme, that such an approach should be applied to 'society's problems'[700].

As the next Chapter will suggest, RAND had been expanding its research expertise into public policy since 1964[701]. But a process of institutional isomorphism seemed to be occurring. Rather than simply contracting private organisations to carry out public policy research, Long argued publically funded research should assume the characteristics of private research organisations, in so far as they should be interdisciplinary, problem led, and applied. This sentiment was reiterated by Joel Snow, who claimed one of the main objective of IRRPOS was that universities should modify themselves to more closely resemble 'think-tanks' like RAND and the Hudson Institute, which he believed had taken a lead in interdisciplinary research[702]. At the time, think-tanks were becoming increasingly recognised

[699] Thomas, 2015.

[700] Long, F. (1971) 'Editorial: Interdisciplinary Problem-Oriented Research in the University', Science, Vol. 171, No. 3975, p. 961.

[701] Jardini, D. (2013) Thinking Through the Cold War: RAND, National Security, and Domestic Policy, *1945-1975*. Smash Books Publishing.

[702] JBP (1970) 'IRRPOS looks for relevance to society's problems', *Physics Today*, Vol. 23, Iss. 11., pp. 61-2.

for the perceived objectivity their position outside of government afforded, and for the operational efficiency their commercial status implied[703].

The management of demand for energy resources, at the intersection of nature and society, fitted into a wider concern with the 'environment'. Nature conservationists, notably the heir to the Progressive tradition, American Aldo Leopold (1887-1948), had long claimed the study of the environment was necessarily interdisciplinary, as the very term acknowledged the relation between society and nature. But with the rise of systems analysis, it was theorised that human society could be similarly examined in systemic ways[704]. Hence IRRPOS was intended to address 'total environmental systems' rather than discrete environmental problems[705]. Accordingly, one of the first major beneficiaries of IRRPOS was Oak Ridge National Laboratory, who received $1.5 million to carry out an interdisciplinary investigation into 'The Environment and Technology Assessment' which addressed the more obvious environmental impacts of energy demand, specifically the two-hundred million tonnes of surface 'strip-mined' coal that had been extracted in America for the generation of electricity since 1940[706].

As historian Julie Klein notes, at this time, interdisciplinary research was promoted by 'an odd combination of liberal intellectuals, conservative elites, and radicals' all of whom 'expressed an interest in breaking down disciplinary boundaries and pursuing more fully and

[703] Medvetz, T. (2012) Think Tanks in America. University of Chicago Press. Chicago. London.

[704] Baird Caldicott, J. (2010) The Oxford Handbook of Interdisciplinarity, and Kwa, C. (1993) 'Radiation Ecology, systems ecology and the management of the environment', in Shortland, M. ed. 'Science and Nature: essays in the history of the environmental sciences. BSHS, Alden Press, Oxford.

[705] McElroy, W. (1971) 'Views: The Role of Fundamental Research in an Advanced Society: The Public Attitude toward science has been changing. How should science and scientists respond?', American Scientist, Vol. 59 Iss. 3, pp. 294-297.

[706] Nephew, E. (1972) 'Healing Wounds', Environment: Science and Policy for Sustainable Development, Vol. 14, Iss. 1.

consciously the interdisciplinary idea'[707]. Calls for interdisciplinary research as also tinged with a range of somewhat anti-statist rationales. For liberals, interdisciplinarity promised more social accountability for government backed science, for conservatives, less government expenditure, and for radicals, a means of countering science in the service of empire. Environmentalism too, in an age when industry often received government backing, was often tied up with anti-establishment beliefs[708]. It was this unlikely alliance of viewpoints within which the science of ERC would be accommodated.

RESEARCH APPLIED TO NATIONAL NEEDS

In 1970 the NSF announced its plan to expand its program of interdisciplinary research. The new programme, titled 'Research Applied to National Needs', had been conceived – in part - as a means of stimulating the nation's faltering economy. The Office of Management and Budget had called on the NSF to increase its expenditures on applied research, while at the same time reducing funding for educational and research endeavours, with the hope that applied research, in developing commercial and marketable technologies, might drive economic growth[709]. RANN would receive $81 million dollars in its first year, a dramatic increase compared to the IRRPOS budget. But it was a relatively small part of the total $622 million NSF budget for 1971. It was assumed that a significant proportion of the money, $74

[707] Klein, J. (1990) Interdisciplinarity: History, Theory and Practice. Wayne State University Press. Also, as historian Simon Shaffer notes 'the virtues of interdisciplinary were urged both by defence administrators and student radicals', so much so that the term *interdisciplinarité* featured on the banners of Parisian student protestors in May 1968. See Schaffer in Barry, A., Born, G. (2013).

[708] A point made in relation to Germany by Weszkalnys and Barry, though applicable to the US. See Barry & Weszkalnys, in Barry, A., Born, G. (2013).

[709] USGPO (1986) A History of Science Policy in the United States, 1940-1985. Report for the Committee on Science and Technology.

million, would be spent on programs transferred from the recently denuded mission agencies, including the Department of Defence and the Atomic Energy Commission[710].

Given the stated financial constraints mentioned above, it was clear that RANN involved redistributing federal funding rather than increasing the budget for science. As historian Bruce Smith wrote 'The NSF, in effect, traded a budget increase for program redirection'[711]. As S*cience News* was quick to point out, the 'NSF [had] proposed a substantial increase in the support of applied research projects […] at the expense of direct student and postdoctoral support and institutional science programs'[712], a move which was unpopular with many scientists, who saw both basic science and science education as sacrosanct[713]. Another significant move was that, for the first time, under this new program the NSF began to sponsor social science, though predominantly economic research[714]. The pragmatic orientation of this new endeavour was captured by a pun on Vannevar Bush's famed 1945 text. The editors of *Science* joked that Bush's 'endless frontier' of scientific knowledge was 'fast becoming the meticulously planned and managed frontier'[715].

It was no surprise that a science journalist, Robert Bazell, described the applied science program as 'new and controversial. He noted, 'what makes RANN unique and controversial is not its support of applied work, but its orientation toward problems' versus the

[710] Baxter, S. (1978) Strategies for Applied Research Management, a Report, Research Applied to National Needs. p. 39.

[711] Smith, B. (1990), p. 79, ft. 16.

[712] Anon. (1971) 'NSF Budget: RANN gets rundown', Science News, Vol. 99, No. 20., p. 331.

[713] See Weinberg (1970), for example.

[714] Mata, T., Scheiding, T. (2012) 'National Science Foundation Patronage of Social Science, 1970s and 1980s: Congressional Scrutiny, Advocacy Network, and the Prestige of Economics', Minerva, Iss. 50, pp. 423-449.

[715] Larsen, O. (1992) Milestones and Millstones: Social Science at the National Science Foundation. Transaction Publishers. p. 95.

conventional 'quality and natural curiosity route' that scientists normally took[716]. As stated earlier, this dichotomy had never as fixed as scientists and policymakers occasionally asserted. In fact, those overseeing RANN exploited this ambiguity. Head of the NSF, the biologist William McElroy considered the word order "research applied" a stroke of genius because it would imply that either basic or applied research would be directed to the solution of identified problems', and the scientific establishment would not feel overly affronted[717]. It, McElroy stated, was less a program of applied research than a new administrative approach, in which research would be supported from 'the societal viewpoint rather than from the scientist's viewpoint'[718].

But what kind of management program was it? McElroy hoped RANN would allow NSF funded research to spread beyond universities to other kinds of research organisations, such as think tanks, and even private businesses[719]. Its newly appointed head, aeronautical engineer Alfred Eggers, noted the organisation was 'precisely in accord' with President Richard Nixon's State of the Union address in 1970, in which the new President had called for root and branch reforms to American government programs, a retraction in foreign intervention, and an emphasis on the quality of domestic government, particularly in protecting the environment, rather than its quantity[720]. Nixon had taken an anti-inflationary approach to the Federal budget for 1970, as he hoped a swathe of budget cuts would stabilise

[716] Bazell, R. (1971) 'NSF: Is Applied research at the take off point?', Science, Vol. 172, no. 3990., pp. 1315-1317.

[717] Belanger, 1989, p. 96, ft. 53.

[718] McElroy, W. (1971) 'Letter: McElroy defends NSF Budget', Physics Today, Vol. 24, Iss. 8, p. 9.

[719] Greenberg, D. (1970) 'Research Priorities: New Program at NSF Reflects Shift in Values', Science, Vol. 170. No. 3945, pp. 144.146

[720] Nixon, R. (1970) 'Annual Message to the Congress on the State of the Union' January 22. Available at: http://www.presidency.ucsb.edu/ws/?pid=2921

the dollar[721]. In short, Nixon's budget had called for a smaller government and reduced funding for large-scale research projects, a fiscal vision in which RANN fitted well.

As RANN developed, lawyer Frank Hersman, Director of the Office of Intergovernmental Science and Research Utilisation at the NSF, recommended that they should imitate the practices of 'American businessmen' specifically encouraging 'innovation', a new managerial term meaning the commercialisation of research[722]. Hersman went on to note that, given the number of problems assailing the United States, 'there simply are not enough resources in government to content ourselves with less than the best solutions'. This disparity, Hersman noted, would require government funded research to act in an entrepreneurial way. As he put it: 'it is the responsibility of the government to do sufficient marketing to determine that conditions are right for the introduction of an innovation'[723]. In its employment of managerial language and the notion of marketing, the program demonstrated a move toward market-driven or market-like approaches to the funding and application of scientific work, and a move away from government funded and centrally directed basic research.

Historian Elizabeth Popp Berman has stated that RANN was part of a new way in which policy maker's conceived of the economic role of science: it was no longer considered as a 'resource' or 'reservoir' to be exploited by industry, as Bush had proposed, but a productive 'engine' directly driving economic productivity, innovation, employment. This process, as Hersman had noted, would require researchers and universities to become more

[721] Boffey, P., Carter, L., Hamilton, A. "Nixon Budget: Science Funding Remains Tight', Science, Vol. 167. No. 3919, pp. 845-848.

[722] Chapter 5.

[723] McElroy, W. (1971).

entrepreneurial[724]. The next section will describe how the entrepreneurial spirit of applied research promoted by RANN coincided with a collection of problems that would be described singularly as an energy crisis, and, as the next three Chapters will demonstrate, this ethos distinctly informed the solutions that the nation's research community developed.

ENERGY CRISES

Contrary to popular accounts of the energy crisis, the embargo imposed by Middle Eastern oil producers in October 1973 was just one part of a far more complicated situation, in which oil was one of many sources of power facing constraint[725]. In 1970 coal provided over half the fuel for electricity generation, natural gas a quarter, oil ten percent, and water and nuclear sixteen and 1.4 percent respectively[726]. America's energy demand had increased by around fifty-percent, from 183 million British Thermal Units per person in 1929 to 293 million in 1968. Low cost oil and electrification had come to supplement already comparatively high levels of coal use[727]. This increase was partly due to population growth. In 1950 there were around 152 million Americans, and by 1970 there were 204 million. A post-war 'baby boom' meant the growth rate had been 3.78 per cent per in 1957, only dropping to 1.74 per cent in 1974[728]. This unprecedented growth provoked concern, no more so than in biologist Paul Ehrlich's *Population Bomb* (1968), an alarmist warning of mass starvation if nothing were

[724] Berman, E.P. (2012: 26) Creating the Market University. How Academic Science Became an Economic Engine. Princeton University Press.

[725] Lifset, R (2014) 'A New Understanding of the American Energy Crisis of the 1970s', Historical Social Research, Vol. 39, No. 4, pp. 22-42., Bosch, F., Graf R. (2014) 'Reacting to Anticipations: Energy Crises and Energy Policy in the 1970s', Mitchell, T. (2010). For a detailed account of the embargo see Venn, F. (2002) The Oil Crisis. Longman Books.

[726] Jacobs, 2008. p. 26.

[727] Nordhaus, W (1973) 'Allocation of Energy Resources', Brookings Papers on Economic Activity, No. 3, pp. 529-576.

[728] Bogue, D. (1985) The Population of the United States. New York, Free Press. p. 4., 260., and Sabin, P. (2013) The Bet: Paul Ehrlich, Julian Simon, and our Gamble over Earths Future. Yale University Press, p. 225.

done lower the growth rate[729]. For the majority of the post-war period, this population also grew richer. In 1947 gross national product had been $282.3 billion but by 1960 it was $439.9, almost doubling. Wages rose and inflation remained generally low, meaning per capita income had increased, on average, by a quarter between 1947 and 1960[730]. Affluence and energy consumption appeared intractably linked, but a complex of problems related to the interactions between fuel types was beginning to emerge.

By the late nineteen-sixties, oil, coal, and their secondary product, electricity would all face restrictions in supply. As early as 1956, but most comprehensively in 1962, the geologist Marion King Hubbert (1903-1989) had discovered that the discovery of domestic crude oil in the United States would peak around 1971, and oil companies increasingly concurred[731]. At the same time, the damage caused by coal mining, acid rain, and air pollution in power generation were becoming increasingly apparent and scientists and a concerned public increasingly called for restrictions on the types of coal that could be combusted: compliance with which raised costs and reduced the total quantity of fuel reserves[732]. Alongside which, gas, whose price was determined by the FPC since the 1960s, had become increasingly scarce, as cost-based pricing had encouraged demand and discouraged investment. Gas was often discovered as a corollary of oil excavation, hence as that slowed down, so too had discoveries of gas reserves[733]. But perhaps most significantly, the production of electricity

[729] Ibid.

[730] In constant 1954 dollars, Collins, R. (2000) More: The Politics of Economic Growth in Postwar America. Oxford University Press.

[731] Bowden, G. (1985) 'The social construction of validity in estimates of US crude oil reserves', Social Studies of Science, Vol. 15, pp. 207-40, Bridge, G. (2010) 'Geographies of Peak oil: the other carbon problem', Geoforum, Vol. 41, No. 4, pp. 523-530.

[732] Tugwell, F. (1988) The Energy Crisis and the American Political Economy: Politics and Markets in the Management of Natural Resources. Stanford University Press. And Lifset, R. (x) Energy Conservation in America: The Case of New York, in Rüdiger, M. The Culture of Energy.

[733] Lifset, 2014.

was becoming increasingly constrained. Since the 1920s, electricity had primarily been generated by burning coal to create jets of steam, which drove turbines connected to coils of wire within a magnetic field, their rotation generating electricity via electromagnetic induction[734]. By generating steam at ever-higher temperatures, akin to the principle of regenerator engines discussed in Chapter 2, the efficiency of electricity generation had increased geometrically and consistently lowered electricity's cost. But by the mid-1960s, the turbine blades used in electricity generation could withstand no further increase in temperature without the metal distorting or fracturing. Industrial engineers were increasingly aware that further economy in electricity production was becoming physically impossible. As a result, in the late 1960s the cost of producing electricity had flat-lined whilst demand continued to rise. Power generation, as historian Fred Hirsch termed it, had reached a point of 'technological stasis'[735].

National demand for electricity had grown at an unprecedented rate of seven percent annually since the late 1960s[736]. This was seen as an indicator of prosperity, similarly demonstrated by the quadrupling sales of electrical appliances since World War II[737]. As mention, this growth in electricity use was a result of population growth, and increased per capita energy use, but increased efficiency in electricity production, as Jevons predicted, had contributed to dramatic increases in electricity demand[738]. And, as electricity had become steadily cheaper, manufacturers had invested little effort in designing appliances that used less energy. The

[734] Hughes, T. (1983) Networks of Power: Electrification in Western Society, 1880 - 1930. Baltimore: Johns Hopkins Press.

[735] Hirsh, R. (2000) Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System. Cambridge MIT Press.

[736] Doctor, R. (1973) Energy Demand in the Future - Reducing the Growth rate, RAND Corporation, P-4992.

[737] Forman, 1987.

[738] Jevons argued 'every such improvement of the engine' even in the case of electricity generation 'does but accelerate anew the consumption of coal', Jevons, W. (1865) The Coal Question; An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines. Macmillan, p. 152-3.

designers of lighting, washing machines, and other household technologies had little incentive to lower the electrical cost of running their products. And as it was, any increases in efficiency went on building larger or more electricity using appliances.[739].

And as late as 1964 the Federal Power Commission (FPC), the industry's regulator, declared 'the challenge facing the electric power industry is to continue the long term trend of selling electricity to the consumer at steadily lower prices'[740]. The FPC had been founded in 1920, with the aim of overseeing federally funded hydropower projects, like the pro-rationing of petroleum that begun in 1930, the provision of electricity was increasingly seen as a Federal responsibility, as utility companies operated across state lines. During the New Deal era, Federal government took on the role of ensuring access to low cost electricity for citizens, in return for granting companies the monopoly rights to supply electricity to a given area. As it was, until 1977 the FPC would force utility companies to sell electricity at a pre-ordained rate, in return for being granted access to profit making[741].

By the nineteen-seventies, in order to continue to meet demand for low cost electricity, rather than pursuing efficient generation, utility companies would begin to develop additional or bigger power plants to increase supply. Given the situation, it was unsurprising the head of the FPC, John Nassikas, warned the press, at a conference in Washington's National Press Club of an imminent 'National energy crisis'. This was followed by the recommendation that

[739] Nye, D. (1992) Electrifying America: Social Meanings of a New Technology. MIT Press. See also Bijker, W. (1992) 'The Social Construction of Fluorescent lighting, Or How an artifact was invented in its diffusion stage', in Law, J. ed. Shaping Technology/Building Society: Studies in Sociotechnical Change. MIT Press: Massachusetts, which provides an account of how electrical utility companies resisted the deployment of energy efficient fluorescent lighting.

[740] USGPO (1965 National Power Survey, Federal Power Commission. USGPO. Fiscal Year 1964

[741] Cantelon, P. (2012) 'The Regulatory Dilemma of the Federal Power Commission, 1920-1977', Federal History, Iss. 4, p. 61.

their industry be deregulated, as 'free enterprise, he claimed, 'holds the best hope for resolving the crunch looming ahead between supply and demand'[742]. In particular, in the case of anti-trust law, which – originally intended to avoid monopolies – were now accused of blocking 'economies of large scale operation'[743]. With increased productivity constrained by metallurgical limits, increasing the scale and number of power plants seemed to be the industry's only hope: the late 1960s were marked by investment in larger plant, super tankers, long-range pipelines, and nuclear power, all of which invited scrutiny from an increasingly concerned public[744]. New and larger plants would require more land, a steady supply of water for coolant, and to be situated at a sufficient distance from communities to avoid pubic opposition.

This last criterion had become increasingly important. For example, in 1958, the utility Pacific Gas and Electric (PG&E) appealed to the FPC to build a nuclear plant in California's scenic Bodega Bay. Soon after, preservationist group the Sierra Club occupied the site in opposition to the development. The campaign marked a shift in environmental sensibilities, from an idea of conservation as the protection of natural resources, to 'environmentalism' as an assertion of desired aesthetic and cultural conditions[745]. This new environmentalism, in contrast to the conservationism of the Progressive era, questioned the ongoing justification for continued economic growth[746]. Marine biologist Rachel Carson (1907-1964) had raised public awareness of environmental damage with her popular book *Silent Spring* (1962) which

[742] Jacobs, M. (2016) Panic at the Pump: The Energy Crisis and the Transformation of America Politics in the 1970s. Hill & Wang, p. 26.

[743] Mitchell, 2011, p. 178.

[744] Vietor R (1987) Energy Poliy in America Since 1945. Cambridge University Press. p. 229.

[745] Hays, S. (1987) Beauty, Health, and Permanence: Environmental Politics in the United States, 1955 – 1985. Cambridge University Press.

[746] Lifset, R. (2014) 'Environmentalism and the Electrical Energy Crisis' Lifset, R. ed., American Energy Policy in the 1970s. University of Oklahoma.

described the effects of pesticide use on the physiology of wildlife, and was serialized in the *New Yorker*[747]. Some of the older generation of nature preservationists had considered nuclear power a 'wilderness saving alternative', compared to hydropower at least, which was often developed in places of natural beauty. Its risks were acceptable, as they would minimize damage to nature whilst allowing economic growth to continue. But a younger 'countercultural' generation disagreed, and considered nuclear power part of a wider system of technocratic, bellicose, and politically repressive policymaking, undergirded by untrammelled economic growth[748]. This newer view was represented by environmentalist and physicist John Holdren, who, from within the more radical ranks of the Sierra Club, re-appropriated the utility industry's term 'energy crisis' to describe the social and environmental implications of continual expansion in energy supply[749].

Environmentalists, in turn, described utility companies' threats of crisis a 'public relations' move, intended to achieve 'procedural convenience'[750]. These procedures had become markedly more stringent. In 1969 newly-elected President Nixon had exploited what he cynically termed the environmentalist 'fad' by signing in, and claiming responsibility for Democrat Senator Henry Jackson's initiative, the *National Environmental Policy Act* (NEPA), partly prompted by public outcry in response to a vast 'blowout' from an underwater oil well in Santa Barbara a year earlier, which, for the first time, committed government to protecting the environment. 'Section 102' instituted mandatory environmental

[747] In fact, Carson's book placed emphasis on pesticide's effect in inhibiting adenosine triphosphate (ATP) production in small mammals. She described ATP as the 'universal currency of energy', Carson, R. (1962) Silent Spring. Mariner Books.

[748] Wellock, T. (1992) 'The Battle for Bodega Bay: The Sierra Club and Nuclear Power, 1958-1964', California History, Vol. 71, No. 2, pp. 192-211.

[749] Holdren, J., Herrera, P. (1971) Energy: A Crisis in Power. San Francisco. Sierra Club Battle book.

[750] Zierold, J. (1984) 'Environmental Lobbyist in California's Capital, 1965-1984', Regional Oral History Office, University of California. Interview conducted by Ann Lage. National Endowment for the Humanitities and the Sierra Club.

impact statements for all areas of industry overseen by Government agencies, including energy utilities[751]. In signing in this legislation, Nixon hoped his demonstrative environmentalism would consolidate his slim electrical victory and distract attention from the Vietnam War. More grandiloquently he orated that 'the seventies will be known as the time when this country regained a productive harmony between man and nature'[752]. Section 102 would also restrict energy supplies, as it created a means for environmentalist opponents of utility company expansion to litigate against new developments, which led to increasingly drawn-out planning processes[753]. So the appeal of Nixon's cod-environmentalism was lost on utility companies, who considered NEPA a regulatory burden on their already troubled industry, leading them to reiterate their warning of a coming energy crisis, no more so than when NEPA's first notable policy, the Clean Air Act (1970), was introduced and limited the combustion of sulphurous types of coal on the grounds of health[754].

Limitations on coal use occurred just as the supply of foreign oil was called into question. Early in 1969 the American Bureau of Intelligence had raised concerns over the scale of the nation's dependence on foreign oil, which had quietly grown to provide a third of America's demand for oil. Aware of growing nationalism and political unrest in the Middle East, Nixon commissioned an urgent review of oil import allowances[755]. Not forgetting that the licencing of foreign oil imports had been encouraged from the 1940s onward as a means of conserving domestic petroleum (Chapter 3). For much of the post-war period, the government's policy

[751] Flippen, J. (2000) Nixon and The Environment. University of New Mexico Press; Vietor, 1987; Mitchell, 2011: 191.

[752] Jacobs, M. (2012) 'The Politics of Environmental Regulation: Business Government Relations in the 1970s and Beyond', in Phillips-Fein, K., Zelizer, J. (2012) What's Good for Business: Business and American Politics Since World War II. Oxford University Press; Flippen, 2000, p. 51.

[753] Vietor, 1987, p. 232.

[754] Mitchell, 2011.

[755] USGPO, Foreign Relations (FR), vol. xxxvi 1969-1976, Memorandum from Nixon to Shultz, March 25 1969: 1.

had been to maintain pro-rationing restrictions on domestic production (Chapter 4), whilst granting American oil companies tax exemptions in recompense. In effect this granted the government to impose a floor and ceiling to oil supply, effectively controlling its price[756]. Companies, in return, profited from generous import allowances that allowed them to sell a quota of lower cost, unrationed, Middle Eastern oil to American consumers at the same price as domestic oil[757]. As a result, costly investment in domestic oil surveying had shrunk, partly contributing to the peak in estimates of recoverable reserves around 1971[758].

Nevertheless, the arrangement had worked reasonably well for much of the post-war period. But in 1967 a six-day war broke out between Israel and neighbouring Arab states[759]. Israel quickly won, but their opponents agreed to impose an export embargo on foreign oil exports as a strategic means of demonstrating opposition to support, militarily or diplomatically, for their enemy. This first embargo failed to have a material effect, aside from damaging Arab oil revenue, as other producers met the shortfall. A year later, a more organised contingent of Arab members of OPEC formed ('OAPEC'), which attracted a greater number of more militant oil producing states like Saudi Arabia and Libya[760]. These states had gradually begun to negotiate better rates of pay for their oil from the Anglo-American oil companies that had long operated in these countries with relative impunity[761] With some irony, as early as 1969 the President of the Iranian National Oil Company, Riza Fal'ah, had described the imposition of higher prices as a 'conservation' policy, of the post-war pro-rationing kind, as leaving oil

[756] Lifset, 2014.

[757] Vietor p. 238, for the British experience of Energy Price Controls see Chapter 10.

[758] De Marchi, N. (1981) 'Energy Policy under Nixon: Mainly Putting Out Fires', in, Goodwin, C., Ed. (1981) Energy Policy in Perspective: today's problems, yesterday's solutions. The Brookings Institution, Washington DC.

[759] Egypt (UAR), Jordan, Syria, see Venn, 2002.

[760] Venn, 2002, p. 75.

[761] Madureira, N. (2014) 'Waiting for the Energy Crisis: Europe and United States on the Eve of the first Oil Shock', Historical Social Research, Vol. 39, Iss , 4., pp. 70-93.

in the ground not only caused its value to appreciate, it conserved this national asset, by not allowing oil to be wastefully sold at too low a rate[762].

As a result of these price rises, the price differential between domestic American oil and foreign began to fall, and the American government's control over oil prices faltered[763]. Nixon's government were aware that demand for fuel might soon become a pressing problem, and established a Department of National Resources in June 1971. This revealed a lack of expertise on energy in government, a suspicion of industry, and a lack of reliable information on fuel reserves[764]. So much so that in June 1971, Nixon imposed an oil price control, reducing its price below pro-rationed levels, in an attempt to control inflation. He warned the nation that "we cannot take our energy supply for granted any longer'[765]. Fearing further losses in profit the American Petroleum Institute spent $4 million on a public relations campaign to warn of an impending energy crunch if direct price controls were not loosened[766]. But Nixon resisted such calls, and introduced economy wide wage and price controls in August, expanding the interventionist powers of government far beyond those of the New Deal era in an attempt to control inflation, using the 'Economic Stabilization Act' that had been introduced on 1970 by a Democrat-ruled Congress. The policy was extremely popular, though Nixon and many of his government privately advocated markets liberalisation. Though the move eased inflation, in effect it meant the cost of oil was subsidised just as evidence of supply constraint became evident[767].

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[762] Ibid and Chalabi, F. (2010) Oil Policies, Oil Myths: Observations of an OPEC Insider,. IB Taurus and Co Ltd.

[763] Vietor, 1987, p. 239.

[764] Graf, R. (2014) 'Claiming Sovereignty in the Oil Crisis' and Vinsel (2012) 'The crusade for credible energy information and analysis in the United States, 1973-1983', History and Technology, Vol. 28, Iss. 2, pp. 149-176.

[765] Jacobs, 2016, p. 30.

[766] Jacobs, M. (2008*) 'The Conservative Struggle and the Energy Crisis.' In Rightward Bound: Making America Conservative in the 1970s, Schulman*, B., Zelizer, J. Eds. Harvard University Press.

[767] Jacobs, 2016, p. 30-6.

Despite America's growing vulnerability, as late as 1969 the Central Intelligence Agency (CIA) had been operating on the premise that 'it would probably be extremely difficult for any country or group of countries to make an embargo effective' due to the complex supply chains of international trade[768]. This complacency would be dramatically exposed in October 1973, when a second, more stringent embargo was imposed thanks, in part to OAPEC's bolstered confidence as a result of the concessions made by Anglo-American oil companies[769]. OAPEC members would cut supply by 5 million barrels a day, and subsequent production cuts of five percent per month would be implemented so long as the West continued to support Israel. Whether the embargo physically reduced the supply of oil is unclear, but it created panic in oil markets, and interfered with the industry's existing allocation methods, which – alongside the earlier negotiated price rises – resulted in an unprecedented four-fold increase in the price of oil[770].

Given the abundance of oil use across the American economy, the effect of these increases in the price of oil were dramatic; once the embargo was imposed $80 billion in oil revenue flowed to OPEC members at a rate of $115,000 per second for over a year[771]. For America, where imported low-cost oil was not only a strategic resource but a means to ensure low levels of inflation, the embargo had more widespread effects, as price rises contributed to a further increases in the rate of inflation, causing increased economic stagnation and decline in

[768] USGPO FR, v .36., Memorandum CIA, August 28, 1969, p. 27.

[769] Venn, 2002.

[770] Adelman, M. (1972) 'Is the Oil shortage real? Oil Companies as OPEC tax collectors', Foreign Policy, 9, Winter, 1972-3.

[771] Economist, 1974, cited in Caffentzis, G. (1992) Midnight Oil: Work, Energy, War, 1973–1992: Autonomedia, NY.

real wages[772]. Though the causes of inflation were multiple, particularly following the end of Bretton-Woods, an important mechanism by which inflation increased was financial rather than oil-based, as the sudden price rise cause credit between producer and consumer to go unpaid, meaning the 'balance of payments', the record of all foreign transactions which would be subtracted from the American dollars held for foreign exchange in the American Treasury, went down. Given the sudden increase in foreign demand for dollars, there was a crisis in the availability ('liquidity') of dollars, causing further inflation[773]. Adopting the parlance of utilities and environmentalists alike, this complex of problems became known, somewhat misleadingly, as the 'energy crisis'[774] owing to its apparent origin in the interrelated restriction of various fuels.

ENERGY DEMAND: A NEGLECTED AREA OF RESEARCH

In response to evidence of constrained supply, in 1972, a year before the OAPEC embargo, the Senate requested RANN spend nearly twice the amount on energy research it had in its first year, $25 million. The expectation was that this investment would lead to the discovery of new sources of power or allow existing fuels to be used more productively[775]. In 1973, the year of the oil embargo, energy research received record levels of federal funding[776]. The NSF received $768 million in total, of which $46 million was spent on RANN energy projects[777] across national laboratories, mission agencies, universities, public and private agencies, and industry organisations– a type of organisation that could now receive federal

[772] As discussed in Chapter 3., see also Prasad, M. (2006) The Politics of Free Markets: The Rise of Neoliberal Economic Policies, in Britain, France, Germany, & the United States. University of Chicago Press. Chicago, London. and Caffentzis (1992).

[773] Maddox, J. (1975) Beyond the Energy Crisis. Hutchinson of London. Mukherjee, S. Modern Economic Theory.

[774] Mitchell, 2010; 2011.

[775] Greenberg, D., Boffey, P. (1973) 'RANN program booming despite fund cut', Change, Vol. 5, No. 4, p. 54.

[776] Though in real terms, as stated, owing to inflation the total NSF budget remained stagnant.

[777] 'J.W.' (1974) 'NSF gets a record $768 million', Science, Vol. 185, No. 4156, p. 1030.

grants. Though the majority of funding was committed to investigating increasing energy supply, and identifying new energy sources, RANN allowed an additional area of expertise to develop: it funded work 'directed toward developing a detailed understanding of the way in which the country utilised energy'[778]. Before now, it had been in few actors' interests to carry out research in how people might use less rather than more energy, but RANN's novel suggestion, documented in subsequent chapters, would be that increased efficiency of energy use, at the point of use, could act to conserve energy, at no cost to economic growth.

In fact, one of the few organisations that encouraged reductions in energy use at this time was a New York utility company, Consolidated Edison. Unable to meet electricity demand in parts of the city during the winter of 1970, 'Con-Ed' had called an end to all promotional efforts to sell their product. In May 1971 they went further, introducing he 'Save-a-Watt' campaign, employing environmentalist rhetoric to encourage consumers to use less ten percent less electricity, particularly at peak periods of demand. Their aim was to overcome a capacity shortage rather than conserve energy. They accepted that reductions in electricity use would deprive the consumer of utility[779]. As we shall see in Chapter 9, in general utility companies often responded with hostility to the idea that society could get by using less energy, and the 'Save-a-Watt' campaign was denounced by utility companies where electricity demand was less constrained[780].

It was no surprise that RANN's significant injection of funding into a previously neglected area of research resulted in a number of novel approaches to reducing energy use. The

[778] Ibid.

[779] Lifset, D. (2008) 'Energy Conservation in America: The Case of New York." in Mogens Rudiger ed. The Culture of Energy. Newcastle upon Tyne: Cambridge Scholars Publishing.

[780] Ibid.

following Chapters will describe in detail how the apparent scarcity of energy resources in the nineteen-seventies led to a reappraisal of the limits of energy resource use, which would propose a new source of energy could be harnessed by society[781]. According to this idea, energy resources could be conserved by using them more efficiently at the point of use.

Presidents Nixon, Ford, and Carter would all demonstrate fealty to the idea of energy asceticism in public broadcasts, turning down thermostats, wearing cardigans, removing lightbulbs, and installing solar panels. But far from this homely approach[782], the science of ERC which informed this actions was a collation of various ideas from systems analysis, cybernetics, graph theory, computer simulation, statistical mechanics, and econometrics, in order to develop a coherent system of thought that proposed a number of ways in which society could collectively act as a control mechanism to conserve energy. As Landsberg's quote at the beginning of this Chapter demonstrated, in focusing on the determinants of energy *use* rather than supply RANN research would help to redefine the very meaning of the term conservation. And as David Harvey has suggested for resources more generally, the discovery of ERC implied that energy resources were 'in effect, technical and cultural appraisals of nature', and rather than obdurate *things*, their properties and material limits could be established according to the structure of social relations within which they were employed [783].

[781] Richardson, T., Weszkalnys, G. (2014) 'Resource Materialities: New Anthropological Perspectives on Natural Environments', Anthropological Quarterly, Vol. 87, Iss. 1, pp. 5-30.

[782] De Marchi, 1981; Mieczkowski, Y. (2005) Gerald Ford and the Challenges of the 1970s. The University Press of Kentucky. Lexington, Kentucky; Horowitz, D. (2005) Jimmy Carter and the Energy Crisis of the 1970s: The Crisis of Confidence Speech of July, 15, 1979. A brief history with documents. Bedford Press. New York, Boston.

[783] Harvey, 1974, p 271.

That is not to suggest RANN ignored the provision of energy, but given the high levels of federal and industry investment in this area, the novelty was federal investment in 'less conventional' areas of research, such as solar power and energy demand[784]. According to a Federal Committee on Public Engineering Policy (COPEP) review of RANN's work, energy demand research guided by the principle that there were 'limits to growth', a term that had been pushed into the public's consciousness by the Club of Rome's study on the exhaustion of resources, published earlier that year[785]. But there was also a hope that 'technological and institutional changes' might 'push back potential limits in the past and will continue to do so' but 'to an extent not entirely predictable'[786].

This was a position reminiscent, if guardedly so, of the nineteenth century Ricardian argument that technology could increase the fertility of mines (Chapter 3), and the twentieth century neo-Ricardian argument proposed by Howard Barnett and Chandler Morse at the Washington research group *Resources for the Future* (RFF), who proposed a form of atomic cornucopianism, based on the idea that nuclear power might render the entire idea of material limits obsolete, providing energy too cheap to meter, which could then be used to construct all the materials that human kind might need[787].

[784] COPEP (1973) Priorities for Research Applicable to National Needs. Committee on Public Engineering Policy. National Academy of Engineering. Washington DC. p.78, 102.

[785] For more on Limits to Growth see Chapter 10.

[786] COPEP, 1973, p. 68.

[787] See note 367. On the basis that nuclear energy would be extremely abundant and low cost, Barnett and Morse suggested the answer to resource limits was 'Neo-Ricardian', as 'the twentieth century's discovery of the uniformity of energy and matter has increased the possibilities of substitution to an unimaginable degree'. This meant material scarcity would become meaningless, as abundant energy could be used to create resources out of any matter. Barnett, H., Morse, C. (1963) Scarcity and Growth: The Economics of Natural Resource Availability. Resources for the Future. Johns Hopkins University Press.

Unsurprisingly, given that RANN now allowed the NSF to sponsor social scientific research, sociological and particularly econometric approaches toward the dynamics of energy demand soon emerged which would bolster the ontology of conserved energy (Chapter 8). Such analysis, as we shall see, were often interdisciplinary, as 'energy demand studies require not just economic analysis, but the engineering capability to assess the present and potential ability to find substitutions for the more energy-intensive technologies'[788]. In attempting to integrate principles of engineering alongside those of political economy, researchers would approach a task similar to that of Jevons in 1865. But they would come to a very different conclusion. Rather than increasing the rate and scale of energy use, they would suggest that individual acts of increased energy efficiency could lead to collective societal conservation of energy resources (ERC). As Harvey argued, just as the concept of scarcity was determined by the way in which society used resources, the science of ERC was similarly social, and would come with specific political requirements, manifesting the need to sustain the conditions that allowed the reproduction of the capitalist system[789].

Accordingly, RANN's focus would not only be on the technological determinants of energy consumption, but also the institutional and regulatory systems which created a market for energy use. As the COPEP review into their work noted, 'the objective [of RANN] is to assess the side effects and long range consequences of alternative institutional designs and regulatory policies, particularly to provide policy makers with the option of considering energy-conserving factors'[790]. This was an important point, as like the earlier policy of pro-rationing, ERC was not only conceived of as a scientific and technological problem, but one of regulation and politics. The implications of this body of applied research on energy

[788] COPEP, p. 72.

[789] Harvey, 1974, p. 275.

[790] COPEP, p. 73.

conservation was that political decisionmaking should be informed by the potential amount of energy resources that could be saved by an given intervention. As Alvin Weinberg would disparangingly remark in 1978, for the more extreme advocates of ERC, it was as if policy should be based on 'thermodynamic imperatives'[791] . But the science that emerged was not strictly thermodynamic, in fact physics woud only play a small part. How then might we begin to conceive of ERC? By employing principles from a range of sciences, ERC might be thought of as an example of what Habermas had termed the 'scientization of policy', in which society was politically remodelled in order to operate as a mechanism for saving energy. Certainly, the applied science of conserving energy, and the ontology of conserved energy resources, would go on to inform political decision-making throughout the nineteen-seventies.

CONCLUSION

Science journalist William Metz noted that, before the energy crisis RANN had been 'badly in need for a goal'[792]. By 1974 there were well over two hundred RANN funded energy research projects, which consumed over 15 percent of the NSF budget[793]. But by 1975, as the energy crisis intensified, there were increasing calls from public and policymakers for a more comprehensive branch of government to address the problems of energy demand. As a result the NSF would transfer all RANN energy projects to the new Energy Research and Development Administration (ERDA)[794]. The work of ERDA will be discussed in Chapter 9, but in general they were the body who would implement the Energy Policy and Conservation

[791] Weinberg, A. (1978) 'Reflections on the Energy Wars', American Scientist, Vol. 66., No. 2., pp. 153-158.

[792] Metz, W. (1974) 'What can the academic community do?', Science, Vol. 184, No. 4134. Energy Issue, pp. 273-278.

[793] NSF 74-22, RANN Document Centre, Energy Research & Technology– Interim Bibliography of Reports, With Abstracts. June 1974.

[794] Berlanger, 1998, p. 109.

Act of 1975, the rationale for which was based on RANN research, fulfilled by a thirty-five former RANN staff, and funded with $52 million dollars originally earmarked for RANN[795]. Here, it will suffice to say that though RANN's work was subsumed by a larger government body, its impact on American energy policy was subtle but considerable. In reviewing RANN, the COPEP report noted that 'applied research confronting human complexities can seldom have the dramatic impact of a space program that reaches the moon in ten years'[796]. But, RANN was never intended to produce dramatic breakthroughs or carry out exploratory missions, but to apply science to society's problems in a more diffuse, entrepreneurial way. In this way, the applied science program, and the science of ERC it helped to create, might be seen as part of a wider shift away from solving problems with state sponsored science to employing state funded technology, an observation which will be expanded upon in Chapter 7.

RANN was similarly critical to the institutionalization of ecology in the United States, providing over $20 million to produce over two-hundred studies detailing energy and mass flows, ecosystem stability and the linkage of natural and social 'ecosystems'[797], a field with many parallels to the science of energy conservation. In fact, if one looks closely at many of the developments in American science in the 1970s, and particularly those which involve the 'technologization' of scientific work, RANN sponsorship and its entrepreneurial prerogatives

[795] Larsen, O. (1992) Milestones and Millstones: Social Science at the National Science Foundation. Transaction Publishers. p. 98.

[796] National Academy of Engineering (1973) Priorities for Research Applicable to National Needs. Report of the ad hoc Steering Committee for the Study of Research Applied to National Needs of the Committee on Public Engineering Policy of the National Academy of Engineering to the National Science Foundation. NAE, Washington.

[797] Golley, F. (1993) A History of the Ecosystem Concept in Ecology: More than the sum of its parts. Yale University Press.

can be easily found in fields ranging from biotechnology to economics[798]. In the following chapters, I argue that RANN's work on the science of energy conservation, though not as dramatic as space exploration, not only contributed to the development of the 'resource ontology' of conserved energy, it also played an important role in granting credibility to a new model of political economy. This argument runs counter to the somewhat misleading view put forward by science writers Richard Green and Wil Lepowski that RANN was a research program that 'looked like something out of a New Deal social laboratory'[799]. In fact, the applied science program of the nineteen-seventies was driven by political imperatives that ran directly against the strongly interventionist principles of the New Deal.

The next three Chapters are intended to provide sufficient evidence to make the claim that RANN was critical to the institutionalisation of a science I have termed ERC, in recognition of its ability to present estimates of conserved energy as if it were a resource like any other. This practices which fashioned this resource were diverse, and its realisation was far more complex than earlier approaches to coal and petroleum conservation. It recast societal fuel use as a general system of *energy* use, in which diverse fuels, the energy consumer, infrastructures of conveyance, and the end-uses of electricity, petroleum, and coal were all part of a causal network which, suitably configured, it came to be argued, could act to conserve energy resources. The systematisation of society's fuel use will be addressed in the next Chapter, and with it, the political significance of this move will become increasingly apparent. Needless to say, given the commercial rationale behind RANN, and the more general shift with regard to the economic role of science, ERC would reflect an increasingly

[798] Vettel, E. (2013) Biotech: The Counter Cultural Origins of an Industry, University of Pennsylvania Press; Mata, T., Scheiding, T. (2012).

[799] Green, Richard J., and Wil Lepkowski. "A Forgotten Model for Purposeful Science."*Issues in Science and Technology* 22, no. 2 (Winter 2006).

market-led approach to political problem solving. But these Chapters will also suggest there is no easy way to characterise the relationship between the science of ERC and the principles of political economy. Influence travelled in both directions, contradictions were co-present, as were clear disagreements between science and the politics.

In this vein, historian of science Dominic Pestre notes that changes in 'knowledge generating activities', such as the NSF's shift from a rhetoric of 'basic' research to that of 'applied', were 'not only predicated on changes in the social order, but also significantly contributed to reshaping [social order]'[800]. Grounded in objective scientific terms, the science of ERC can be seen as a means of 'technicalising' a program for societal transformation, driven by the motive of conserving the vital resources of energy. In this way, the history of the science of ERC might be thought of as an example of 'scientific politics', the mistaken idea that the complexities of political decision-making can be made comparable to the supposed certitudes of science[801]. In that vein, it is worth considering that American science was, as a result, rendered similarly instrumental as Soviet science had been in earlier decades[802], though here science was put in the service of limitless capitalism rather than communism. The science of ERC would suggest that energy could be conserved by reorganising society in specific ways, it would also suggest that economic growth could be decoupled from energy use, meaning that the American state could continue to grow. Harvey had warned that the threat of scarcity was used by the ruling class, as a means to impose authoritarian interventions. With similar ideological implications, ERC would become predicated on the liberalisation and

[800] Pestre, D. (2003) 'Regimes of Knowledge Production in Society: Toward a More Political and Social Reading', Minerva, Iss. 41, pp. 245-261.

[801] Pestre, 2003, p. 75.

[802] A point made by Mirowski, P. (2013) 'A history best served cold', in Isaac, J. Bell D, eds. Uncertain Empire: American History and the Cold War. Oxford University Press, p. 64.

minimisation of government. A move which might be thought of as a form of controlled decontrol.

CHAPTER 6. SYSTEMATISING ENERGY DEMAND AT THE RAND CORPORATION

This chapter argues that simulation become central to the science of ERC (ERC) in the nineteen-seventies. Under the auspices of the RANN program, researchers at Californian think-tank the RAND Corporation produced graphical and computer-based simulations of energy demand. These simulations were the first to demonstrate how energy demand could be reduced at a societal level at no loss to forecasted economic growth. Representing the state of California, RAND's simulation modelled the dynamics of the state's energy demand up to the year 2000. The model marked an advance of previous forecasting techniques based on the extrapolation of historic determinates of demand. RAND's dynamic model represented demand as a complex of interrelated energy-using variables. Owing to its realism and granularity it was argued that the model could be used to test policies intended to reduce the growth rate of energy demand. By comparing forecast scenarios in which demand reducing measures were taken with those in which none were taken, for the first time, it was possible to demonstrate how society could act as a conservative mechanism, saving fuel which would have been used in a forecasted profligate future. Most significantly, drawing on the principles of graph theory, computer science, and cybernetics, the simulation's developer argued that California's energy infrastructure could be cast as a 'system' which could be programmed as if it were a computer. Suitably reconfigured, fluctuations in energy demand could act as informational signals in a causal feedback loop, automatically and iteratively reducing energy demand. Recasting California's energy infrastructure as a computational apparatus marked a significant development in the science of ERC.

INTRODUCTION

In 1948 California's Research and Development ('Research and Development' or 'RAND') Corporation was formed as an offshoot of Douglas Aircraft, a military contractor employed

by the U.S. Air Force during the Second World War. Despite this independence, RAND continued to receive the majority of its contracts from the U.S. military. Given this patronage, historians have tended to portray RAND as the quintessential Cold War think tank, an independent and thus objective organization whose researchers were able to provide dispassionate, rational approaches toward strategic problems[803]. Accordingly RAND was noted for creating rationalized means of decision-making, which emphasized objective reasoning over subjective experience[804]. The organization was also a prolific site for knowledge production in a variety of fields less immediately associated with Cold War strategy[805]. RAND analysts made considerable contributions to fields as disparate as economic theory[806] and earth sciences[807]. As a result, historian Jacob Darwin Hamblin has argued, a curious strand of environmentalism developed at RAND and elsewhere, in which environmental problems were increasingly cast as problems of national security, and national security cast as an environmental problem[808]. And during detente, environmental problems gained the catastrophic mantle[809]. This chapter argues that a similar amalgamation of Cold War rationality and environmentalism can be traced in the ERC research carried out at

[803] Amadae, S. (2003) Rationalizing capitalist democracy: The Cold War origins of rational choice liberalism. Chicago University Press. Chicago; Thomas, W. (2015) Rational Action: the sciences of policy in Britain and America, 1940-1960. MIT Press.

[804] Erickson, P. et al. (2013) How Reason Almost Lost Its Mind: the strange career of Cold War rationality. University of Chicago Press.

[805] Hounshell, D. (1997) 'The Cold War, RAND, and the Generation of knowledge, 1946-1962' Historical Studies in Physical and Biological Sciences, Iss., 27. pp. 237-267; Hounshell, D. (2000) 'Medium is the message, or how context matters: The RAND Corporation builds on economics of innovation, 1946-1962', In A. Hughes and T. Hughes ed. (2000) System, Experts, and Computers. MIT Press; Jardini, D. (2013) Thinking Through the Cold War: RAND, National Security, and Domestic Policy, 1945-1975. Smash Books Publishing.

[806] Mirowski, P. (2002) Machine Dreams: Economics as a Cyborg Science. Cambridge University Press, Cambridge.

[807] Doel, R. (2003) 'Constituting the Postwar Earth Sciences: The Military's Influence on the Environmental Sciences in the USA after 1945', Social Studies of Science, Vol. 33, Iss. 5, pp. 635-666.

[808] Darwin Hamblin, J. (2013) Arming Mother Nature: the birth of catastrophic environmentalism. OUP.

[809] Dalby, S. (2009) Security and Environmental Change. Polity, Cambridge.

RAND. This aim is to do more than reveal another discipline's 'cold war dirty laundry'[810], and instead to show how demand for energy produced a new approach to resource policy that melded older conservationism with the mathematics of optimisation and simulation.

At the end of his Presidency, in 1961, Dwight Eisenhower had made cuts to defence funding as part of a wider attempt to achieve détente, the softening of Cold War tensions. As a result, the 'military-industrial complex' looked to diversify their clientele. RAND, for example, partly moved into public policy, looking into how complex urban problems in Los Angeles could be better managed[811]. By the late nineteen-sixties, RAND research had been increasingly tarnished by its relation to the increasingly unpopular and unsuccessful war in Vietnam, so the organization welcomed the opportunity to reorient its expertise toward less contentious problems of public policy. And as a result, thanks to a concerted marketing effort, the organisations methods for decision-making were increasingly implemented at a variety of levels of American government[812].

Looking to extend this service, in 1969, RAND's vice president Gustave Shubert developed a five year plan that looked to extend the organization's expertise into new fields of concern, this included 'environmental control and conservation'[813]. And so, by the end of the sixties, with the launch of the NSF's program of applied research (Chapter 5), given RAND's intention to diversify, and the organisation's expertise in both the social and physical sciences, it was no surprise they were successful in applying for 'problem-orientated'

[810] Isaac, J. (2007) 'The Human Sciences in Cold War America' The Historical Journal, Vol. 50, Iss. 3, pp. 725-746.

[811] Light, J. (2002) 'Urban Security from Warfare to Welfare', International Journal of Urban and Regional Research, Vol. 26, Iss. 3, pp. 607-613.

[812] Jardini, D. (Out of the Blue Yonder: The Transfer of Systems Thinking from the Pentagon to the Great Society, 1961–1965' in, A. Hughes and T. Hughes ed., System, Experts, and Computers. MIT Press.

[813] Jardini, 2013.

research funding. With a budget of $180,000, they were contracted by the NSF to carry out a research on the problem 'The Growing Demand for Energy'[814].

As outlined in the preceding Chapter, by the nineteen-seventies, America's growing demand for energy had become increasingly problematic, not least because the efficiency of electricity generation had reached a point of stasis, the discovery of domestic oil reserves had peaked, and Middle Eastern oil suppliers had grown increasingly bullish in the late nineteen-sixties, all the while population and per capita demand for energy increased. The unproblematic and low-cost supply of energy had, for most of the post-war period, helped support economic growth and increasing individual affluence, if this supply faltered, as it appeared to have done, so too would America's stable post-war economic growth. As the first RANN conference had noted, the problem of constricted energy supply was closely related to the problem of sluggish economic productivity and environmental pollution.

Given this complex of problems, RAND's research project was intended to do three things to address the problem of growing energy demand. The first was to 'identify and quantify the factors that will influence the future demand for energy'; the second 'to develop methods of elating these factors to estimates of energy demand'; and, thirdly, to develop forecasts of demand could allow 'alternative policies and uncertain future events' to be tested[815]. This Chapter describes how RAND's employees, working on the 'Growing Demand for Energy' project, such as the project's director and former nuclear engineer Ronald Doctor, a member of the preservationist Sierra Club, appeared to combine a genuine concern for the environment with their organization's reputation for rationalization and computational

[814] Morris, D., Anderson, K, Doctor, R., Mooz, W. (1971) Proposal for Continuing Work on The Growing Demand for Energy', WN-7359-NSF, March. NSF, RAND Corporation. Working Note.
[815] Ibid.

science.

A decade before the problems of energy supply emerged RAND had already begun using its perceived objectivity to assist conservationists. In 1963 a Federal plan to develop a hydropower plant in the Grand Canyon had been announced. In response Alan Carlin (1937), a RAND economist and member of the environmentalist group the Sierra Club, which had been founded in 1892 (Chapter 4), had contacted the organization's director, David Brower (1912-2000) to inform him of a cost-benefit analysis (CBA) study RAND had carried out for a similar project 1958[816]. This analysis proved such a project would be highly uneconomical[817]. Brewer deployed this report against the Federal Bureau of Reclamation's rival analysis[818], and then contracted RAND to carry out a more up-to-date cost analysis[819]. This report made the argument against the Grand Canyon development more forcefully. Ironically for later anti-nuclear activists, RAND's favourable CBA was based on a comparison to low-cost nuclear power. A year earlier President Johnson had put legislation in place which ensured all federal spending had to go with the lowest-cost alternative in compliance with a standardized 'Planning Programming Budgeting System' (PPBS), itself a product of RAND research[820]. Given the lower cost nuclear proposal, RAND's analysis was authoritative enough to stop the project in 1967. Carlin's later report on the dam controversy made the suggestion that the Federally administered system of cost benefit analysis lacked sufficient objectivity to assess conservation-based decisions, in its place, he suggested the

[816] For more on Brower see Chapter 9.

[817] Pearson, B. (2002) Still the Wild River Runs: Congress, the Sierra Club, and the Fight to Save Grand Canyon. University of Arizona Press.

[818] Ackerman, F. (2008) Poisoned for Pennies: The Economics of Toxics and Precauation. Island Press.

[819] Carlin, A., Hoehn, W. (1967) The Grand Canyon Controversy-1967: Further Economic Comparisons of Nuclear Alternatives. RAND Corporation. P-3546

[820] West, W. (2011) Program Budgeting and the Perfomance Movement. The Elusive Quest For Efficiency in Government. Georgetown University Press..

use of 'a revised set of guidelines and an impartial group to apply them'[821]. RAND had justified its own role in conservationist policymaking.

Alan Carlin would be involved in RAND's energy demand project, whilst also acting as chair of the Los Angeles chapter of the Sierra Club[822]. RAND's energy research was also led by a man who was far from the conventional Cold War strategist. In a later interview Doctor recalled his enthusiasm for nuclear power had ended following a conversation with representatives of environmentalist campaign group Friends of the Earth and the anti-nuclear Union of Concerned Scientists in 1970, who drew his attention to the uncertainties and risks involved[823]. On leaving RAND, Doctor would promote solar power at the Californian state commission[824]. As a result of such a mix of individual interests, his brief account of RAND's work on energy demand, historian of nuclear power Thomas Wellock has asked if RAND had been 'co-opted by environmentalists'[825]. More likely, is that RAND's approach toward the problem of energy demand combined both environmental and technocratic sensibilities. As Wellock notes, RAND was an organisation whose professional reputation had been built on providing clients with optimal solutions to strategic constraints[826]. In order to address the problem of energy supply, the organization would use its growing authority in conservation issues, and analytical methods developed in earlier research programs that were grounded in Cold War strategic reasoning: RAND's systems analytical approach would prove central to

[821] Carlin, A. (1968) 'The Grand Canyon Controversy: Lessons for Federal Cost-Benefit Practices', Land Economics, Volume XLIV, No. 2, pp. 219-227.

[822] Sierra Club, Angeles Chapter, Chronologies, Available at: http://angeles2.sierraclub.org/about_us/chapter_history/chronologies

[823] Wellock, T. (1998) Critical Masses: Opposition to Nuclear Power in California, 1958-1978. University of Wisconsin Press., p. 139 .

[824] Johnson, C. (2015) "Turn on the Sunshine": A History of the Solar Future. Unpublished Doctoral Thesis, University of Washington.

[825] Wellock, T. (1998), p. 139.

[826] Citing Alan Carlin, who in negotiating the contract, claimed "RAND would not be lackeys for the Club" (Wellock, 1998, ft. 113)

their answer to the problem of American energy supply.

FORECASTING WITH GRAPHS

A large part of the RAND's authority, during and after the Cold War, lay in the development of forecasting techniques. During and after the Second World War, RAND's researchers had made significant advances in using computer simulations to improve the accuracy of meteorological forecasting[827]. Computer simulation had first been developed as a means of predicting the behaviour of fissile material during the Manhattan project. Simulation was soon used for meteorological forecasting; led by Manhattan project mathematician John von Neumann (1903-1957), a team of mathematicians at Princeton University had used one of the earliest computers, the Electronic Numerical Integrator and Computer (ENIAC), consisting of eighteen thousand vacuum tubes, informational switches which could automate the calculation of a series of partial differential equations to simulate the dynamics of weather and climate, with the intention that the weather might be known, with some degree of probability, in advance[828].

During the Cold War simulation forecasting spread into other domains. In 1962 aeronautical engineer Ralph Lenz (1919-2012), chief of planning in the United States Air Force, introduced the term 'technological forecasting' to describe the set of methods he had developed forecasting how technological change might occur and at what rate. Lenz's hope was that systematic analysis of probable futures could guide long-term planning[829]. Lenz's methods were looser than Neumann's, and involved 'extrapolation of existing rates' of

[827] Edwards, P. (2006) 'Meteorology as Infrastructural Globalism', Osiris, Vol. 21. pp. 229-250.

[828] Gramelsberger, G. (2011) 'From Computation with Experiments to Experiments with Computation', in Gramelsberger, G. ed. From Science to Computational Sciences: Studies in the History of Computing and Its Influence on Today's Sciences. Diaphenes Press. University of Chicago.

[829] Martino, J. (1972) An Introduction to Technological Forecasting. Gordon and Breach Publishing.

growth from historic data, drawing 'analogies to biological growth', and, more formally, using partial differential equation to create 'dynamic simulation'[830]. Two years later RAND researchers, statisticians Olaf Helmer and Theodore Gordon expanded Lenz's technological forecasting methods, and set out a general theory of prediction which, they stated, would allow any organisation 'to deal with socio-economic and political problems as confidently as we do with problems in physics and chemistry'[831]. Here was a stark example of the assertion that policy making could become a science[832]. The roots of this claim predated Lenz's work, and lay in a 1958 paper in which Helmer had proposed, for disciplines lacking natural laws, such as public planning, the testimony of experts provided the next best basis for achieving consistent outcomes in non-scientific contexts: the consistencies of expert knowledge were as close to a natural law as could be hoped for. On this basis Helmer proposed an 'epistemology of the inexact sciences'[833]. Central to this new epistemology was the 'Delphi technique', named after the Greek oracle. Delphi, as a means of divination, required 'expert interviewees' to undergo recursive rounds of interview, after which the entire group of experts were shown the anonymized results of all other respondents, on the basis of which they could then calibrate their original response[834]. If the interview pool was sufficiently large Helmer asserted that the method could render subjective opinion into statistically probable facts.

At the time, energy demand forecasting inadvertently provided a suitable example of an

[830] Lenz, R. (1962) Technological Forecasting. ASDTDR62414, Aeronautical Division, USAF.

[831] Andersson, J. (2012) 'The Great Future Debate and the Struggle for the World', American Historical Review, Vol. 117, Iss. 5, pp. 1411-1430.

[832] Thomas, 2015.

[833] Helmer, O., Rescher, N. (1958) 'On the Epistemology of the Inexact Sciences', RAND Corporation, P-1513.

[834] Cornish, E. (1977) The Study of the Future: an introduction to the art and science of understanding and shaping tomorrow's world. World Future Society

inexact science. Existing forecasts were carried out by the industry regulator, the Federal Power Commission (FPC), industry organizations such as the National Petroleum Council (NPC), and the National Science Foundation (NSF). All of whom, at the time, made broadly the same claim: demand for energy would double every ten years for the foreseeable future[835]. Unsurprisingly, they all used a common method, which was to estimate demand as a factor of extrapolations of historic electricity price increases, population growth, changes in per capita income, and the price of gas[836]. Price elasticity was established by looking at historic evidence of price rises, but in general energy was considered fairly inelastic, and closely correlated with rates of economic development[837]. The idea that energy was a price inelastic good would prove highly significant for economists' approach toward the problem of energy conservation, as will be discussed in Chapter 8. At this time, since the Second World War, the FPC had attempted to oversee the provision of low cost electricity, and utility companies had, on the whole, been able to approximate this ideal: electricity had been produced at a steady rate of increased efficiency and lower cost. As a result, this relatively rudimentary modelling technique seemed appropriate and had proved to be fairly accurate.

The problem with such extrapolative forecasting methods, as RAND researcher and engineer Stanley Marshall Greenfield argued, in one of the organization's first publications on the problem of energy demand was that 'pure extrapolation from the past' as the basis for future decision-making 'tend to be self-fulfilling' as 'an attempt to meet the projected demand leads

[835] Searl, M. ed. (1973) Energy Modeling: Art, Science, Practice: Working Papers for a seminar on energy Modelling. Resources for the Future, Washington.

[836] Gas is a significant as it was potentially both a substitute for, and byproduct of, oil, and was increasingly used in the generation of electricity. Chapman, et al. (1972)

[837] Following the price rises of 1973, one analyst would hypothesis that this inelasticity was a result of low energy prices negating increases in efficiency, creating the illusion of correlation between energy use and economic growth (Socolow, 1985, 4-5). Chapman, D., Tyrell, T., Mount, T. (1972) 'Electricity Demand Growth and the Energy Crisis', Science, Vol. 178. No. 4062, pp. 703-708.

to the creation of the forecast capacity'[838]. For slow moving industries like electrical power, extrapolative forecasts guided long-term investment in infrastructure. A forecast increase in demand would imply the need for investment in new plant, the development of which would need to begin ten to fifteen years before the forecasted electricity was needed. Once the plant was complete, more power would come online, which according to the Jevonian theory of induced demand outlined in Chapter 2, would lower the cost of electricity and encourage higher rates of consumption. In effect, Greenfield argued the growing demand for energy was a problem that was, at least in part, created by the shortcomings of contemporary forecasting[839].

As a fairly recently hired member of staff, during his first year at RAND mathematician Fred Roberts (1943--) had published a method for making decisions in situations where economic valuation was not possible. The answer, in his view, was to choose a statistically proven number of options from a ranked list established by experts, imitating Helmer and Gordon's Delphi technique[840]. Roberts was also called upon to give a mathematical formulation to the nebulous concept of 'quality of life'[841]. It was no surprise that, with a willingness to engage with qualitative information and non-mathematical concepts, Roberts was well suited to addressing the inexact science of forecasting energy demand[842]. Assigned to the Growing Demand for Energy project, Roberts' proposed that energy demand forecasts should not simply extrapolate from past trends. Instead demand should be forecasted via a model which

[838] Greenfield, S. (1970) Projection and Distribution of Waste Thermal Energy, RAND Corporation, P-4540, p. 1.

[839] Greenfield estimated that the U.S. would produce 65^{10} megawatts of waste thermal energy by the year 2000 (Greenfield, 1971: 4).

[840] Roberts, F. (1968) 'What if utility functions do not exist?' RAND, D-18106-PR.

[841] Roberts, F (1969) 'The quality of life: what it means and what we can do about it', RAND, D-19306-DOT.

[842] RAND's proposal for 1971 had committed the organisation to 'experiment with alternative ways of synthesizing [...] diverse factors [of energy use] into comprehensive and self-consistent scenarios', Morris, D., Morris, K., Doctor, R., Mooz, W. (1971) Proposal for Continuing Research on the Growing Demand for Energy, a Working Note Prepared for the National Science Foundation, RAND Corporation WN-7359-NSF.

represented the interrelated microeconomic factors of which aggregate demand was composed. In doing so, Roberts claimed 'we can make both the forecasting problem and the problem of forecasting effects of new technology or institutions precise' and, introducing the concept of optimisation, discussed in Chapter 4, he advised that RAND could 'define strategies for choosing alternatives to obtain desired environmental constraints and also give criteria for a strategy to be optimal'[843].

In 1970, Roberts's colleague Stanley Greenfield had bemoaned the absence of 'feedbacks' in energy demand forecasting[844]. The term feedback was borrowed from control engineering, it described a mechanism in which fluctuations in values between variables in a system could be recognized by that system, and accommodated according to predefined criteria. Both Herbert Jevons and Harold Hartley had discussed the potential fuel savings possible using such mechanisms in post-war Britain (Chapter 3). For example, a thermostat which regulated the temperature of a room, according to the temperature desired by the homeowner, and in relation to fluctuations in external temperature, could be expected to reduce the amount of energy used, if the homeowner so wished[845]. Feedback mechanisms were a central concept in control engineering, and had become increasingly influential as a means of describing mechanisms that were 'purposeful' in so far as their operation could be directed toward a predefined goal. In one of the earliest papers on 'cybernetics', the science of informational control, mathematician Norbert Wiener had described the human neural system as a 'teleological mechanism'[846]. By the nineteen-seventies, the notion of feedback had become a

[843] Roberts, 1971, p. 404.

[844] Greenfield, 1971, p. 2.

[845] Mayr. O. (1971) 'Adam Smith and the Concept of the Feedback System: Economic Thought and Technology in 18th Century Britain', Technology and Culture, Vol. 12, No. 1., pp. 1-22.

[846] Wiener, N. (1948) Cybernetics: Or Control and Communication in the Animal and Machines. MIT Press.

catch-all term to describe inputs of information to a system in a variety of fields[847]. Roberts' proposed forecasting method, adopting the terminology of cybernetics, would purposefully accommodate the reciprocal feedbacks of component parts of the energy system, such as power plants, consumers, automobiles, and levels of employment.

To achieve forecasting with simulated feedback mechanisms, Roberts went back to an earlier method, graph theory, a branch of mathematics that used visual representations of related variables as the basis for calculation. In 1736, Swiss mathematician Leonhard Euler (1707-1783) had demonstrated that the seven bridges of Königsberg, now Kaliningrad (in Russia), traversing the river Pregel and a small island called Kneiphof, could not all be crossed without going over one of the bridges twice. Euler's demonstration of this impossibility is normally taken as the beginning of the mathematical analysis of graphs. Each graph is composed of 'nodes', a compulsory point; in Euler's case these were the bridges, and the 'edges', the paths between the bridges[848]. During and after World War II, mathematicians had increasingly used the analysis of graphs to solve problems in cryptography, logistics, and transportation[849]. Graph theory became one of the archetypal Cold War scientific sciences of optimization[850]. In the 1950s, optimality, as discussed in Chapter 4, was a term that had moved from an adjective describing the most favourable outcome from a set of predefined circumstances, to mean a mathematically formalisation of the maximum or minimum possible value, according to the criteria of the modeller, that could be derived from a given set of constraints. To optimise Euler's problem, for example, the distance travelled over all

[847] Kline, R. (2015) The Cybernetics Moment. Or Why we call our Age the Information Age. Johns Hopkins University Press.

[848] Biggs, N., Lloyd, K., Wilson, R. (1976 [1986]) Graph Theory, 1736-1936. Oxford University Press.

[849] Tutte, W. (1998) Graph Theory as I Have Known It. Oxford University Press.

[850] Brentjes, S. (1994) 'Linear Optimisation', Grattan-Guinness, I. ed. Companion Encyclopedia of the History & Philosophy of the Mathematical Sciences. Volume 2. Johns Hopkins University Press.

the bridges could be considered optimal if the distance travelled was minimized.

In 1951, econometrician Tjalling Koopmans claimed to have gone some way in solving the Cold War by demonstrating that both planned and unplanned economies could be structured in a way which optimised the allocation of resources, meaning assertions of the superiority of either capitalism or communism were purely ideological[851]. In Chapter 4 it was shown how Koopmans' work was responsible for the conflagration of optimal allocation and resource conservation, leading some to suggest that an unimpeded market in resources was the best way to conserve resources, in so far as free market was believed to use resources with greater efficiency than that of a centralized economy; thereby allowing economic growth with the use of comparatively less resources. Assertions of optimality were a component of Cold War reasoning[852]. Originally a strategic and ideological idea, optimisation became a form of applied mathematics, which implied that resources could be optimally allocated. Roberts would use graph theory to apply optimization methods to the analysis of energy demand[853].

Graph theory resonated with RAND's enthusiasm for another archetypal cold war form of knowledge, cybernetics: a collective of sciences concerned with informational feedback and

[851] Koopmans, T. (1951) 'Efficient Allocation of Resources', Econometrica, Journal of the Econometric Society Vol. 19, Iss. 4. Cowles Foundation Paper 52.

[852] Koselleck argues the concept of optimality had utopian roots, stretching back to the eighteenth century Enlightenment, and that its' assertion provided a seemingly inviolable source of political authority that served only to heighten and perpetuate Cold War tensions. Koselleck, R. (1977) Critique and Crisis: Enlightenment and the Pathogenesis of Modern Society. MIT Press.

[853] Roberts not the first to apply graph theoretical techniques to the provision of energy. In 1847 Prussian physicist Gustav Kirchoff (1824-1887), also from Konigsberg, used graph theory to calculate the current in an electrical circuit. The law of energy conservation meant that the value of a current flowing into a node must equal the value flowing out. Hence in a grid, current must equal zero. Chen, W-K. (1997) Graph Theory and Its Engineering Applications. Advanced Series in Electrical and Computer Engineering, Vol. 5, World Scientific Publishing.

the control of systems[854]. Graphs, like cybernetics, could represent dynamic systems as series of 'feedback loops': relays that conducted energy or information between a circuit of variables, either according to the constraints of a physical law or externally inputted command. For instance a water-clock was constrained by gravitation whereas a thermostat could be set at a given temperature to set a constraint[855]. But as historian David Mindell has argued, a similar theory of automated control mechanisms had similarly been developed by electrical engineers, who had built analogue models of the electrical networks. Particularly the work of Harold Hazen in the 1930s, whose network analyser, an analogue computer able to simulate the flow of current in the electrical network, led him to a general theory of 'servo-mechanisms' and systemic control[856]. In this way, cybernetics and electrical engineering both provided an analytical language to describe and design systems that could fulfil a given task[857]. That is, relays could be structured in such a way that they could guide the subsequent behaviour of a system[858].

Understandably, the principles of cybernetics were a significant influence upon the emerging discipline of computer science, providing a language to design and discuss computer programs: purposive sets of interrelated hierarchical instructions[859]. Inevitably, from 1948 onward RAND researchers were also at the forefront of this new science. RAND's Computer Sciences Department was established in 1962, replacing the 'Numerical Analysis

[854] On RAND's and cybernetics see Amadae (2003), Mirowski (2002), and Thomas (2015) amongst others. On cybernetics more generally see Kline (2015).

[855] Mayr, O. (1979) The Origins of Feedback Control. MIT Press.

[856] Mindell, D., (2002) Between Human and Machine: Feedback, Control, and Computing Before Cybernetics. Johns Hopkins University.

[857] Edwards. P. (1996) The Closed World: Computers and the Politics of Discourse in Cold War America. MIT Press., p. 18.

[858] Beniger, J. (1989) The Control Revolution: Technological and Economic Origins of the Information Society. Harvard University Press., p. 39.

[859] Kline, 2015.

Department'. The RAND group would make major contributions to computer science, from developing new programming languages, to producing early work in artificial intelligence (AI), and distributed communications, the conceptual basis of the internet[860].

Under the auspices of RANN, Roberts argued that energy demand could be simulated in a way which combined graph theory, cybernetics and computer science. Roberts' contention was that each variable of energy demand and supply, such as population or the number of factories, could be represented as a node, which was related to other nodes via physical or informational feedback. Time could be simulated by 'time-stepping', inputting data to the nodes in a sequence that represented chronological fluctuations in values and iteratively calculating their co-related changes in value. For example, nodes could be causally related according to an increase in physical quantities, in the case of population, or according to variations in price information. Feedbacks either reduced or increased the value of the node they affected; 'negative feedback' reduced the value of that node. If there were more negative feedbacks in the system, total energy demand would be reduced as 'deviations are counteracted', whereas a majority of positive feedbacks would mean 'deviations are amplified', and total demand for energy would increase[861].

To illustrate his reasoning Roberts' made the work of Japanese anthropologist, mathematician, and systems analyst Magoroh Maruyama (1929--), who having come to the United States in 1950, and studied in Berkeley, went on to receive a doctorate from Lund University. In 1963, Maruyama published a paper in *American Scientist* which argued that systems analysis had focused on self-regulating or 'deviation reducing' systems for too long,

[860] Ware, W. (1997) RAND and the Information Evolution: A History in Essays and Vignettes. RAND Corporation., p. 9.

[861] Roberts, F. (1971) Signed Digraphs and the Growing Demand for Energy. RAND Corporation. R-756-NSF.

owing to the science's cybernetic origins. This was curious, he conjectured, given the ubiquity of examples of deviation amplification, both social and natural: capital accumulation was one, erosion and evolution another. Systems deviated, Maruyama had written, when 'mutual causal relationships […] amplify an insignificant or accidental kick, build up deviation and diverge from the initial condition'. He term the study of deviation amplification 'the second cybernetics'[862] to differentiate his approach from the original cybernetic ideas, promoted by figures like Ross Ashby or Norbert Wiener, which focused upon homeostatic processes. Situations in which deviations within a given system are counteracted, and stability achieved[863]. Later in life, Maruyama would recollect that he had become interested in the interactions between disparate elements as a result of his interest in Japanese garden design and floral art, which he believed manifest a non-linearity lacking in Western intellectual culture[864].

ROBERTS' ENERGY DEMAND SYSTEM

Drawing on Maruyama's work, Roberts' proposed that a 'signed digraph', a means of representing systems, could be used to simulate energy demand. In this kind of graph, the 'edges' between nodes could be given a value that denotes their 'strength', the strength of each edge acts in a specific direction. In Figure 1, three nodes (A, B, C) are connected by three edges (X, Y, Z). Nodes could represent any significant variables in the system, and their connection by an edge indicates their relation. The direction of each edge was indicated

[862] Maruyama, M. (1963) 'The Second Cybernetics: Deviation-Amplifying Mutual Causes', American Scientist, Vol. 5, Iss. 2, pp. 164-179.

[863] Hayles, K. (1994) 'Homeostasis, Reflexivity, and the Foundations of Cybernetics', Configurations, Vol. 2, No. 3, pp. 441-467.

[864] Maruyama, 1988 for example, Japanese floral arrangement, 'Ikebana', is an art form in which practitioners attempt to simulate natural structures, such as the seasons, and the relation of different elements within them. Maruyama, M. (1988) 'This week's citation classic: the second cybernetics, Maruyama, M.' Citation Classic, No. 8, ISI, p. 12.

with an arrow, and the strength is 'signed' either positive or negative. A negative edge X - would suggest that an increase in node A 'inhibits' or decreases the value of node B. Each pair of connected nodes could be weighted in order to show variations in strength affects other nodes. For example, A, B = 10, and B, C = 5. This would create a 'weighted signed digraph'. Marayuma had shown that 'cycles', or feedbacks, between nodes were 'deviation amplifying' if the cycle had an *even* number of negative signs, as in the example below. An *odd* number of negative signs would mean any deviation would be counteracted. This meant that the structure and strength of a graph simulation could lead to dramatically different outcomes. In a system structured with an odd number of negative signs, graph values would decrease (via inhibitive processes), as compared to a system with an even number of negative signs, which values would increase (via amplification).

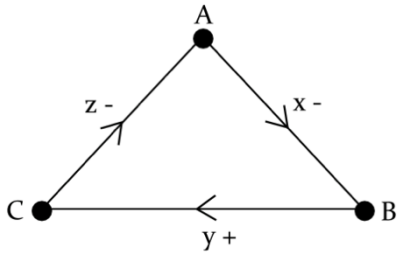

Figure 6.1. A Simple Signed Digraph

In presenting his appropriation of Maruyama's reasoning, Roberts claimed digraph simulation of energy demand could be hoped to do five things. First, it would provide a more granular and therefore more realistic method for forecasting energy demand. Second, by testing the simulation with different nodes and values, it would allow the identification of 'variables or forces which underlie the growing demand for energy'. Third, unlike earlier extrapolative forecasts, digraphs could test the introduction of new technologies and institutions, represented by the addition of new nodes. Critically, and fourthly, given that

'rapidly increasing energy use is in apparent conflict with the quality of the environment' digraphs could help researchers to formulate 'alternative policies' to reduce energy use. That is, returning to the homeostatic principles of first cybernetics, the energy system could be considered as a means of countering systemic deviations. Fifthly, Roberts argued digraphs offered the means to *optimise* energy demand[865]. Each node could be considered as a constraint, and a linear programming equation could be used to calculate the optimal allocation of resources across the nodes, whilst still maintaining the desired structure and function of the system as a whole. In this respect, Roberts argued his digraphs were no different to 'simultaneous equations, input-output analysis, econometrics, matrix analysis, and so on', in so far as they provided a means for representing the the allocation of resources in an economy. The benefit of 'visual representation', he stated, is that it 'makes many of the relationships very clear and understandable'[866].

The reconfiguration of energy demand in terms of a directional graph would be central to the science of ERC for three reasons. The first was that the method would allow the calculation of an optimal allocation of energy within a graph, which could be simulated as a time-stepping procedure, in which a sequence of numerical data was entered iteratively to represent the process of time. In a dynamic graph, replete with a requisite amount of negative feedbacks, it could be hoped that increases in energy demand would be counteracted. Second, it followed that digraphs could act as programmable devices that, by adding negative feedback loops, could be used to develop ways of reducing energy demand. Third, graph analysis would play a role in constructing the idea that the energy

[865] Roberts, 1971.

[866] Roberts, 1971, p. 406.

infrastructure was a 'system'[867].

Following contemporary American sociologist Talcott Parsons (1902-1979) definition, meant 'a network of interconnection, the state or activity of one component influencing the state or activity of other components'[868]. Systems could involve heterogeneous components, mechanical, electrical, and organisational, and were amenable to mathematical or computational analysis[869]. Such a conceptual leap was not ungrounded. The historian Thomas Hughes, in his history of electrification, took the development of electrical systems as studies of archetypal 'complex systems', by which he meant 'coherent structures of interacting, interconnected components'. His history of electrification described how the notion of the 'network' became both the guiding idiom and infrastructural reality of the electrical 'system'. General systems, Hughes noted, could be composed of a wide range of components, one of which was information[870].

Roberts developed a basic energy demand model by adapting a digraph from Maruyama's work, which described the dynamics of urban waste disposal. In Roberts' graph the energy system was represented by a series of nodes and their relation by edges. Using this structure, the 'behaviour' of an energy using system could be described. To demonstrate, in the above example, an increase in energy use (U) would decrease the quality of the environment (Q), which would counter deviation between the nodes (edge $U, Q = -n$.). Whereas an increase in energy use (U), would increase the population (P), which would lead to deviation

[867] Mitchell argues it was the energy crisis which systematised energy How Energy Became a system', in Mitchell, T. (2011) Carbon Democracy: Political Power in the Age of Oil. Verso.

[868] Mason, A. (2006) 'Images of the Energy Future', Environmental Research Letters, Vol. 1, Iss. 1, pp. 20-25.

[869] Hughes, A., Hughes, T. (2010).

[870] Hughes, T. (1983) Networks of Power: Electrification in Western Society, 1880 - 1930. Baltimore: Johns Hopkins Press; Hughes, T., Hughes, A. (2000) Systems, Experts, and Computers: the systems approach in managing and engineering, World War II and after. MIT Press.

amplification over time (edge, *U, P* = + *n*). According to Maruyama's definition, as the whole system in Figure 3 had an *even* number of negative signed edges, the system was deviation amplifying: an increase in the value of a single node (a 'pulse') would cause energy demand to increase. Though the model was simple, given that America's energy demand was problematically increasing Roberts could safely hypothesise that the complex reality of energy demand was in some sense similarly structured.

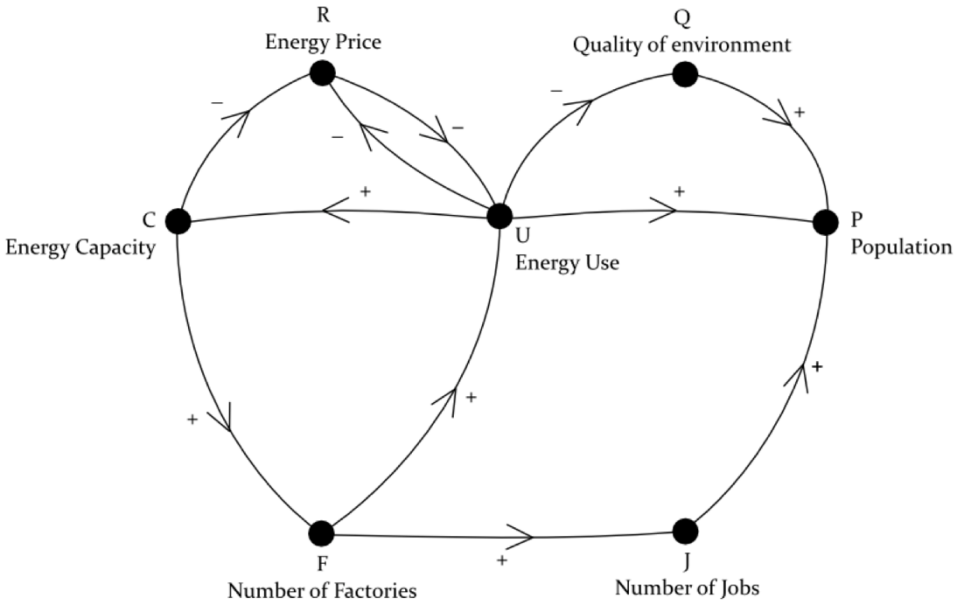

Figure 6.2. Signed Digraph Representing the Dynamics of Energy Demand
Adapted from Roberts (1971)

On the basis of this simple model, Roberts' proposed a solution to the first of RAND's research objectives, the reduction of energy demand. Those nodes that caused the greatest amplification in demand should be focused upon by policymakers or engineers. But more importantly, the dynamics of energy demand could be tested via this representative system. For example, a node could be added which simulated the addition of a new energy intensive form of transport, or one which represented the effect of a tax on electricity. In fact, Roberts proposed the model could even be used to formulate demand reduction policies, as anything that could offer 'deviation countering sub processes' would act to reduce net energy

demand[871]. In graph theoretical terms, Roberts had found one solution to the energy crises: assuming the dynamics of the model corresponded to the actual infrastructure of energy demand, deviation countering nodes and loops could be introduced to the energy system.

Though Roberts' proposed model appeared to offer some mathematical formalisation, the data on which the structure, nodes, edges, and weights, was based drew on the inexact science of the Delphi method. As Roberts admitted, as it did not describe a natural scientific situation, despite the apparent sophistication of the forecasting model, the model relied upon the 'subjective judgments of groups of experts'[872]. To explain how his data had been collected, Roberts explained how he had come to populate a small section of the model: energy using transport. For 'Round One' he had submitted a 'free response' questionnaire to a panel of experts, asking them which factors they considered most impactful and 'allowing the imagination to run free'[873]. The panel had consisted of the ten RAND researchers employed on the energy demand project, from whom Roberts received only eight responses.

The second round, with the same experts, required them to rate the resulting five hundred variables according to importance (median overall importance, and relative importance). Once each variable had been accorded a relative and overall rank, the most relevant variables could be identified according to according to a 'magnitude estimation procedure', whereby the most important variable was rated 100, and all others relative to this. Admitting the flaws in this process, Roberts noted that 'One respondent said he felt that all his numbers were "totally meaningless"'[874]. In Round Two, Roberts calculated the median and geometric mean

[871] Roberts, 1971, p. 397.

[872] Roberts, F. (1972) Building an Energy Signed Digraph I: Choosing the Nodes. RAND Corporation, R-0927/1.

[873] Roberts, F. (1972), p. 3.

[874] Ibid, p. 15.

from each response, and used this to compute 'Kendall's Tau', a correlation coefficient for generating a ranked hierarchy of co-dependent variables according to the magnitude of their significance in relation to the system as a whole.

Round three involved asking the panel of experts to judge the relationship between each of the nine nodes as either positive or negative, or if there is no significant relation. On this basis, each expert was given a shuffled pack of 72 cards representing each pair of nodes. Each of the seven respondents would then consider whether there was a relation between nodes. In doing so, the eight experts created 576 estimates of the relation between nodes[875]. Despite a gloss of formal mathematics, Roberts' admitted that 'the choice of nodes for an energy demand signed digraph falls at least in part in the realm of opinion'[876]. From the entire list of possible nodes, the nine most significant variables that Roberts' method resulted in provided some representation of the most significant dynamics in energy-using transport, though their selection was far from objective and remarkably human. The resulting digraph, a combination of graphical mathematics and slightly flimsy data collection, helped to develop some picture of the energy system's complexity.

Using such graphs, Roberts claimed it was possible to illustrate 'the effect of various strategies for modifying the energy demand system'. Those nodes that could be altered with significant savings and without a significant effect on the behaviour of the system as a whole. The digraph could also be used to identify feedback loops which Roberts' claimed 'contribute

[875] Where respondents disagreed, a minimum threshold for the existence of a node was imposed, according to the criteria of the modeler, such as ≥ 6. The estimates of relation could also be used to give each edge a weight. For example, if an edge has been assigned four 0, one +, and two -, the edge's strength would be – 1. Weight and edge threshold could also be established mathematically, or in relation to the median value or some other statistical criteria. Roberts, F. (1972).

[876] Ibid, p. 5.

so greatly to stability or instability'[877]. Stability, in this sense, meant deviation against increases in energy demand[878]. Stability could be measured by identifying the full range of feedback loops within the model, both node to node loops, and cycles between multiple or all nodes, and the number of these loops which contain an odd or even number of positive (destabilising) or negative (stabilising) signed edges[879]. Roberts' suggestion was that the identification of easily manipulated feedback loops could then be used to develop policies to reduce energy demand.

GEOMETRIES OF DEMAND

In concluding his study, Roberts admitted digraph models were imperfect and that whatever the level of complexity 'you never know for sure' if a variable had been omitted[880]. But as Olaf Helmer had suggested back in 1958, a certain level of inaccuracy was characteristic of all sciences. Helmer had opined that the important thing, from a practical perspective, was that simulations could demonstrate 'specifically predictive instrumentalities'[881] upon which effective policy decisions could be made. Like many kinds of simulation, the aim was not realism but pragmatism[882]. Despite the imprecision of the expert opinion that underlay Roberts' digraph method, its application to policymaking would prove highly significant. Roberts' simple simulation provoked an entirely new conceptualisation of the energy demand system: for the first time, the interrelations between electricity demand and supply would be

[877] Ibid, p. 27.

[878] 'a system is called *stable* if the value of no variable gets larger and larger in any situation which some external change is introduced at some other variable'., Roberts, F. (1976) 'Strategy for the Energy Crisis', in Axelrod, R. Structure of Decision: The Cognitive Maps of Political Elites. Princeton University Press., p. 168.

[879] Roberts, 1976, p. 145-6.

[880] Ibid, p. 28.

[881] Helmer, O., Rescher, N. (1958) p. v.

[882] Lenhard, J. (2011) 'Artificial, False, and Performing Well', in Gramelsberger, G. ed. From Science to Computational Sciences: Studies in the History of Computing and Its Influence on Today's Sciences. Diaphenes Press. University of Chicago

thought of as if they were informational signals in a programmable computational system.

To explain this, it is necessary to understand how a deceptively simple graph can be considered as a computational device. In Roberts' model, the strength of nodal relationships could be made contingent upon others' values. So, for example, in figure 3, the strength of the relationship between energy capacity and energy price (*C, R*) could be calculated as a factor of the number of jobs and the population (*J, P*). The efficiency of energy capacity and price might be weakened if population increased beyond a certain point, as seemed to be occurring in the U.S. at the time, and number of jobs might decrease as plentiful human labour replaced energy as a form of capital. So the strength of the edge *C, R* would be a function of the relationship (*J, P*). This kind of graph, composed of dependent coefficients was known as a 'functional digraph'[883]. By suggesting each node was a co-efficient of the value of other relations in the system, Roberts introduced computation into the model. The model was still essentially only a diagram. But computation is not a practice confined to digital computers or programmed code[884]. Computation is a theory of logical procedures that can take place in many different mediums. Given a set of variables and a small set of logical operations, relations between variables can be structured so that increasingly complex operations could be carried out. This structure could be used to simulate complex phenomena. Its automated elements could be considered as an analogue of purposive reasoning.

It was this computational capability that would allow the digraph simulation to act as a forecasting device. Once energy demand was suitably represented as a structure of

[883] Roberts, 1971.

[884] Hayles, K. (2005) My Mother Was a Computer: Digital Subjects and Literary Texts. Chicago.

informational relations, Roberts wrote that an initial 'pulse', or input of quantitative data into the nodes, could be used a means of simulating change over time, and thereby allowing the forecasting of future energy demand. A pulse could be simulated by inputting a certain value to a node, nodes or all nodes, at a certain point in time, or list of values that represent changes over time, or the sudden intervention of a new technology or an event, such as an unexpected increase in population[885]. For example, the number of factories ('F') at the present time could be shown by n and the increment of time as n + 1. This increase in the initial pulse, and its relation to all other nodes can be forecasted as a sequence representing time (n_1, n_2, n_3, n_n.) and so on. Unlike extrapolative forecasts, digraph forecasts took account of the various dynamics from which net energy demand was composed, and importantly, how that demand might be reduced by a range of interventions. Clearly in extant forms of extrapolative forecasting, demand rates could be reduced by increasing prices, reducing population, or reducing per capita income. But these were not politically feasible or desirable means of intervention.

An important outcome of using digraphs as a forecasting device was that, specific values aside, the structure of a graph could provide a characterization, or the 'geometry', of future demand. According to the structure of the energy system, demand could be shown to increase exponentially, arithmetically, or logistically.[886] These different geometries of growth were the result of different configurations of positive and negative feedback loops. An unstable system of energy demand, replete with a majority of positive feedback loops, would cause the amplification of energy demand and an arithmetic increase in demand. As Roberts wrote, contemporary environmentalists had argued that 'if energy capacity

[885] Roberts suggested pulses could be formalized as 'pulse processes' (Roberts, 1971), most clearly explained in Roberts (1976: 148).

[886] Roberts, 1976, p. 148 terms these 'geometric methodologies'.

increases, this leads to an increase in energy use, which in turn leads to further energy capacity. The initial deviation was amplified, and we say there was a positive feedback through the system'[887]. For a scenario of exponential growth, one only needed to recall Jevons' forecast (Chapter 2). In contrast, a stable system of energy demand would contain a majority of negative feedback lops, which would cause logistic growth in energy demand. In effect, the two different types of general structure, unstable and stable, provided two different profiles of the growth rate of future energy demand.

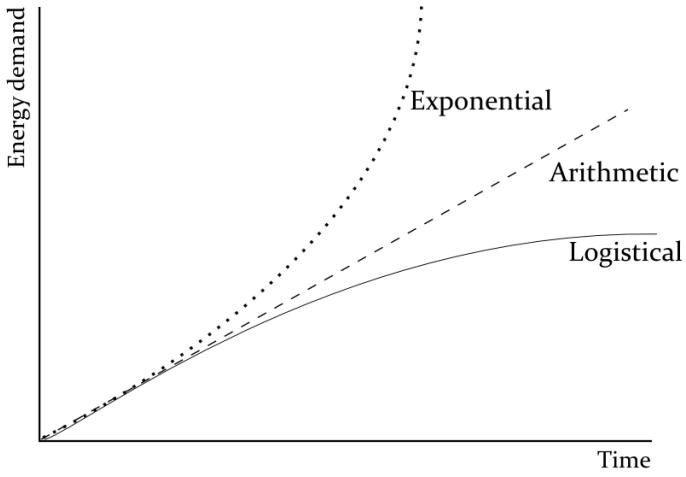

Figure 6.3. Types of Growth Rate
Adapted from Gershenfield (1999)

INFRASTRUCTURE AS AUTOMATON

Roberts's digraph had another computational facet: in the language of computer science, the graph, and by analogy the infrastructure of energy demand itself, the shifting network of natural resources, power plants, appliances, electrical conveyance and human intentionality, could be considered as an automaton[888]. Historically, mechanical automata were machines

[887] Ibid, p. 146.

[888] Barry, A. (2016) 'Infrastructure and the Earth', in Harvey, P., Bruun Jensen, C., Morita, A. eds. Infrastructure and Social Complexity. London. Routledge.

that functioned as if they were human, or even performed tasks in a more than human way that was believed to avoid human error and prejudice[889]. With the development of computer science, the term automata was used to describe programmed models of machines that perform computations on an input by moving through a series of states or configurations: in effect, automata described specific informational processes in such a way that they could be automated, and carried out without human intervention[890].

Though automata had existed as a concept since the medieval times, automata theory, as a formal analytical language, emerged in 1936, when Alan Turing (1912-1954) developed an idea for a computer which involved a machine that could read symbols on a strip of tape, and carry out a set of actions according to predefined rules: either moving the tape left (0) or right (1), or replacing or erasing a symbol[891]. Turing's idea was one of the foundations of contemporary computing as it described a system that could build calculations combining simple bits (0/1) of information into infinite computational arrangements[892]. In 1950, using the example of tape-reading machine, Turing proposed that computational automata could imitate cognition, if not thought itself, owing to their analogical similarity to the operation of the brain[893].

RAND's Fred Roberts had been influenced by automata theory, and this had a direct bearing on his work on forecasting energy demand. Roberts had graduated from Stanford where he had completed a doctorate using graph theory to explain 'indifference' as a variable in

[889] Schaffer, S. (1999) 'Enlightened Automata' in The Sciences of Enlightened Europe. Ed. Clark, W., Golinski, J., Schaffer. Chicago University Press.

[890] Daintith, J., Wright, E. (2008) 'Automata' in Oxford Dictionary of Computing. Sixth Ed. OUP.

[891] Truitt, E. (2015) Medieval Robots: Mechanism, Magic, Nature, and Art. University of Pennsylvania Press.

[892] Agar, J. (2003) The Government Machine: a Revolutionary History of the Computer. MIT Press.

[893] Schaffer, S. (2001) 'O.K. Computer' in Ansichten der Wissenschaftsgeschichte, Hagner, M. ed. Frankfurt.

decision-making[894]. Roberts completed this study under the supervision of mathematician and computer scientist Dana Scott (1932--), a key figure in the development of 'finite automata', a form of computation that was simpler and more practically applicable than Turing's a-machine. Scott's innovation was that computational decision making would be confined to a finite set of options rather than an infinite number, as in Turing's approach[895]. Building on the work of neurophysiologists, finite automata imitated cognition, in so far is they could simulate thought by relaying information between a set number of states. 'States' were conditions that came about as a result of a given input ('transition'), and according to a set of pre-determined rules. The simplest finite automata would be an 'on/off' switch, which has 'memory' in so far as it 'remembers' whether or not it on or off. As a user presses a switch, the output depends on the pre-existing state of the switch. Its finite set of states means it can only be on or off, and its finite input – the switch – determines this. Extending this simple example more complex systems, finite automata could allow the creation of systems that could act as if they had memory[896].

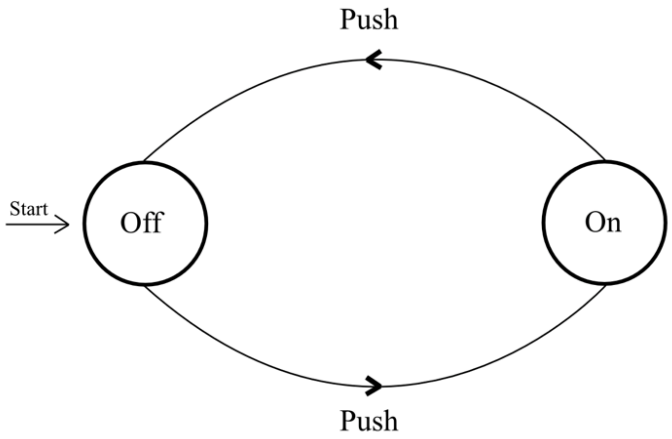

Figure. 6. 4. A Finite Automaton Consisting of an On/Off Switch
Adapted from Hopcroft, Motwani, Ullman, 1969 [2001]).

[894] Roberts, F. (1978) Graph Theory and Its Applications to Problems of Society. SIAM Philidelphia.

[895] Scott, D., Rabin, M. (1959) 'Finite Automata and their Decision Problems', IBM Journal of Research and Development, Vol. 3, Iss. 2.

[896] Hopcroft, J., Motwani, R., Ullman, J. (1969 [2001]) Introduction to Automata Theory, Languages, and Computation. Addison Wesley.

A representational relation between forms of graphical notation and cognition had long been asserted in neurology. In 1943 the neurophysiologist Warren McCulloch and mathematician Walter Pitts, in a paper titled 'A Logical Calculus Immanent in Nervous Activity' had developed a system of notation that could be used to represent the causal relations between neurons in the brain[897]. Neurons were represented as 'soma' with in or outgoing 'axon' linking to each other in a network, each weighted with a specific factor, and able to receive or transmit a signal to others according to predefined thresholds and time series. With the rise of cybernetics, it became increasingly common to equate the mind with a mechanism, a network of neurons that could be turned on or off. Sets of On/Off switches could imitate cognition, reasoning in logical steps[898]. If cognition could be represented as computational steps, as a finite automaton, it followed that such steps could imitate memory by representing a sequence of events. Admittedly the type of memory automata simulated was semantic rather than episodic or experiential: it was based on a neuronal structure and the relay of information within this, rather than the recognition of an actual experience. Despite this alteration, advocates suggested something akin to memory could be simulated via computation[899].

This semblance of cognition was what was so novel about Roberts' forecast, it implied that the system could be programmed: if the graph could be configured so that it had *odd* number of negative signed edges, or new loops introduced, the system would iteratively counteract any increase ('deviation') in energy demand. In effect, it could 'learn' from the

[897] Kline, 2015.

[898] Dupuy, J-P. (2000) The Mechanization of the Mind: On the Origins of Cognitive Science. DeBevioise, M. Trans. MIT Press

[899] Bowker, G. (2005) 'Cybernetics in the 1960s', in Memory Practices in the Sciences. MIT Press., p. 170

addition of new nodes or variations in the value of nodes or edges[900]. This ability to respond to change marked a dramatic break in the science of ERC. By analogy, if the digraph was at all representative of the physical infrastructure of energy demand, then presumably the material infrastructure of energy demand, suitably structured, could similarly carry out calculative work. The model's ability to learn, which suitably reconfigured could be assumed to occur in the energy infrastructure itself, would enable the infrastructure behave in a homeostatic way[901].

In this way, as well as systems analysis, Roberts' graph drew on the antecedent science of cybernetics. Famously, in 1942 British psychiatrist and cybernetician Ross Ashby (1903-1972) built a device consisting of linked transducers and resistors, the 'homeostat', able to always return to a stable state following an external disturbance. Like machines or organisms, homeostasis suggested critical variables like resource supply, population growth, and environmental damage could be kept within acceptable limits[902]. Roberts' model implied that, cast in homeostatic terms, energy demand could be configured so that forecasted scarcity could delayed if society engaged in stabilising behaviour[903]. Through a system of informational feedback, the model indicated that society's rate of energy use could be iteratively reduced, meaning a proportion of the total availability of energy would be saved from use. As Hungarian-American mathematician John von Neumann (1903-1957) stated that cybernetics had shifted science from 'a past emphasis on the subjects of motion, force, energy and power, to a future emphasis on the subjects of communication,

[900] Lenhard (2011) notes artificial neural networks also marked the beginning of machine learning.

[901] Pickering, A. (2011) The Cybernetic Brain. Sketches of Another Future. University of Chicago Press.

[902] Hayles 1994.

[903] Bowker, 2005, p. 164.

organization, programming and control'[904]. From the perspective of cybernetics, as fellow mathematician Norbert Wiener (1894-1964) claimed, human agency produced 'local and temporary islands of decreasing entropy in a world in which the entropy as a whole tends to increase'[905].

By the nineteen-seventies, cybernetics had diffused into a variety of disciplines, from sociology to computer science[906], so it came as no surprise that energy analysis was similarly infused with cybernetic reasoning. But in order to understand the significance of Roberts' cybernetic analysis of energy demand, it can be compared to conventional neoclassical economic analysis. In orthodox economics, as Jevons (Chapter 2) had argued, there was no means to regulate the redistribution of demand for coal. If coal were used more efficiently, this would lower its price, inducing demand from other economic actors. Recast as an automata, the infrastructure of demand could act as its own means of regulation: iteratively reducing the rate of energy consumption as other variables of demand increased in quantity of value[907]. In contrast, the system Jevons presented in *The Coal Question* (TCQ, 1865) could be thought of as a system with an even number of negative feedback loops, or a majority of positive feedbacks: which meant demand for coal was amplified.

Thinking back to Chapter 2, as energy analyst Steve Sorrell argued much later suggested, Jevons' observation that the use of 'spare heat' in blast furnaces reduced the amount of coal needed to make iron, thereby reducing iron's cost, which in turn made steam engines cheaper

[904] Burks, A., Aspray, W. (1987) The Papers of John von Neumann on Computing and Computer Theory. MIT Press.

[905] Wiener, N. (1955) The Human Use of Human Beings: Cybernetics and Society. MIT Press., p. 36.

[906] Kline, 2015.

[907] As Ashby wrote 'a system with feedback may be both wholly automatic and yet actively and complexly goal-seeking' (Bowker, 2005: 171).

to build, could be termed in the language of systems analysis as a 'positive feedback cycle'[908]. In Jevons's account population, per-capita energy use, technology, *inter alia*, could all be considered as positive feedbacks, which meant that demand for coal was grew exponentially as his book's frontispiece famously illustrated (Chapter 2). The technologies of 'perfect control' that Jevons' had outlined, particularly the 'steam engine governor' were, as later historian of technology Otto Mayr demonstrated, control mechanisms within this system; a means of 'feedback' information from the engine's operator to the system in a way which could be either positive or negative, depending on the objective of the operator[909]. In contrast to Jevons' model, the energy infrastructure depicted in Roberts' model could be configured so that there was a majority of negative feedback loops, which would stabilize the demand for energy, thereby decelerating or levelling off increases in demand. The two models, distant in time and method presented two very different scenarios for the human use of energy. Seemingly inexorable and disastrous increases in energy demand could, according to Roberts' new forecasting technique, be shown to be avoidable. The future could be stabilised if certain actions were taken in the present[910].

CALIFORNIA'S ELECTRICITY QUANDARY

What where the implications of the systematisation of energy demand for the actual practices of political economy? In order to understand its effects, we turn to the state of California. At a cocktail party in 1971, lawyer, Emilio Varanini, an assistant at the California state legislature, met some of RAND's energy researchers. Varanini had been tasked with addressing California's growing demand for energy. The meeting result in an agreement that

[908] TCQ: 155, and Sorrel, S. (2009) 'Jevons Paradox Revisited: The evidence for backfire from improved energy efficiency', Energy Policy, Vol. 37

[909] Mayr, O. (1971) 'Maxwell and the Origins of Cybernetics', Isis, Vol. 62, No. 4, pp. 424-444.

[910] Mitchell, T. (2014) 'Economentality: How the Future Entered Government', Critical Inquiry, Vol. 40, No. 4.

RAND would model the state's energy use using the latest computational technology[911]. The computational significance of Roberts' earlier work had been belied by the simplicity of his graphs, which analysed only a few components of a particular branch of the energy system. A more realistic and granular model of U.S. energy demand would require the simulation of a vast array of nodes and edges, which would be 'functional' in so far as they were defined as coefficients of other nodes or edges. In his first publication on the topic Roberts admitted this was beyond scope of human mathematics, but that it could 'probably be handled by existing computer techniques'[912]. Accordingly, the principles of Roberts' model would provide the basis for a more ambitious simulation carried out by RAND. Toward the end of the year the California State Resources Agency (CSRA) provided a contribution to RAND's existing RAAN program and the study began[913]. This was not the first time the state of California had worked with the think-tank. Two years earlier RAND had helped formulate social policy, an issue of national security during the 1965 Watt's riots in Los Angeles[914].

California was beset with developmental problems at this time, but the problem of energy was particularly acute. By 1971 the major electrical companies, PG&E, Southern California Edison, and San Diego Gas and Electric had begun to warn the Californian legislature that shortages, brownouts and blackouts were imminent[915]. Part of the reason was that geology and geography worked against the state. Aside from hydropower, there had been a lack of readily available petroleum resources until the twentieth century, when substantial fields

[911] Wellock, 1998, p. 138.

[912] Roberts, 1971, p. 407.

[913] Mooz, W., Mow, C. (1972) The Growing Demand for Electrical Energy in California, RAND Corporation, R-IOB4-NSF/CSRA.

[914] Light, J. (2002) 'Urban Planning and Defense Planning, Past and Future', Journal of the American Planning Association, Vol. 70, Iss. 4, pp. 399-410.

[915] Lifset, R. (2014) 'Environmentalism and the Electrical Energy Crisis' Lifset, R. ed., American Energy Policy in the 1970s. University of Oklahoma.

were found near Los Angeles and San Joaquin. In addition, seismic activity was fairly common, limiting possible sites for power plant development. The state was also prone to drought, so the use of water as a plant coolant was often contentious[916]. The production of electrical power had reached a point of stasis, which meant increased efficiencies of production were not possible. Greater numbers of larger plants would be required if electricity were to be produced at a low cost. Added to which, the state was also the centre of the countercultural and environmental movements, some of whom actively opposed nuclear power, as discussed in Chapters 5 and 9. But at core the problem was economic. As of 1970, California's population growth, prosperity, and rising per capita demand for electricity would require the doubling of electrical capacity every eight-and-half years. Compound growth at this rate would be entirely unsustainable. As RAND's first report noted: 'This rate of growth cannot continue, for it would theoretically outstrip the ability of society to finance, build, and even find room for the generating facilities – to say nothing of supplying them with fuel and their impact on the environment'[917].

Led by Ronald Doctor, the California energy demand project was based on the premise that the State's current 'rate of growth cannot continue, for it would theoretically outstrip the ability of society to finance, build, and even find room for the generating facilities – to say nothing of supplying them with fuel and of their impact on the environment'[918]. To address this quandary Doctor's team would create a computer-based version of Roberts' model. To a large degree the simulation that was produced could be considered as a more sophisticated version of the graphical model that Roberts had first proposed. The model would take a numerical form, which could be told to carry out a time-stepping procedure, in order to

[916] Williams, J. (1998) Energy and the Making of Modern California. University of Akron Press.

[917] Mooz & Mow, 1972.

[918] Mooz & Mow, 1972, p. v.

obtain a representation of the system's behaviour over time. In this sense, the logics of Roberts' model were translated into an algorithmic code, a finite sequence of instructions for processing quantitative data[919]. The idea, common to Cold War rationality, was that if California's demand for energy could be rendered in an algorithmic form, quantitative variables within that algorithm could be recalibrated in order to give an optimal solution to the problem of energy demand[920] by reducing energy consumption whilst maintaining economic growth.

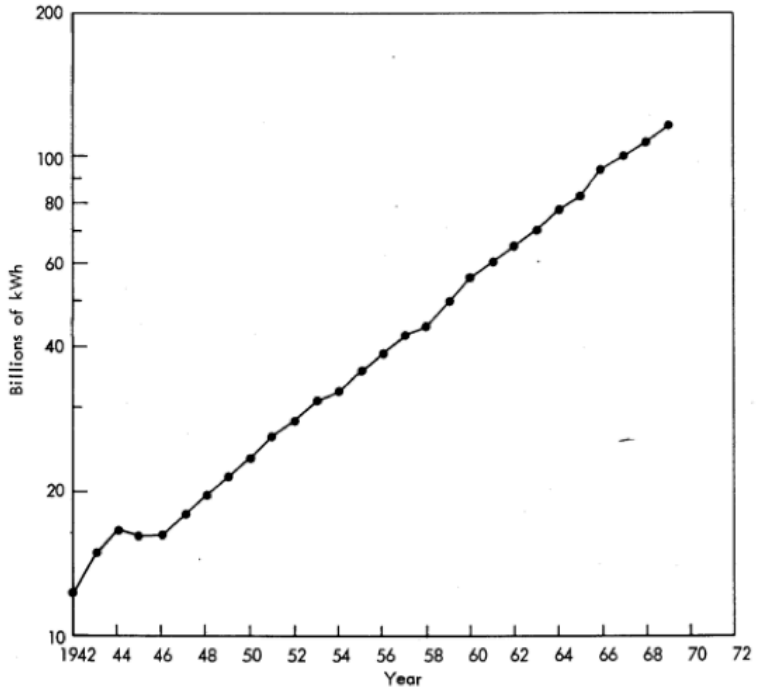

Fig. 11—Historical California electrical energy consumption

Figure. 6.5. Historical Increase in Californian Electrical Energy Consumption
RAND R-1084-NSF/CSRA.

RAND researchers William Mooz and C.C. Mow gathered a range of empirical data that described aspects of California's economy, meteorological conditions, population density, and other variables of demand. RAND employee Sharon Anderson then programmed a

[919] Gramelsberger, G. (2011a) 'What do numerical (climate) models really represent?', Studies in History and Philosophy of Science, Vol. 42, Iss. 2, pp. 296-302.

[920] Erickson, P et al. 2013.

dynamic model of electrical energy demand into a workable computer program. The model was written in a programming language 'FORTRAN IV', first developed as part of the Manhattan Project[921], which was run on RAND's IBM 360/65 computer, which had been installed in 1968 and promised calculation at three times the rate of the previous '7044' computer[922]. The model was structured as series of connected sub-models. Residential demand for electricity, for example, was calculated as a function of demography, electrical appliance ownership ('saturation'), climate, housing type, electricity cost, and any promotional activity engaged in by utility companies. The aim was to create a model of sufficient representativeness and computational complexity that it could be used for realistically testing the outcome of different policy scenarios for the future demand for energy[923].

The program offered a far more detailed representation of the determinants of energy demand than Roberts' graphical abstraction. California was divided into socio-economic sectors: the residential, industrial, commercial, and agricultural; and each sector was subdivided according to its individual factors of energy demand, down to the level of individual energy using appliance. Lighting and heating, for example, or air conditioning or television, were all represented by data on common appliance's energy use, rate of use, and estimates of appliance ownership. For industry, commerce, and agriculture, data on the energy intensity of specific economic activities were inputted, measured in kWh per $ earned. Each sector and appliance was then further categorized according to the electrical

[921] Galison (1992) describes the martial origins of FORTRAN, before it became the common language of programming in high energy physics – see Ch. 6.

[922] Anderson, S. (1973) A Methodology for Projecting the Electrical Energy Demand in California: A Users Guide to the Model. RAND Corporation, R-1107-NSF/CSRA.; DeWard Brown, G. (1968) The 360. The RAND Corporation. P-3892.

[923] Doctor, R. (1973) Energy Demand in the Future - Reducing the Growth rate, RAND Corporation, P-4992.

utility companies from whom they derived power, as each company served a different region of the state[924]. This array of quantitative data could be used to calculate dependent variables. For example: as electricity rose in cost, the model simulated domestic consumers' substitution of gas for electricity; but where substitutes were unavailable, or for certain types of inflexible industry, demand would remain inelastic[925].

As Sharon Anderson wrote in the program's supporting documentation, the model not only served as a forecasting device but also 'as an analytical device to systematically and consistently analyse alternative assumptions about the future and their effects on electrical energy demand', alternative futures could be discerned[926]. Each run of the model required just 64 kilobytes of processing power and could be carried out in thirty-two central processing unit (CPU)[927] seconds, meaning running the program through the hardware as relatively quickly and cheaply. In earlier decades, the cost of computing had placed some limits on the optimization mathematics that could be carried out. As a result, the complexity of models had been restricted to the confines of computational power. But by the nineteen-seventies, owing to increased processing power and lower hardware costs, such limits had lifted[928]. This would have implications for computational econometrics, which will be discussed in Chapter 8. But here, increased computational power meant the problems of energy demand occurred just as myriad computer-based scenarios could be run at low cost and with unprecedented ease. As Fred Roberts had imagined 'the introduction of new

[924] Anderson (1971) [RAND R-1107-NSF/CSRA] contains an overview of the model's function, but full sectoral information can be found in R-991-NSF/CSRA (manufacturing) R-995-NSF/CSRA (residential) and R-1106-NSF/CSRA (commercial).

[925] Mooz & Mow, 1972, p. 39.

[926] Anderson, 1973, p. 1.

[927] Central Processing Unit cycles per second. i.e. the number of times a computer can compute a set of instructions in a given second.

[928] Erickson 'The Bounded Rationality of Cold War Operations Research', in Erickson, P et al. 2013.

deviation-countering sub processes' and the manipulation of nodes ('parameters') could be carried out without the constraints and costs implied by altering the actual system of energy demand[929]. Now every energy-using appliance in every home, factory, or workplace could be manipulated, and each determinant of demand could become a deviation countering sub process, helping to stabilize rather than increase demand, In so far as a more efficient appliance replacing an inefficient appliance became a negative feedback rather than a positive one[930].

As a result of the granularity of RAND's model, they were able to develop demand forecasts that demonstrated how electricity demand could fall far below the levels anticipated by extrapolative forecasts. Their model showed how residential energy use would 'taper off' owing to household's being saturated with appliances. A similar taper could be seen to occur in industry as the 'earlier substitution of electrical energy for manpower approaches ceilings'[931]. The simulation forecast that RAND's more accurate forecast could lead to a situation in which 196 billion kilowatt-hours less electricity would be used by the year 2000, as compared to the 'conventional utility prediction'. Utility companies' forecasts were 23 per cent higher than RAND's 'base' forecast. But perhaps the most significant outcome of the exercise was that the simulation showed how dramatic decreases in energy use could occur at no loss to forecasted rates of economic growth. Unlike earlier extrapolative forecasts of electricity demand, RAND's model demonstrated that there need not be a direct correlation between electricity demand and economic development. In effect, for the first time, RAND showed that economic growth could be decoupled from energy use. Just as geologists had

[929] Roberts, 1971.

[930] A full explanation as to how appliances became understood as a means of energy supply is explained in Chapter 7.

[931] Mooz & Mow, 1972, p. 24.

procedures for estimating potential reserves of coal and oil, now advocates of energy conservation could estimate the potential scale at which resources would *not* be needed. In effect simulation "created" resources through their forecast abnegation[932].

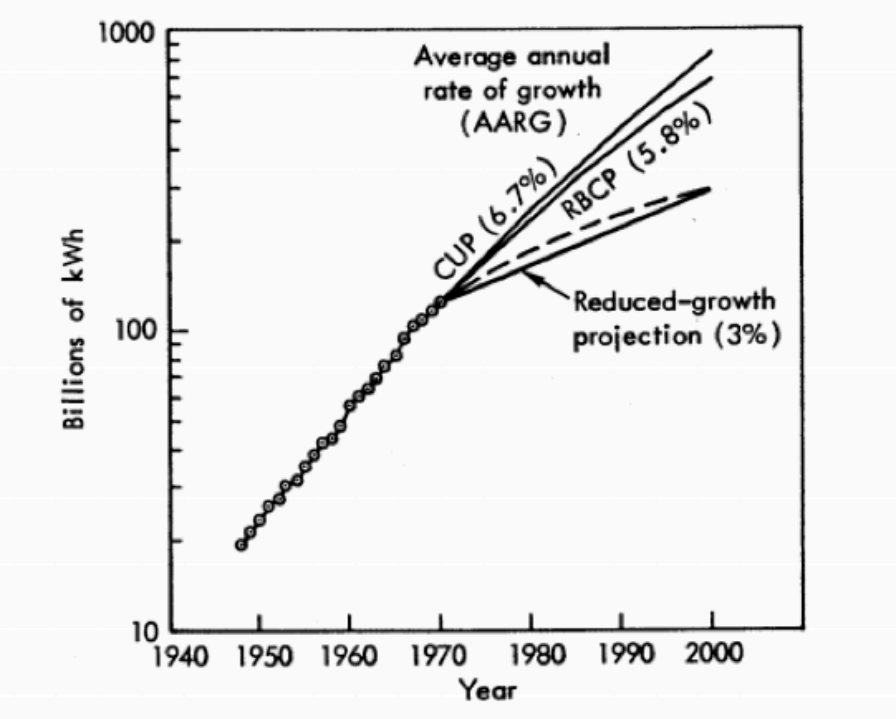

Figure. 6.6. Slowing the Growth Rate in California's Electricity Demand.
'CUP': Conventional Utility Prediction (6.7%), 'RBCP': RAND Base Case Projection (5.8%), and the 'Reduced-growth projection (3%)'
RAND Corporation, R-1116-NSF/CSA: p. 7.

Employing Anderson's model to address California's energy quandary, Doctor and his colleagues devised a set of scenarios which illustrated the simulated effect of policies designed to slow the growth rate of California's electricity demand below a 'base' scenario in which no intervention took place. Building on Roberts' idea of identifying 'manipulable nodes' RAND researchers recommended substituting gas for electricity where possible, using solar energy where possible, insulating homes, improving the efficiency of air-conditioning efficiency and lighting, and constructing 'low energy' buildings. They

[932] Meier, A. K., J. Wright, et al. (1983). Supplying Energy Through Greater Efficiency. Berkeley, CA, University of California Press.

calculated that such interventions could reduce the annual growth rate of electricity demand from five to a three per cent. This would eradicate the need for over one hundred power plants by 2000. If, as other RAND research had argued, California's geothermal energy was also successfully exploited, there would be no need for new power plants from 1985 onward[933]. With suitable interventions in place, it was claimed energy demand could be reduced by as much as fifty per cent, as compared to earlier estimates of electricity demand produced by extrapolative forecasting.

In terms of policy, Doctor advocated that this dramatic saving could be achieved relatively painlessly via 'voluntary cooperation', taxation, financial incentives, and the prohibition of certain practices'. Suitably reconfigured, just as in the eighteenth and nineteenth-centuries, when self-regulating mechanisms such as the steam-engine governor provided a point of reference for liberal theories of self-regulating markets, the RAND model of energy demand implied that that government intervention in energy markets should be limited to fairly prosaic policies for optimising energy-use such as taxation and subsidisation, designed in a way that did not interfere with the system's own allocative capabilities[934].

Doctor also proposed that the Californian state legislature should create a new institution to coordinate 'all energy conservation policies'[935]. RAND's research into the determinants of energy demand had appropriated the nineteenth-century preservationists' term 'conservation', which had previously meant the restriction or scientific management of a resource's use. It was now used to describe a situation in which systems analysis would be

[933] Doctor et al, 1972, p. vii

[934] Mayr. O. (1971) 'Adam Smith and the Concept of the Feedback System: Economic Thought and Technology in 18th Century Britain', Technology and Culture, Vol. 12, No. 1., pp. 1-22.

[935] Doctor et al, 1972, p. xiv.

applied to slowing the growth rate of energy demand.

In this Chapter's introduction it was shown that certain RAND employees were also members of California's leading conservationist organisation, the Sierra Club. Staff migrated between the two organisations, and RAND had been employed by the Club. Clearly environmentalism and policy science were not mutually exclusive activities. But the re-orientation of individual's agenda was stark. Unsurprisingly RAND's work was an environmentalist's dream. One Californian assemblyman called it 'political dynamite' in so far as it undermined the case for new nuclear power entirely[936]. Only seven years earlier, one of the Californian energy demand project's lead authors 'C.C.' Mow had been working on defence applications for systems analysis and a hypothetical bombing system cryptically titled 'B-X'[937]. In 1973, the newly appointed head of the RAND Energy Policy Program, Fred Hoffman had moved from the Defence Departments' Systems Analysis group. But perhaps most clearly, there was an inescapable irony that the simulative method, hardware, and code, used to model energy demand, and to demonstrate the possibility of energy conservation, had been derived from technologies required in the development of the nuclear bomb[938]. Cold War strategists were warning of Malthusian and environmental limits, and formulating policies which would later be attributed to and enthusiastically adopted by countercultural environmentalists (Chapter 9). But as this history shows, both a forecasting method and a series of policies, which would become commonplace ideas within the science of ERC, were developed from within the systems analytical approach and computational practices of this quintessential cold war think-tank.

[936] Wellock, 1998, p. 140.

[937] Mooz, W. (1965) The B-X: a hypothetical bomber cost study, RAND Corporation, RM-4635-PR; Mow, C. (1964) Dynamic Response of Lined and Unlined Underground Openings, RAND Corporation, RM-3962-PR.

[938] Galison, P. (1992) 'Fortran, Physics, and Human Nature', in The Invention of Physical Science, Vol. 139, Boston Studies in the Philosophy of Science. pp. 225-260.

INFORMATIONAL FIX

There was another register on which it was important to understand RAND's proposed method for conserving energy resources, which demonstrates how ERC was part of wider move away from assuming 'industrial' solutions could salve societal problems. To demonstrate the scale of California's energy demand problem, in the late 1960s, California State University professor of engineering Charles Washburn (1937-2009) had framed California's energy problem in geographic terms. He calculated that if the FPC's forecasts of future energy demand were correct, by the year 2000 California would need eighty new nuclear power plants, which would have to be sited along the Californian coast to use seawater as coolant. So pressing was the problem meant that by 2020 Washburn estimated there would be a plant every two miles of coast[939]. Thanks to their environmentalist sympathies, Doctor and his colleagues picked up on Washburn's work[940]. It was clear that long before the OAPEC embargo, California's energy crisis was a technological and spatial one, rather than one of restricted flows of oil. Before returning to the history of energy demand simulation, a brief digression into another, related, RAND project will help illustrate why the promise of energy demand reduction was so appealing to California's policy makers.

Under the RANN program, RAND researcher, engineer Richard Salter would propose an unusual solution to California's energy problem that reinforced the spatiality of the problem of energy demand. In doing so, Salter's proposal gives some indication of how energy demand reduction provided informational solution to a physical problem. Salter's idea was

[939] Wellock, 1998, p. 82.

[940] Doctor, 1972, p. 3-4.

that power plants could be constructed on a series of buoyant platforms constructed off the West Coast. The unfortunately named Floating Offshore Power Platform (FLOPP) was intended to generate sufficient quantities of electricity offshore to meet demand, conveniently using seawater as coolant and relaying electricity to shore via underwater cables. Salter's exploratory study described how FLOPP would be shaped like a 'pop bottle', with all but the neck submerged, and each fraction of the vessel containing a different stage of the electricity generation process; coolant water would enter the base, and steam and emissions would leave the funnel at the top. It was hoped offshore power generation would alleviate land-use conflicts and was seen as preferable to placing plant underground, as other RAND engineers had claimed[941], with the additional benefit that plants at sea were safe from seismic activity[942]. Though Salter's plan was never realised, it was not the only such idea. That year two utility companies had formed a joint venture 'Offshore Power Systems', with the pant to create floating nuclear reactors, though the project was abandoned by the end of the decade[943]. Given such exploratory engineering, energy demand reduction perhaps offered a more credible and less risky solution to the problem of energy demand.

Borrowing Washburn's earlier spatial illustration, Doctor and colleagues quantified energy demand reductions in terms of the power plants that would *not* need to be built. The RAND simulation had shown that with suitable demand-reducing policies in place the construction of one-hundred and thirty 1,200 megawatt power plants could be averted by the year 2000[944].

[941] Watson et al, 1972.

[942] Salter, R. (1972) A Floating Power Platform Concept for the West Coast, RAND Corporation, P-4939.

[943] Wellock, T. (2013) Waves of Uncertainty: the demise of the floating reactor concept', U.S. NRC, blog, available at: http://public-blog.nrc-gateway.gov/2013/09/26/waves-of-uncertainty-the-demise-of-the-floating-reactor-concept-part-ii/

[944] Doctor, 1972

Energy conservation was presented as an informational solution to a material and spatial problem, with the advantage that information has no significant spatial requirements itself[945]. In the immediate post-war period, when organised labour threatened to constrain the supply of manufactured goods, industrial engineers had responded by automating significant parts of the production process[946]. Similarly, when the supply of energy was constrained, RAND's work suggested energy allocation could largely automated, and the supply of available energy prolonged with the resultant rate of use.

The automated reduction of the energy demand growth rate, according to RAND simply required the slight reconfiguration of existing energy infrastructure, and via taxation, subsidies, and the promotion of efficient technologies. Rather than their being some kind of centrally administered increase in energy supply, controlled energy allocation would be carried in a decentralised, small-scale way, with each node or parameter playing a role. With an appreciation of the systemic reasoning which underlay RAND's systems analysis, the proposed approach to energy demand reduction might be considered part of a wider cultural shift, encouraged by the promise that society was becoming increasingly 'post-industrial' or even 'information-based'[947]. The proposed conservation of energy can be, in geographer David Harvey's phrase, be considered a kind of informational 'spatial fix', a means of averting the physical expansion of energy-based economic growth, by suggesting that informational feedbacks could act as a supplement to physical plant[948]. Information, of

[945] Clarke, B. (2002) 'From Thermodynamics to Virtuality', From Energy to Information: Representation in Science and Technology, Art, and Literature. Ed. Clarke and Henderson. Stanford: Stanford University Press, 2002: 17-3., p. 29-31.

[946] Noble, D. (1984) Forces of Production: A Social History of Industrial Automation. New York Knopf. 'Beyond the very real constraints of energy and matter exists a realm in which human thoughts and actions remain decisive' p. xiii.

[947] Harvey, D. (1989) The Condition of Postmodernity: An Inquiry into the Origins of Cultural Change. Cambridge Massachusetts Press., p. 49.

[948] Harvey, D. (1982) The Limits to Capital. Oxford University Press.

course, in contrast to plant, has no proper scale, or intrinsic size[949].

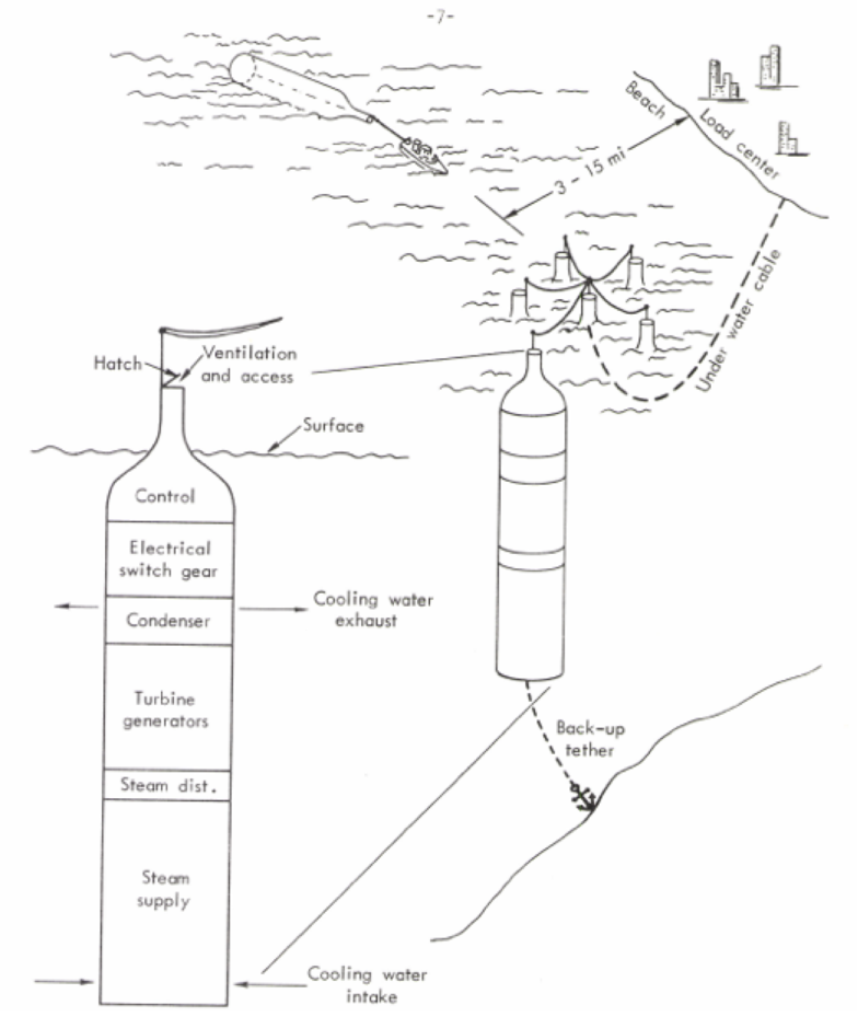

Figure 6.7. FLOPP, A Concept for Offshoring Electricity Generation
Salter 1972, RAND P-4939.

CONCLUSION

This Chapter has sought to demonstrate how the contemporary ERC was a science that emerged from the practices of systems analysis, and corollary fields of optimization, simulation and computerization. Systemic analysis of energy demand was first carried out at the archetypal cold war research organization, the RAND Corporation. In his account of

[949] Clarke, B. (2002) 'From Thermodynamics to Virtuality', From Energy to Information: Representation in Science and Technology, Art, and Literature. Ed. Clarke and Henderson. Stanford: Stanford University Press, 2002: 17-3.

RAND's work on California's energy demand, historian Thomas Wellock wrote that the organization's 'bland pronouncements were revolutionary stuff; they were the first hints that there were limits to energy supplies and that it might be necessary to re-order social and economic priorities'[950]. His claim is correct in so far their work did demonstrate the constraints to energy demand, and that they proposed that these might be overcome by reconfiguring the determinants of this demand. But Wellock's account does not explain *how* RAND achieved evidence of energy demand reduction. Demand reduction, it is argued here, could only be demonstrated as a result of cybernetic reasoning, and the notion of feedback. This allowed researchers to forecast multiple demand scenarios, accommodating increasing numbers of feedbacks. By contrasting RAND's forecast with the kind produced utility companies, a novel claim could be made: economic growth, normally correlated with increased energy demand, could be demonstrably decoupled from increasing energy use, at least within the confines of the simulation.

Historian Paul Edwards has written that in the post-war years the logics of computation offered American engineers, strategists, and policymakers a metaphorical means of structuring their understanding of the world. In the Cold War period, everything from the brain to the state was recast as though it were *like* a computer[951]. Part of this assimilation involved recasting reality as if it were a 'closed, self-referential system', in which real-world variables could be as easily manipulated as values in a computer program[952]. Similarly, economic historian Philip Mirowski has shown how in the preceding decades American economists, often affiliated to RAND, developed a belief that an idealised market was a computational apparatus, that in assigning prices to goods and acted as a means of calculating

[950] Wellock, 1998, p. 139.

[951] Edwards, 1994, p. 161.

[952] Ibid, p. 341.

optimal modes of allocation[953]. It should come as little surprise, given the significance of energy as a vital strategic resource, that the dynamics of energy demand would be recast in computational terms, as a system for relaying energy and information.

Nor should application of cybernetic principles to ERC come as a surprise. Historian Andrew Pickering has theorised that cybernetics provided a 'universal metaphysics', meaning human and non-human entities were blurred by principles of mutual causation[954]. As a result, the computational principles of cybernetics could be found in almost all disciplines other than physics at this time[955]. Just as elsewhere in cybernetic science, a gunner, gun, and enemy pilot could form an 'abstract causal loop'[956], so too could the infrastructure of energy use. Armed with such a worldview, RAND's researchers demonstrated how human energy users could enter into a system of feedback, in which their fluctuating demand could be thought of as an informational signal that affected other nodes in a circular system[957]. In some sense, RAND's approach marked the realisation of the Herbert Jevons and Harold Hartley's vision of control engineered automation of fuel use (Chapter 3), but instead of being applied to specific industries, the principle of feedback control was extended to the entire 'system' of energy use.

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[953] Mirowski, 2002.

[954] Pickering, A. (1995) 'Cyborg History and the World War II Regime', Perspectives on Science, Vol. 3, No. 1, pp. 1-48.

[955] Dupuy, 2000.

[956] Galison, 1994.

[957] Bateson, 1971: 443, In the same year as Roberts' study, anthropologist and cybernetician Gregory Bateson (1904-1980), in an unrelated study of the practices of Alcoholics Anonymous, stated a general principle of cybernetics that reiterated the theoretical basis of Robert's model:

'We might say that any on-going ensemble of events and objects which has the appropriate complexity of causal circuits and the appropriate energy relations will surely show mental characteristics. It will compare, that is, be responsive to difference […] It will "process information" and will inevitably be self-corrective either toward homeostatic optima or toward the maximization of certain variables'.

Bateson, G. (1971) 'The Cybernetics of "Self": a theory of alcoholism', Psychiatry, Vol. 34, Iss., 1. p. 1-18.

By analogy RAND claimed the energy infrastructure could be represented by lines of code, and could be manipulated like code. Amplification of energy demand could be automatically and iteratively reduced by adding negative feedbacks, and by creating an infrastructure that could act in a purposive way. As a result of this reconceptualization of the dynamics of demand, the government of energy was no longer considered as a problem of increasing supply, but on reconfiguring society in such a way that its infrastructure would use less energy at no cost to economic growth (decoupling). In RAND's simulation it could be demonstrated, within the confines of the program at least, that human action, aggregated at a societal level, could slow growth in energy demand, which adopting the language of environmentalists could be considered as 'conserving' energy otherwise consumed. As with Ashby's homeostat, the RAND model assumed a simple abstract model could stand in for the mess, non-linearity, and complexity of reality. It reinforced an idea that humans acted as mechanisms for maintaining environmental homeostasis, without inquiring whether this was actually the case beyond the confines of the model.

CHAPTER 7. REDEFINING EFFICIENCY: THE ROLE OF THE AMERICAN PHYSICS PROFESSION

In the 1970s cuts to federally funded science occurred alongside an oversupply of well-qualified physicists, leading to a disciplinary employment crisis. As discussed in Chapter 5, the prerogatives of American science were shifting, research was increasingly 'applied' rather than 'basic'. In this environment, a number of physicists came to question the purpose of their work. Faced with war in South East Asia, the energy crises, and growing campus radicalism, some turned against basic research, such as the somewhat esoteric work of particle physics. Nuclear physics too, was entering a period of disestablishment. Détente meant warheads were less in demand and there was growing worries about deploying nuclear power at the scale imagined in the 1950s. In this context, a number of laboratories, universities and individual physicists turned away from the 'big science' endeavours of post-war physics and toward a new, small-scale applied science of energy research conservation (ERC). In doing so, physicists would apply the theory, methods, and computational practices used in particle and nuclear physics towards the goal of reducing national energy use. A significant milestone in this transformation was the 1974 American Physical Association ('APS') Summer School, during which participants formulated authoritative estimates of the reductions that could be achieved in the rate of America's energy use according to physical principles. Attendees, as we shall see, came to agree that the engineer's notion of efficiency could be redefined according to a later nineteenth-century definition of thermodynamics. For the first time ERC was cast in strictly thermodynamic terms. In doing so, energy-using appliances were reconceived of as sources of energy *supply* as well as demand. In this Chapter, recounting this development, it will be argued that physicists' growing interest in energy conservation was driven, in part, by their discipline's adaptation to changes in the wider environment. Such adaptations cannot be easily categorised. For some energy

conservation offered environmental salvation, for others, a means of disarming the nuclear state, whilst others still considered energy conservation a defensive weapon to disarm the Middle Eastern 'oil weapon'.

FORMAN THESIS REVISITED

In 1967 the thirty-year-old physicist turned historian of science Paul Forman (1937--) had just finished his doctorate at the University of California. He had argued the development of quantum physics in the Weimar Germany had partly depended upon 'environmental' factors. By which Forman meant physicist's rejection of deterministic explanations of the kind associated with classical physics, was a reflection of a more general hostility to rationalist intellectual culture. A move, he argued, prompted by Germany's wartime defeat and an ensuing crisis of confidence amongst the intelligentsia. Forman's thesis, now well-recognised in the history of science, emerged from a research group 'Sources for History of Quantum Physics', established in 1961 with the support of the National Science Foundation ('NSF'). Led by Thomas Kuhn (1922-1996) the project had attempted to reconstruct the history of the quantum revolution using a vast archive of interviews, letters, documents, and the personal papers of Heisenberg, Bohr, Born and Schrodinger, amongst others. As Forman's fellow doctoral student John Heilbron (1934--) noted, the project was an unprecedented exercise in historiography[958], the discipline's first attempt at 'big history'[959]. The project had gained significant credence from Kuhn's recently published and widely read *Structure of Scientific Revolutions* (1962) in which he had argued that the development of scientific knowledge was

[958] Heilbron, J. (1968) 'Quantum Historiography and the Archive for History of Quantum Physics' History of Science, Vol. 7, Iss, 1., pp. 90-111.

[959] Dennis, M. (1997) 'Historiography of Science: An American Perspective', Science in the Twentieth Century. Hartwood Academic Papers. Krige, J. Pestre, D. eds.

governed by scientific paradigms (normal science) that were interrupted by revolutionary paradigmatic shifts.[960]

Such a shift appeared to be ongoing. In 1968, biographer of the 'counterculture', Berkley historian Theodore Roszak (1933-2011) had written of a growing belief in the 'myth of objective consciousness' amongst students across America[961]. Such thinking had seeped into Forman's work. His thesis had begun by declaring 'The fiction of an autonomous development in the world of scientific ideas has been maintained by systematically mistaking description for explanation, and by systematically refusing to look for or at contrary evidence'[962]. In response, he offered a general method for providing a social explanation for the development of scientific knowledge. As outlined in a later publication, he argued the historian 'must insist upon a causal analysis, showing the circumstances under which, and the interactions through which, scientific men are swept up by intellectual currents'. The causal relation between science and society could be easily discerned, as scientists would 'adapt the content of their science to the values of their intellectual environment'[963]. Only if their discipline was held in very high esteem by the public would a significant degree of intellectual autonomy be assured[964]. The case of Weimar Germany was instructive, as it demonstrated how advances in quantum physics had emerged during a period of hostility to the very notion of scientific progress. The antiscientific climate of Weimar Germany had

[960] Fuller, S. (2001) Thomas Kuhn: A Philosophical History of Our Times. Chicago University Press.

[961] Roszak, T. (1968: 211) The Making of a Counter Culture: reflections on the technocratic society and its youthful opposition. Doubleday, New York.

[962] Forman, 1967 cited in Cassidy, D. (2011: 270) 'Paul Forman and the Environment and Practice of Quantum History', in Carson, C., Kojevnikov, A., Trischler, H., eds. Weimar Culture and Quantum Mechanics: Selected Papers by Paul Forman and Contemporary Perspectives on the Forman Thesis. Imperial College Press.

[963] Forman, P. (1971) 'Weimar Culture, Causality, and Quantum Theory, 1918-1927: adaptation by German Physicists and Mathematicians to a Hostile Intellectual Environment', Historical Studies in the Physical Sciences, Vol. 3, pp. 1-115.

[964] Ibid.

prompted a move away from conventional notions of 'causality' which had resulted in significant advancements in physical theory.

Forman believed his 'environmental' epistemology of science also held lessons for the 1970s. Noting the intelligentsia of the late 1960s shared with Weimar Germany an 'antagonism toward analytical rationality generally and toward the exact sciences and their technical applications particularly'. Forman noted a similar reaction against both the institution and forms of knowledge produced by post-war science in his lifetime:

> *'As sentiments of resentment and antagonism toward the scientific enterprise – coupled with a revival of existentialist* Lebensphilosophie - *have become prominent in the last few years, so have the expressions of and concessions to these same sentiments within the sciences themselves. We are indeed witnessing in America today a widespread and far-reaching accommodation of the scientific ideology to a hostile intellectual milieu.*[965] *'*

What was this hostile milieu? We had some indications in Chapters 5 and 6. Science was undergoing a period of financial and political disenfranchisement, and the entire idea that 'basic' science was worth pursuing had come under attack. In the following chapter, this situation is used to re-address Forman's argument that during periods of hostility, science can transform in order to be accommodated in a oppositional environment. Forman's thesis provides a useful model for developing a social explanation for the shift many physicists' research took in the nineteen-seventies, particularly the move from research in nuclear, high-energy, and particle physics, toward the applied science of ERC. A shift that might be described, as it was in Chapter 5, from a culture of science to one of technology.

In fact, in a paper thirty-six years later, Forman also described the historical significance of the shift from 'science', associated with the transcendent ideals of 'modernity', to

[965] Forman, 1971, p. 7.

'technology' associated with the more uncertain and ambiguous principles of 'postmodernity' around the year 1980. In making his argument, Forman wrote that 'the last place to look for transformative effects of this epochal shift in cultural values is the most characteristically modernist of our scientific enterprises, the high-energy, particle-physics accelerator laboratories'[966]. This Chapter does not disagree with Forman's wider argument, but it is claimed that such laboratories were in fact one of first places that this epochal shift could be discerned in the mid nineteen-seventies, as they made significant contributions to the science of energy resource conservation, and the work of these laboratories can be seen as an early indicator and component of technological postmodernity.

THE POST-WAR ROLE OF PHYSICS

Historian of physics Daniel Kevles memorably described the 'Los Alamos generation', those physicists who developed the hydrogen bomb at the end of the War, as 'a kind of secular establishment'[967]. In creating the fissile plutonium and uranium that enabled the decisive act of dropping 'Little Boy' and 'Fat Man' on the Japanese cities of Hiroshima and Nagasaki, physicists became the centre of American military power. Nuclear bombs were unparalleled experiment in the release of energy. Each exploding with a force equivalent to over ten thousand tonnes of conventional explosive, or eighty-eight terra-joules, equivalent to the sudden combustion of 670 thousand gallons of oil[968]. Nuclear bombs were an energy weapon, and on this basis Kevles argued physicists were granted the power to influence policy and to obtain Federal resources 'largely on faith'[969]. But Forman disagreed, arguing that physicists

[966] Forman, P. (2007) 'The primacy of science in modernity, of technology in postmodernity, and of ideology in the history of technology', History and Technology, Vol. 21, Iss. 1, pp. 1-152.

[967] Kevles, D. (1978 [1995: ix]) The Physicists: The History of a Scientific Community in Modern America. Harvard University Press.

[968] My calculation. See Reed, B. (2014) The History and Science of the Manhattan Project. Undergraduate Lecture Notes in Physics. Springer Press.

[969] Kevles, 1995.

had been 'used' by the American state, and the discipline bent into an instrumental science, in which 'pure' science was debased for martial and commercial applications. Technologies derived from physics research such as radar, spectroscopes and lasers, provided the basis for an increasingly technological post-war economy[970]. But irrespective of whether physics was the state's master or servant, both Kevles and Forman could agree that physics was closely integrated into the post-war American state for much of the post-war period[971]. But by the late nineteen-sixties, this centrality had begun to provoke opposition. As a 1968 *New York Times* headline asked was there 'revolt against physics?' The article noted physics was 'no longer the dominant glamour king of the sciences, as it was in the heyday of research in nuclear and solid state physics during World War II and the succeeding decade'[972]. What had prompted this degree of disestablishment? [973]

The first problem was budgetary. After the War 'basic' research in physics received twenty times the funding it had before. In 1953, the United States spent an estimated forty-four million dollars on such research[974]. By 1965, the Subcommittee for military research and development had lopped-off almost 25 per cent of basic research funding and in 1969 Senator Mike Mansfield had pushed through his eponymous amendment which prohibited the Department of Defence from financing research not directly related to specific military objectives. To alleviate this sudden shortfall, Congress increased the National Science

[970] Forman, P. (1995) "Swords into Ploughshares": breaking new ground with radar hardware and technique in physical research after World War II', Reviews of Modern Physics, Vol. 67, No. 2, pp. 397-455. and Forman, P. (1987) "Behind Quantum Electronics: national security as basis for physical research in the United States, 1940-1960', Historical Studies in the Physical and Biological Sciences, Vol. 18, Iss. 1, pp. 149-229.

[971] Oreskes, N. (2014) 'Science in the Origins of the Cold War' in Oreskes, N., Krige, J. ed. Science and Technology in the Global Cold War. MIT Press.

[972] Anon. 'Revolt against Physics?', *New York Times*, Feb. 12, 1968: 38., cited in Kevles, 1995, p. 412.

[973] Kevles 1995, p. 410.

[974] Forman, P (1987) 'Beyond quantum electronics: national security as basis for physical research in the United States', Historical Studies in the Physical Sciences 18. pp. 149-229.

Foundation's (NSF) budget for basic science by eighty-five million dollars in 1969, and then ten million in 1970. As noted in Chapter 5, the problem was macro-economic, the economy's post-war rate of economic growth was beginning to slow, and inflation was swallowing up budgetary increases. Cuts to funding of non-essential Government services were considered politically necessary. And such cuts came with a re-evaluation of science's role in society: this new economic reality required that science should be interdisciplinary, problem-driven, and 'applied'.[975]

Physics, like science more generally, entered an employment crisis. In the 1960s the number of physics doctorates had increased by a factor of three, over one thousand five hundred a year were granted by the decade's end[976]. But owing to budget cuts, by the middle of the seventies, the level of research funding was per cent lower than it had been in 1967 whilst the total number of trained physicists was higher[977]. As a result of this shift in disciplinary funding and 'manpower', an employment crisis began. In the good years of federal funding, in the early 1960s, the employment of scientists and engineers had increased nearly 50 per cent and a fifth of the nation's physicists worked directly for government. By 1968, it has been suggested that ten-percent of all jobs in the United States, not just science and engineering, stemmed from the defence department and related industries. In the years of budgetary decline, the employment crisis became readily apparent: by 1971 a quarter of these physics related jobs disappeared. Sixteen-thousand scientists and engineers became unemployed in the following years[978].

[975] Kevles, 1995, p. 411.

[976] Kaiser, D. (2002: 136) 'Scientific Manpower, Cold War Requisitions, and the Production of American Physicists after World War II', Historical Studies in the Physical and Biological Sciences, Vol. 33, pp. 131-159.

[977] Kevles, 1995: xii.

[978] Kaiser, 2002: 151.

Widespread unemployment, historian of physics David Kaiser argues, was a sign that the discipline's 'Cold War nexus of institutions and ideas collapsed'. That is, the 'Cold War regime' of geometrically increasing budgets for basic research, which was closely, if in-directly seen as a means for securing the military power of the American state, was coming to a close[979]. But rather than disappearing entirely, Kaiser noted 'other modes of being a physicist crept back in.'[980] His example was the University of California's *Fundamental Fysiks Group,* a countercultural quantum research group at the Lawrence Berkeley Laboratory. Led by Elizabeth Rauscher and George Weissman, the group looked into theoretical quantum physics, a field abandoned in the pragmatic post-war period. Bell's theorem, non-locality and even parapsychology, subjects dropped from curricula due to their pseudo-scientific reputation were picked back up[981]. Similarly, historian Cyrus Mody notes physicists embarked on new pedagogic, entrepreneurial, and technological experiments. His example was Santa Barbara physicist Philip Wyatt who developed a commercially available inverse-scattering particle characterising device, originally a military technology, but which Wyatt used commercially to study pollution and even to test the efficacy of antibiotics[982]. Historian Patrick McCray tells the story of Gerald K. O'Neill, a Princeton physicist who responded to the energy crisis by developing a commercially lucrative project proposing that NASA should begin harvesting solar energy from space[983]. Within this shifting environment for research, this chapter will show how some physicists responded to their discipline's growing disestablishment by applying their knowledge to the problem of energy demand.

[979] Mirowski, P., Sent, M. (2002) Science Bought and Sold: Essays in the Economics of Science. University of Chicago.

[980] Kaiser, D. (2011) How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival: WW Norton.

[981] Kaiser, 2011, and Mody, C. (2013) 'Santa Barbara, Physics, and the Long 1970s', Physics Today, Vol. 66, Iss. 9, pp. 31-37.

[982] Mody, 2013.

[983] McCray, P. (2013) The Visioneers: How a Group of Elite Scientists Pursued Space Colonies, Nanotechnologies, and a Limitless Future. Princeton University Press.

THE NEEDS OF EMPIRE

The injunction to spend less on physics had come from nearly all sides of the political spectrum. An increasing number of 'countercultural' radicals opposed continued Federal expenditure on 'basic' research, as it was believed to have allowed the Department of Defence to direct research agendas, egregiously so against the backdrop of the Vietnam War. Physics was obviously culpable, as since 1960 a small number of 'elite' physicists had been secretly consulted by the Department of Defence's Institute for Defence Analysis ('IDA'). Known as the 'JASONS', an acronym of the months of the year they met. Their role had become increasingly public during the Vietnam War, and their proposals, such as the creation of an electronic barrier to cut-off the Ho-Chi-Minh trail, or deploying small-scale nuclear weapons in South East Asia, had provoked disgust from the anti-war movement[984]. At the same time, non 'elite' scientists were increasingly drafted, as the military were desperate for soldiers to feed the escalating War. Deferments were revoked for undergraduates in 1967 and graduates in 1969, drawing physicists directly into the war[985]. Scientists were well aware of this escalating situation. At the 1970 meeting of the American Association for the Advancement of Science (AAAS) in Chicago, Herbert Fox, a forty year old physicist called for a new 'Science for the People', in opposition to the current situation where 'the minds of students are bent to the needs of empire'[986].

In 1969 young radicals and older members of post-war Leftist groups had called on the AAAS to publicly oppose the Vietnam War. Their response was to suggest they did not make political statements. Incensed, at the 1970 AAAS meeting the radicals attempted to indict AAAS president, chemist Glenn Seaborg, and they chased the physicist Edward Teller,

[984] Bridger, S. (2015) Scientists at War: The Ethics of Cold War Weapons Research. Harvard University Press.
[985] Kaiser, 2011.
[986] Kevles, 1995, p. 403.

'father of the H-bomb' around the meeting room. Others handed out leaflets and held parallel sessions on radical ecology (a politicised form of ecology that involved reforming human society as well as the environment) and the ongoing problem of unemployment in science[987]. Heilbron and colleagues were at the December 1970 meeting when it was disrupted by a group of radicals, Forman did not attend owing to illness, but the influence of such events were readily apparent in his historical work[988]. But at the same time, American conservatives, particularly an ascendant 'new right' increasingly opposed continued investment in physics for the obvious reason that it represented unwarranted government expenditure in the expansion of the state[989]. This renewed form of conservatism, which would grow increasingly influential, combined militarism, conservative cultural values, and libertarian economic theory[990]. It appeared there was a backlash against 'big government technocratic solutions' from both the 'hippie left' and 'new right' alike[991].

As a result, a diverse coalition formed, who for various reasons, sought a new relation between physics and federal government. Out of this reconfiguration, an approach to ERC emerged which applied the laws of physics to the problem of growing energy demand. In Forman's language, physicists' move to energy conservation research could be considered one aspect of the changing 'accommodation of the scientific ideology to a hostile intellectual

[987] Moore, K. (2008) Disrupting Science: Social Movements, American Scientists, and the Politics of the Military. Princeton University Press. On radical ecology, Robin, L. (1998) 'Radical Ecology and Conservation Science: An Australian Perspective', Environment and History, Vol. 4, No. 2, pp. 191-208.

[988] Heilbron, J. (2009) 'Cold War Culture, History of Science and Postmodernity: Engagement of an intellectual in a Hostile Academic Environment'. In Weimar Culture and Quantum Mechanics. Selected Papers by Paul Forman and Contemporary Perspectives on the Forman thesis. Carson, C., Kojevnikov, A., Trischler, H. eds. Imperial College Press.

[989] Kevles, 1995: 410. Philips-Fein, K. (2009) Invisible Hands: The Making of the Conservative Movement from the New Deal to Reagan. Norton. New York. London.

[990] Waterhouse, B. (2011) 'The Corporate Mobilisation against Liberal Reform', in What's Good For Business: Business and American Politics Since World War II. Oxford University Press.

[991] McDougall, W. (2000) 'The Cold War Excursion of Science', Diplomatic History, Vol. 24, Iss. 1, pp. 117-227.

milieu'. In response to a shifting intellectual and financial environment, and with a growing awareness of an energy crisis, a number of prominent physicists would re-orientate their work away from 'pure', nuclear or military affiliated research, and instead pursue small-scale, applied research which would seek to maximise the efficiency with which energy was used. In a sense, physicists became engineers, using the laws of physics to produce technologies rather than extending the frontiers of scientific knowledge. As always, the divide between science and politics was never disentangled, and could never hope to be. Accordingly, the science of ERC seemed to simultaneously meet the needs of political radicals, an increasingly hegemonic and imperial state, and those who wanted to see improvements in the productivity of the American economy.

ENERGY IN POST-WAR PHYSICS

This thesis's introduction noted how the laws of energy, its conservation and dissipation, had become the fundament of physical explanation in the mid-nineteenth century. As philosopher of science Ernst Mach (1838-1916) wrote in 1872 'The place given to the law of the conservation of energy in modern science is such a prominent one that the question as to its validity […] obtrudes itself'[992]. Since, these laws had weathered a number of discoveries that had unsettled their supposed universality. At the turn of the century, physicists had struggled to explain how 'uranic rays' kept emitting energy, seemingly in contradiction to the first law. Once radioactivity was better understood, its' decrease over time could be measured. This led to the discovery of the neutrino, which pulled nuclear physics back under yoke of the laws of thermodynamics. A decade or so later, with the popularisation of statistical mechanics, the idea that thermodynamics could be rendered probabilistically, rather than as inalienable laws,

[992] Mach, E. (1872 [1911]) History and Root of the Principle of the Conservation of Energy. Trans. Jourdain, P. Chicago Open Court Publishing.

gained increased currency. This left open the possibility of exceptions to thermodynamic law, at least as statistical possibilities, if not within the realm of human experience[993]. But despite these challenges to the solidity of energy's laws, from the 1930s onward nuclear, particle, and solid-state physics would reinvigorate the explanatory pre-eminence of energy.

By the outbreak of World War Two 'particle accelerator' research had become one of the discipline's most prestigious fields. The term referred to a process wherein particles, bits of matter at a subatomic level, were given sufficient energy to split themselves from a nucleus, so they were sufficiently distinguished to allow the measurement of their physical properties. Physicists sought to 'accelerate' particles, subjecting them to high velocity motion, by increasing the energy which held them together. The physicist Ernest Lawrence (1901-1958) had formulated the idea of the cyclotron in the late 1920s. The idea was to accelerate a particle in a vacuum, via an electrical charge passed through a magnetically induced circular path, consisting of two sides of opposing magnetic field that iteratively accelerate the particle via electromagnetic attraction and repulsion. Sufficiently accelerated, the particles would tear away from the nucleus[994]. Greater accelerations, requiring higher inputs of energy, in terms of current rather than quantity, revealing ever-greater detail about the fundamental properties of the material world[995]. Hence in later decades particle acceleration became known as 'high energy physics'[996].

[993] Bridgman, P. (1932) 'Statistical Mechanics and the Second Law of Thermodynamics', Science, Vol 75, Iss. 1947, pp. 419-428. See also Meyerson (1991); Stengers, (2010).

[994] Cassidy, D. (2011: 53-6) A Short History of Physics in the American Century. Harvard University Press.

[995] 'highness' referred to the charge that was imparted, it did not suggest HEP was a particularly large consumer of energy. Sessler, A., Wilson, E. (2007) Engines of Creation: A Century of Particle Accelerators. World Scientific Publishing Company.

[996] Kevles notes that the most powerful accelerator of the 1970s, the Tevatron would have needed to have been a trillion times more powerful than they were to test the 'Grand Unified theory' (Kevles, 1995: xv). However, this did not mean that high energy physics was a science that consumed particularly significant quantities of electrical energy.

By the 1970s, high-energy research of this kind received nearly a third of the federal budget for physics[997]. It had become the archetypal 'big science', a moniker that acknowledged the scalar relation between the level of investment, research infrastructure, and research teams[998]. Accelerators grew from table or room-sized hardware to the size of airplane hangars. By 1970 seventeen-hundred postgraduates worked in the field[999]. But it was not accelerators that demanded so many workers, so much as the detectors used to measure the highly energised particles. Generally, this stream was directed at a highly pressurised tank of liquid hydrogen, which provided a cushion of simple nuclei, a blank canvas for the identification of particles. As the hydrogen was held just below boiling point, the movement of charged particles through the liquid left a trail of bubbles. This 'heat track' could then be used to determine the momentum, mass, rate of decay, and – eventually – give an identity to the particle[1000]. Using a mechanised photographic process to capture these tracks, researchers could collect data requiring months of analysis in a short space of time. As historian of science Peter Galison memorably wrote, this required "armies" of technicians and scanners' to sort 'the endless stream of 70mm negatives'[1001].

These 'bubble chambers' became the 'factories of physics'[1002], and their operation was increasingly rationalised. Laboratories developed image 'reading' machines. At the Lawrence

[997] Cassidy, 2011: 129.

[998] Westwick, P. (2003) 'High-Energy Physics' in Heilbron, J. Ed. The Oxford Companion to the History of Modern Science. Oxford University Press.

[999] Galison, P. (1987) How Experiments End. University of Chicago Press.

[1000] Pickering, A. (1985) Constructing Quarks: Sociological History of Particle Physics. University of Chicago Press, Galison, 1987: 139.

[1001] Galison, P. (1992: 225) 'Fortran, Physics, and Human Nature', The Invention of Physical Science, Vol. 139, Boston Studies in the Philosophy of Science, pp. 225-260.

[1002] Galison, P. (1997: 315) Image and Logic: a material culture of microphysics. Chicago University Press.

Berkeley Laboratory, Luis Alvarez (1911-1988) and his team used the 'Frankenstein', a machine named after engineer Jack Frank[1003], which drove a cursor along the heat track image, registering its coordinates. This would produce a geometrical curve, from which the particle's motion could be translated into mathematical terms, which recorded the particles' energy and momentum. Conservation principles, laws of natural constancy of the kind discussed in this thesis' introduction, underwrote particle analysis. The assumption that energy was conserved was one conservation principle amongst many, against which the classification of subatomic particles was made[1004]. In a paper in *Scientific American* detailing their work, members of Alvarez's laboratory stated that 'the new classification system takes advantage of the fact that nature conserves many quantities (in addition to energy and momentum) and shows various symmetries (such as between left and right)'[1005]. In physical theory, all systems have fundamental quantities (mass, angular momentum, charge, energy) that are always conserved ('constant') in order for that system to confirm to known physical laws[1006]. From the basis of conservation laws, a system of notation ('quantum numbers') provided a benchmark from which to describe the properties of particles. Accordingly, those working in particle physics were, were experts in the thermodynamics of liquefied gasses and adept in measuring unstable thermodynamic systems in relation to conservation laws[1007].

[1003] Seidel, R. (1996) 'From Mars to Minerva: The Origins of Scientific Computing in the AEC Labs', Physics Today, Vol. 49, Iss. 10, pp. 33-39, acknowledges Hugh Bradner as co-inventor, Galison (1996) does not.

[1004] As Pickering writes 'On the one hand, they applied already established laws as definitions, more clearly to establish what was new in the interactions of elementary particles; on the other, they constructed new, empirical, conservation laws in order to systematise experimental data and to characterise the fundamental interactions', Pickering, A. (1985) Constructing Quarks: A Sociological History of Particle Physics. University of Chicago Press., p. 50.

[1005] Chew, G., Gell-Mann, M., Rosenfeld, A. (1964: 80) 'Strongly Interacting Particles', Scientific American, Vol. 210, Iss. 2, pp. 74-93.

[1006] Daintith, J. ed. (2009) Dictionary of Physics. Oxford University Press.

[1007] Galison, 1992.

Computational methods were also becoming increasingly important in physics. During the Second World War, computer simulation had been used by physicists in Los Alamos to understand the process by which neutrons diffuse at the core of a nuclear reaction[1008]. This established the 'calculating machine' as a central technology for post-war physics, to the extent that a new field of 'computational physics' emerged in which experiments, physical laws, and empirical parameters could be symbolised via sets of numbers and differential equations calculated at a rate and level of complexity beyond human capabilities[1009]. Using 'numerical simulacra of reality' as a new ways of exploring the properties of physical phenomena became increasingly widespread in the physics community[1010]. So much so, that by the mid-1960s, physicists were the primary users of contemporary 'supercomputers', and computational experimentation joined theoretical and experimental research as a third mode of scientific inquiry[1011].

Having worked with the 'MANIAC' computer at Los Alamos, Alvarez was one of the first to recognise that computers could play a role in bubble chamber analysis. In the mid-1960s he hired a programmer, Frank Solmitz, to write code for an IBM 650 to analyse digitised output from the 'Frankenstein'. A gifted student of Fermi's, Arthur Rosenfeld, joined Solmitz. Together they developed a number of program 'scripts' designed to improve the speed and accuracy of heat-trail analysis. The programming language FORTRAN ('FORmula

[1008] Galison, P. (1996) 'Computer Simulations and the Trading Zone', in Galison, P., Stump, D. eds. The Disunity of Science: Boundaries, Contexts, Power. Stanford University Press. See also Seidel, R. (1998) "Crunching numbers" computers and physical research in the AEC laboratories', History and Technology, Vol. 15, Iss. 1., pp. 31-68.

[1009] In 1971 French nuclear physicist Lew Kowarski noted the rise of computational physics had led to the emergence of a new kind of physicist: 'a data processor specialized in using computers' (Roberts, cited in Galison, 1996: 113-4).

[1010] Feigenbaum, M. (1995) 'Computer generated physics', in Twentieth Century Physics. New York, pp. 1823-1853.

[1011] Cassidy, 2011: 153: ft 18.

TRANslating') simplified their programming, but it was still difficult and specialised work. At the end of the decade Alvarez's team received a Nobel in recognition of their discovery of numerous particles and, significantly, in recognition of their development of a computerised data analysis system[1012]. The demands of high-energy physics had created a team of skilled scientists able to draw physical data from a complex apparatus via the mediation of a computer.

At the same time as high-energy physics was becoming partially automated, owing to détente the demand for nuclear physicists was decreasing. In 1968 the first nuclear Non-Proliferation Treaty was signed, with reactors opened to safety inspection across the world. In 1968, the Strategic Arms Limitation Treaty ('SALT') was signed, and international organisations began to discuss nuclear disarmament. With a growing number of restrictions placed on nuclear weapons it could be assumed nuclear power would offer physicists alternative means of employment. But utility companies were increasingly unwilling to invest in nuclear power plants unless the government provided indemnity against accidents. The Price-Anderson Act, passed in 1957, did just that, but the agreement had achieved this goal thanks to the Atomic Energy Commission ('AEC') engineer's estimate that a nuclear accident would be so catastrophic that no private insurers could possibly take such a risk. The expert's report, 'WASH-740', projected deaths into the thousands and property loss in the billions of dollars should an accident occur. An update in 1964 came to a more dramatic conclusion. There could be as many as 45 thousand fatalities and the loss of an area the size of Pennsylvania. The AEC's report had recommended these findings should be covered up to avoid 'great difficulties in obtaining public acceptance in nuclear power'[1013]. Once made public a year

[1012] Seidel, 1996.

[1013] Ford, D., Kendall, H. 'Nuclear Misinformation', Environment: Science and Policy for Sustainable Development, Vol. 17, Iss. 5, pp. 17-27.

later, as a result of the Freedom of Information Act, WASH persistently provoked concern from private investors, meaning the development of nuclear power slowed[1014]. In 1973 *Physics Today* noted that in 1966 the Federal Power Commission had planned to develop thirty-one nuclear power plants by the 1980s, but by 1972 only ten had been built[1015].

Though three-quarters of physics graduates still specialised in nuclear and solid-state physic which Kaiser termed 'suburban physics' owing to their perceived lack of prestige compared to HEP, by the nineteen-seventies employment prospects in these fields looked increasingly limited[1016]. Young physicists no longer saw the allure of nuclear physics. Some even turned their expertise on its head, publicising their knowledge of the risks of nuclear power, or providing detailed technical critiques of reactor designs. One prominent example was Amory Lovins (1947), who had moved from Harvard to study nuclear physics at Oxford in 1968. During vacation, he met environmentalists during climbing expeditions in Wales[1017]. There he met the former head of California's *Sierra Club* David Brower (1912-2002)[1018]. Brower had set up a Washington-based environmentalist campaign group *Friends of the Earth* ('FOE') in 1969, which soon spread internationally[1019]. In 1971, Brower advised Lovins to leave academia to join the London office[1020]. There he published books and articles arguing that nuclear power was technologically flawed, environmentally deleterious, and indivisible

[1014] Balogh, B. (1991: 16) Chain Reaction: Expert Debate and Public Participation in American Commercial Nuclear Power. Cambridge University Press.

[1015] Golden, J. 1973: 70) 'APS considers plan for energy study', Physics Today, Vol. 26, Iss, 11, p. 69.

[1016] Kaiser, D. (2004) 'The post-war suburbanization of American Physics', American Quarterly, Iss. 56, pp. 851-888.

[1017] Lovins, A., Brower, D. (1971) Eyri, Or Mountains of Longing. Friends of the Earth. London.

[1018] McPhee, J. (1971) Encounters with the Archdruid. Farrar, Straus and Giroux.

[1019] Veldman, M. (1994) Fantasy, the Bomb, and the Greening of Britain: Romantic Protest, 1945-1980. Cambridge University Press.

[1020] Brower, D. (1989) The Sierra Club: A Guide. Sierra Club Books.

from Cold War nuclear weapon development[1021]. We will return to Lovins' work in Chapter 9, as here we are concerned with those physicists who worked *within* the conventional scientific establishment.

CONSERVATION AND THE NEEDS OF EMPIRE

The 'National Laboratories' would prove an important site for the reorientation of physical research. This consortium of laboratories where the atom bomb had been developed. Lawrence Berkeley Laboratory's accelerator had been used to isolate the isotope from which the uranium for 'Little Boy' had been derived, and the government's reactors at Oak Ridge National Laboratory ('ORNL') in Tennessee had produced the plutonium for the tester 'Trinity' and 'Fat Boy' bombs[1022]. Immediately after the war, under the auspices of the newly-founded Atomic Energy Commission (AEC), the laboratories would, according to the wishes of President Roosevelt, contribute to the development of the 'arsenal of democracy'[1023], the weapons that would maintain peace during the Cold War. ORNL continued to focus on isotope development, though ostensibly for the peaceful use of nuclear power. Alongside which, Argonne ('ANL') and Brookhaven ('BNL') developed new reactors and carried out commercial, non-classified physical research. Los Alamos remained dedicated to developing nuclear weapons. Later, Lawrence Livermore, established near San Francisco in 1952, would compete with Los Alamos in developing warheads. In 1960 alone, these laboratories consumed four-billion dollars of federal funding and billions more in infrastructural costs[1024]. As Kevles noted, by the late nineteen-sixties a coalition of opinion

[1021] Lovins, A. (1975) World Energy Strategies: Facts, Issues, and Options. London: Friends of the Earth.

[1022] Seidel, 1986: 137

[1023] Westwick, P. (2003) The National Labs: Science in an American System, 1947-1974. Harvard University Press. Crease, R. (1999) Making Physics: A Biography of the Brookhaven National Laboratory, 1946-1972. University of Chicago Press.

[1024] Ibid.

had formed against continued increases in federal investment in physics. This section describes how this increasingly oppositional '*lebensphilosophie,* inspired some physicists to turn to the study of ERC.

Formed in 1947, ORNL was situated in the remote Tennessee Appalachia. Where electricity was readily available thanks to the earlier efforts of the Tennessee Valley Authority in harnessing the Tennessee River as means for hydroelectricity[1025]. During the war ORNL had hosted the graphite reactor that would produce uranium and plutonium for Los Alamos. But after the war, the laboratory became a subsidiary of Argonne laboratory, and its work was overseen by engineers from the chemical company Du Pont. It became an industrial research organisation rather than a scientific one. In subsequent years, under the directorship of physicist Alvin Weinberg (Chapter 5), the laboratory transformed into a pioneering nuclear research laboratory, producing new research on nuclear materials' testing, neutron irradiation, breeder reactors, and even nuclear-powered flight[1026]. This transformation was the result of the revised Atomic Energy Act of 1954, which opened up the nuclear industry to private enterprise. ORNL would carry out research on behalf of industry, with government indemnity, as Weinberg noted, allowing them 'take those risks which are too great, too open-ended for private industry'[1027].

As it diversified, the AEC increasingly funded research into the effects of nuclear fallout and irradiation. So much so that, somewhat unexpectedly, the AEC became the largest funder of

[1025] Johnson, L., Shaffer, D. (1994: 16) Oak Ridge National Laboratory: The First Fifty Years, University of Tennessee Press.

[1026] Johnson, L., Schaffer, D. (1994) Oak Ridge National Laboratory: The First Fifty Years. University of Tennessee Press.

[1027] Seidel, R. (1986) 'A Home for Big Science: The Atomic Energy Commission's Laboratory System', Historical Studies in the Physical and Biological Sciences, Vol. 16, Vol. 1, pp. 135-175.

ecological research in the United States at this time, and the ORNL its most significant laboratory. Biologist Stanley Auerbach became the laboratory's first ecologist in 1954, studying the path of radionuclides through the environment. By the 1960s ORNL had a team of twenty-two ecologists working at its 'Radiation Ecology Laboratory'[1028]. Following an abandoned attempt to create a 'big ecology' project under the 'International Biological Program' in the early 1970s, the 'little science' of ecology would carry on at the laboratory alongside the big science of nuclear physics[1029]. But nuclear physics, as mentioned, entered somewhat of a decline at the start of the decade. Federal investment faltered, reactors went unbuilt, and the Los Alamos generation retired. Weinberg acknowledged the laboratory was changing. In his annual speech to employees in 1970 to note that 'ecologists have displaced the physicists and the economists as high priests in this new era of environmental concern'[1030].

In this respect ORNL was in step with America more generally. In April that year twenty-million Americans had celebrated 'Earth Day'. All kinds of organisation had held 'teach-ins' to discuss human environmental impact[1031]. A number of ORNL staff had participated. But the institution's environmental credentials were tempered by the fact that the laboratory still worked primarily on nuclear engineering. That year the laboratory received approval to store highly radioactive waste in Kansas's salt mines, and develop a High Flux Isotope reactor, a 'super-duper cooker' for producing radioisotopes[1032]. Weinberg had presciently realised that

[1028] Bocking, S. (1995) 'Ecosystems, ecologist, and the Atom: Environmental Research at Oak Ridge National Laboratory', Journal of the History of Biology, Vol. 28, Iss., pp. 1-47.

[1029] ORNL's director Alvin Weinberg had coined the term 'big science' in 1961, to describe the large-scale, costly, and collaborative efforts to build accelerators, reactors, rockets and so on. Kwa, C. (1993) 'Modeling the Grasslands', Historical Studies in the Physical and Biological Studies, Vol. 24, No. 1, pp. 125-155.

[1030] Weinberg, A. (1970) 'State of the Laboratory, 1969', ORNL Review, Winter 1970, Vol. 3, Iss. 3, pp. 1-14.

[1031] Rome, A. (2010) 'The Genius of Earth Day', Environmental History, Vol. 15, Iss. 2, pp. 194-205.

[1032] Johnson & Schaffer, 1994.

the vogue for environmentalism meant new streams of funds were becoming available, and – just like RAND's Ronald Doctor – he successfully applied for funding under the NSF'S new funding programme, 'Research Applied to National Needs' ('RANN')[1033]. With a new revenue stream, the organisation committed itself to 'launching an interdisciplinary attack on problems of the environment'[1034].

This new-found environmentalism did not mean ORNL had rescinded on its martial obligations. In 1971 President Nixon had appointed former RAND defence analyst James Schlesinger (1929-2014) as chairman of the AEC. The Commission had just received Congressional approval to investigate non-nuclear sources of energy as a result of growing fears about future restrictions in energy supplies. Schlesinger was an archetypal Cold War military and policy strategist. In 1960, he had published a book on the relation between political economy and national security[1035]. And at RAND he had worked on applying the principles of systems analysis to the political process, according to the post-ideological rationale that 'by introducing numbers, systems analysis serves to move arguments from the level of ideology or syllogism to the level of quantitative calculation[1036]. At the AEC, Schlesinger begun discussing the 'energy dilemma' in equally systemic and strategic terms.

In a 1972 speech to New York businessmen Schlesinger opined that environmentalists were right to challenge the 'presupposition that irrespective of policy objectives and constraints, demand for energy grows'. Going further, he stated that 'If we describe the increasing

[1033] Not forgetting ORNL had successfully applied for funds under the IRRPOS scheme (Chapter 5).

[1034] Weinberg, A. (1971: 10) 'State of the Laboratory – 1970', ORNL Review, Winter 1971, Vol. 4, No. 4, pp. 1-12.

[1035] Schlesinger, J. (1960) The Political Economy of National Security: A Study of the Economic Aspects of the Contemporary Power Struggle. Praeger, New York.

[1036] Schlesinger, J. (1967) 'Systems Analysis and the Political Process', The RAND Corporation, Santa Monica, California, P-3464.

dependence on foreign fuels as a threat to the national security, to the balance of payments, or the steadfastness of foreign policy, then we would seem obliged to consider measures more drastic for conserving on energy use'. As a result, he implored his audience of businesspeople to 'do somewhat better than automobiles that move at 10 miles to the gallon and badly insulated buildings'[1037]. With the increasing threat of an effective Middle Eastern oil embargo Schlesinger was clearly suggesting energy efficiency could contribute to the maintenance of national security and American economic sovereignty[1038]. The meta-context of the Cold War, even during these years of détente, was inescapable. A year before American oil production peaked in 1971, the Soviet Union had become the world's leading oil producer. Though not a direct confrontation, the embargo of 1973 could be seen as the proxy conflict under the veneer of detente. Iraq was a Soviet ally, and they had provided arms to a number of Arab nationalist states, which we can assume buoyed their confidence during the embargo[1039].

In an unprecedented move, Weinberg insisted Schlesinger's 'intelligent statement' be reprinted in full in the *ORNL Review*[1040]. Just as ORNL had once supported the development of nuclear weapons to assist in American nuclear strategy, now as Schlesinger had recommended, ORNL's engineers could contribute to national security by helping the United States use less energy[1041]. Accordingly, Weinberg established a committee to review the potential opportunities for non-nuclear research at ORNL. This would evolve into a

[1037] Schlesinger, J. (1972) 'The Energy Dilemma: remarks at a meeting of The Conference Board, and association of New York business men, April 1972', ORNL Review, Summer 1972, Vol. 5, Iss. 4., pp.8-15.

[1038] Graf, R. (2014) 'Claiming Sovereignty in the Oil Crisis "Project Independence" Global Interdependence in the United States, 1973/4', Historical Social Research, Vol. 30, Iss. 4, pp. 43-69

[1039] Painter, D. (2014) 'Oil and Geopolitics: The Oil Crises of the 1970s and the Cold War', Historical Social Research

[1040] Weinberg, in Schlesinger, 1972: 9.

[1041] For more on the weaponisation of environmentalism see Darwin Hamblin, J. (2013) Arming Mother Nature: the birth of catastrophic environmentalism. OUP.

permanent 'Conservation and Renewable Energy Program'[1042], which would work on designs for improved turbine efficiency, the use of waste heat in power generation, coal gasification, battery power, solar power, synthetic fuels ('synth-fuels'), and home insulation[1043]. Unaffiliated to any specific technology, the groups' aim was to formulate new ways to save energy. David Rose, a nuclear engineer and pro-nuclear environmentalist from Massachusetts Institute of Technology (MIT) was hired to lead the team, which included the mechanical engineer Eric Hirst, a self-confessed environmental activist[1044]. Their role was to measure the savings made possible by new technologies, often invented or tested at ORNL, such as the 'Annual Cycle Energy System' that used a heat pump to cool homes in summer and heat them in winter. The measurements of efficiency savings made for a single appliance could then be scaled-up and projected forward to estimate the potential implications of the widespread use of energy efficient technologies at a national or state level: here was an overt demonstration of the idea of metrology as a resource[1045].

The problem with these early studies was that savings observed in the laboratory were crudely estimated. For example, in 1971, the work of ORNL physicist John Moyers suggested a twenty per cent increase in home insulation could mean a 20 per cent reduction in national energy consumption[1046]. Such estimates failed to take the effects of the price mechanism, price elasticity, or behaviour change into account (Chapter 8). Such studies abstracted the parameters of energy demand; Moyers recast home energy use as a system of

[1042] By 1993 this would be the largest energy centered research group at the ORNL, Johnson & Schaffer, 1994, p. 172.

[1043] Hammond, A. (1972) 'Conservation of Energy: The Potential for More Efficient Use', Science, New Series, Vol. 178. No. 4065, pp. 1079-1081.

[1044] Krause, C. (1977) 'Household Energy Use: From Consumption to Conservation', ORNL Review, Fall 1977, Vol. 10, No. 4, pp. 11-18.

[1045] Johnson & Schaffer, 1994.

[1046] Weinberg, A. (1973) 'State of the Laboratory: 1972', ORNL Review, Winter 1973. Vol. 6, No. 1, pp. 1-15.

parameters, whose relation, via wall thickness or roofing material for example, was represented by difference equation. FORTRAN was used to translate these equations into a program that simulated the physical constraints of a conventional home, and then the programmer could reconfigure this code to optimise the household's consumption of energy[1047]. In code, the home could be re-engineered to be directly responsive to variations in price, energy and insulation. It was far from certain whether such savings were possible in actual homes[1048].

```
**FTN,L,E,M,G.
C  FORTRAN COMBINATION OF RESID SERIES
       DIMENSION UFL(4),CFL(4),UCH(4),UCC(4),CC(4),UW(4),CW(4),R(4,4),
      1  TCN(4,4),H(4,4),S(4,4),CAPGH(4,4),CAPEH(4,4),CAPGAC(4,4),
      2  CAPEAC(4,4),FIXGH(4,4),FIXEH(4,4),FIXGAC(4,4),
      3  FIXEAC(4,4),SAVGAS(4,4),SAVELH(4,4),SAVEAC(4,4),TOTGH(4,4),
      4  TOTEH(4,4),TOTGAC(4,4),TOTEAC(4,4),NCASE(17),NREG(5)
C  READ CASE TITLE
       READ(50,900)NCASE
  900  FORMAT(17A4)
C   READ BUILDING DIMENSIONS
       READ (50,980)DLEN,DWID,AWN,AWS,AWEW
  980  FORMAT(5F10.0)
C   CALCULATE BUILDING AREAS
       AWALL=16.*(DLEN+DWID)
```

Figure 7.1. Section of FORTRAN Code Showing Building Dimensions
Moyers (1971: 97)

In October 1973, OAPEC imposed their embargo on countries supporting Israel in the Yom Kippur war. Schlesinger's fear had been correct; America's dependence on foreign oil had been exploited by hostile Arab states[1049]. The long forecast energy crisis had arrived. Nixon response was to announce the nation's most ambitious attempt to reduce energy demand and increase domestic supply: 'Project Independence'. He orated 'in the spirit of Apollo and with

[1047] Moyers, J. (1971) The Value of Thermal Insulation in Residential Construction: Economics and the Conservation of Energy. ORNL-NSF Environmental Program. ORNL-NSF-EP-9.

[1048] See Chapter 9 for discussion on this. Johnson & Shaffer, 1994.

[1049] Painter, D. (2014) 'Oil and Geopolitics: The Oil Crises of the 1970s and the Cold War', Historical Social Research, Vol. 39, Iss. 4, pp. 186-208.

the determination of the Manhattan Project' America must develop 'the potential to meet our own energy needs'[1050]. As a result, the ORNL's, and other laboratories evidence of the potential reductions in energy demand that might be achieved gained increasing political prominence. In March 1973 marine biologist Dixy Ray Lee replaced Schlesinger as the head of the AEC. Engineer Floyd Culler had become the head of the ORNL[1051], and was called on to contribute evidence to Project Independence. Ray Lee's final report on the matter, *The Nation's Energy Future* (1973), made use of estimates of demand reduction made by ORNL and other national laboratories, as well as RAND's 'Growing Demand for Energy' project (Chapter 6). Drawing these various estimates together, Lee's report provided a detailed account of how the United States could become 'energy independent' by 1985, by reducing energy demand by 3 per cent per year, an estimated conservation rate very close to that of RAND's (Chapter 6), and measured as the equivalent of 4.7 million barrels of oil a day[1052].

'Project Independence', as outlined in Lee's report, provided Nixon's government with an empirically grounded means to defend his government's response to the energy crisis. Nixon wanted to avoid large-scale investment in energy supply technologies, expenditure which would potentially have worsened the ongoing inflation crisis[1053]. Nixon's response to the energy crisis were intended to remain coherent with his Party's intention to reduce the size of government[1054]. Hence the plan was to use coal rather than oil in power plants, to somewhat

[1050] Shulman, P. (2015) Coal and Empire: The Birth of Energy Security in Industrial America. John Hopkins University Press.

[1051] Weinberg had left ORNL to join Nixon's temporary Federal Energy Administration ('FEA').

[1052] Ronald Doctor of RAND, Arthur Fraas of ORNL's Energy efficiency department[1052], and a man called Monte Canfield, who worked for the Ford Foundation, contributed to Lee's work (USGPO, 1973: 164). See also Johnson & Schaffer, 1994

[1053] de Marchi, N. (1981) 'Energy Policy under Nixon: Mainly Putting Out Fires', in, Goodwin, C., Ed. (1981) Energy Policy in Perspective: today's problems, yesterday's solutions. The Brookings Institution, Washington DC.

[1054] Jacobs, M. (2008) 'The Conservative Struggle and the Energy Crisis.' In Rightward Bound: Making America Conservative in the 1970s, Schulman, B., Zelizer, J. Eds. Harvard University Press.

re-invigorate nuclear power research, to develop mass transit systems, to lower speed limits to 55 miles per hour, and to exploit domestic oil from new fields in Alaska, amongst other interventions[1055]. The approach was far from 'environmentalist as Nixon removed the restrictions on power plant development and emissions standards he himself had implemented in 1970[1056]. The final *Project Independence* report, published in October 1974, had involved over 400 public servants, throughout August and September, ten public hearing had been held and nearly 7 thousand pages of advice collected from the public. Historian Rudiger Graf described the resulting policy proposals were a 'paradoxical blend of technocratic and grass-roots democracy'[1057]. But despite Nixon's call for home-spun 'prudence and common-sense', the majority of authoritative estimated savings were the work of national laboratories like ORNL.

Once Nixon had resigned over the Watergate scandal in August 1974, President Ford continued to attempt to implement Project Independence[1058]. Next year, with the support of the NSF and other federal funds, the ORNL's conservation program, along with other RANN funded programs, formed the basis of the government's new, permanent Energy Research and Development Administration[1059] (ERDA, see Chapter 5). As Schlesinger had hoped, humble energy-using technologies had become enlisted in the pursuit of 'national security'. As in the closed, strategically linked world of Cold War geopolitics, energy conservation could be considered an attempt to break the strategic exploitation of resource dependency, such as the West's reliance on foreign oil. To some extent it allowed the continuation of the

[1055] Grossman, P. (2013: 34) U.S. Energy Policy and the Pursuit of Failure. University of Cambridge Press.

[1056] Flippen, J. (2000) Nixon and the Environment. University of New Mexico.

[1057] Graf, R. (2014) 'Claiming Sovereignty in the Oil Crisis "Project Independence" Global Interdependence in the United States, 1973/4', Historical Social Research, Vol. 30, Iss. 4, pp. 43-69.

[1058] Weinberg, A. (1974) 'Project Independence and Future R&D', Science News, Vol. 106, No. 24, p. 374.

[1059] Fehner, T., Holl, J. (1994) Department of Energy, 1977-1994. United States Department of Energy. Energy History Series: 18.

conflict under the veneer of détente[1060]. This strategic deployment of ERC continued when Schlesinger became President Carter's Secretary of Energy, the first in America's history, in his newly founded Department of Energy in October 1977[1061]. That month, addressing the eighteen member states of the newly founded International Energy Agency ('IEA') Schlesinger warned that 'the future of our free societies' rested on the pursuit of an independent energy policy[1062]. In the event, the majority of the proposed policies were never implemented, independence remained an aspiration. As Graf claimed, the sheer amount of intellectual effort expended on *Project Independence* was important for another reason. It helped legitimise the idea that 'energy' was a coherent field of knowledge, and to define the new discourse of 'energy policy'[1063].

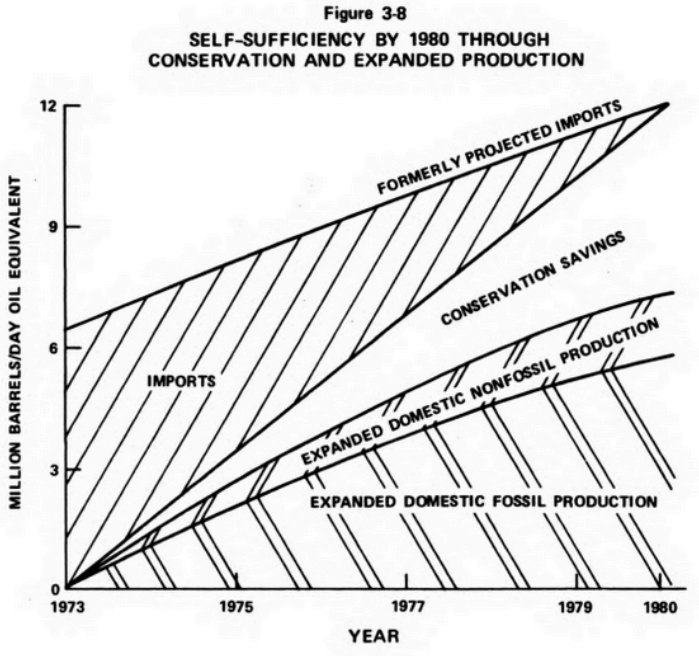

Figure 7.2. Estimated Contribution of Energy Conservation to Project Independence.
Lee (1973: 46)

[1060] A point Paul Edwards makes in relation to information technologies, drawing on the work of Stephen Ambrose: Edwards, P. (1994) The Closed World: Computers and the Politics of Discourse in Cold War America. MIT Press. See Ambrose, S. (1973[1971]) Rise to Globalism: American Foreign Policy Since 1938. Harmondsworth, Penguin.

[1061] Fehner, T., Holl, J. (1994).

[1062] Lewis, P. (1977) 'Schlesinger warns West US Energy Plan is Vital', *New York Times*, pp. 92-97.

[1063] Graf, 2014, p. 52.

In April that year President Carter had delivered, in his words, an 'unpleasant talk'. On television and radio he warned the ongoing energy crisis was a historically unprecedented problem which threatened to overwhelm the country unless Americans were willing to accept considerable sacrifices. He stated the crisis required 'the moral equivalent of war', a phrase borrowed from pragmatist philosopher William James (1842-1910). James had theorised that, in the absence of war, government must find other means to instil 'martial character' in citizens[1064]. Carter hoped his warning might encourage self-sacrifice in pursuit of the 'cornerstone' of his plan, the conservation of energy. Carter hoped conservation – following Nixon's reasoning - would eradicate demand for foreign oil. In a turn of phrase which implied conserved energy was ontologically real, as if it were a fuel like any other, that it was 'the quickest, cheapest, most practical source of energy'[1065].

Historically, the government's approach to energy resource shortages had been to increase supply, expanding oil fields and building new plant, but now Carter and others were suggesting reductions in energy demand were equivalent to increased energy supply. Prince Sa'ud al Faisal (1940-2015) of Saudi Arabia had termed the embargo an 'oil weapon' in Beirut's paper *Al Anwar* in November 1973[1066]. Broadcasting to America's citizenry, Carter later claimed consumer behaviour could become the basis of a new counter weapon, in so far as self-sacrifice would reduce the West's vulnerability to Middle Eastern oil. The weaponisation of ERC was no more apparent than when, at the end of the decade, Edward Teller, co-inventor of the thermonuclear bomb, ardent anti-environmentalist, and cold war

[1064] James, W. (1910 [1971]) The Moral Equivalent of War, and Other Essays. New York, Harper & Row. Less remarked on is James's suggestion that the 'moral equivalent of war' was analogous to the 'mechanical theory of heat' (p. 13) owing, presumably, to the determinate but imperfect control one exerted on the other.

[1065] Horowitz, D. (2004) Jimmy Carter and the Energy Crisis of the 1970s: The Crisis of Confidence Speech of July 15, 1979: a brief history with documents. Bedford University Press.

[1066] Graf, 2014.

'Hawk' described energy conservation as a 'powerful defensive weapon'[1067]. This requires a further expansion of historian Timothy Mitchell's term 'carbon democracy'. Mitchell argued that control over flows of energy were used to impose specific forms of political relations, we might add that a nation's ability to demonstrate it could reduce its energy use could provide a means of imposing certain political relations: in this case, regaining American resource sovereignty was believed to allow American foreign policy to remain unchanged[1068].

CAMPUS CONSERVATION

Physicists' radical aspirations were more clearly demonstrated in the more liberal climate of America's universities, although they become embroiled in Cold War science along with the government laboratories. During the war California's Lawrence Berkeley laboratory ('LBL') had separated the uranium-235 isotope for nuclear bombs. After the war LBL became a national laboratory in all but name, receiving generous direct support from the Federal government[1069]. Robert Oppenheimer (1904-1967), physics professor at Berkeley, and former head of the Los Alamos project, characterised the situation in 1948: 'the University of California is a great liberal university that is the only place in the world, as far as I know, that manufactures, under contract with the United States government, atomic bombs' – a situation he compared to monks making liquor[1070]. Throughout the fifties and sixties, federal investment continued to flow in, only levelling off in the late sixties. As a result of budgetary cuts, by the 1970s, underemployed physicists were returning to esoteric subjects such as Bell's theorem[1071], or even, in Forman's case, the history of science. Others became

[1067] Teller, E. (1983: 80) 'Energy and Peace', in Bark, D. ed. To Promote Peace: U.S. Foreign Policy in the Mid-1980s. Hoover Institution, Stanford University Press.

[1068] Mitchell, T. (2011: 143) Carbon Democracy: Political Power in the Age of Oil. Verso Books.

[1069] Seidel, R. (1983) 'Accelerating Science: The Postwar Transformation of the Lawrence Radiation Laboratory', Historical Studies in the Physical Sciences, Vol. 13, No. 2, pp. 375-400.

[1070] Kevles, 1990, p. 244.

[1071] Kaiser, 2011.

increasingly entrepreneurial, and others still, politically radical. But LBL remained a major contractor for military research after the war, and by the 1960s the laboratory's particle accelerator, the Cyclotron, situated on hills above the campus, reminded the student body of this fact[1072].

By tracing the career of Berkeley physicist Arthur Rosenfeld (1926--) this section describes how university physicists found their careers re-orientated by cultural shifts on campus, and most notably, by the events of the energy crisis. In 1954 Rosenfeld had completed a doctorate at Chicago University with Enrico Fermi (1901-1954). He was the last student to work with the Italian physicist, famed for his contributions to both the Manhattan Project and the development of nuclear fission[1073]. Rosenfeld and fellow students had published their notes on Fermi's nuclear physics course which became the standard text in the field. With Fermi's recommendation, Rosenfeld became a professor of experimental particle physics at LBL in 1956[1074]. Amongst physicists he is perhaps best known today for founding the 'Particle Data Group' which continues to this day to create a central repository for particle physics data[1075]. As argued above, this field would help equip young physicists to develop a rigorously physics-based approach to the conservation of energy.

Berkeley had a legacy of radicalism stretching back to before the war, when a number of dissident German émigré scholars had been granted tenure. Notably sociologist Leo Löwenthal (1900-1993), who would introduce the university to the work of the Frankfurt

[1072] Rorabaugh, W. (1989) Berkeley at War: the 1960s. Oxford University Press.

[1073] Segré, E. (1970) Enrico Fermi, Physicist. University of Chicago Press.

[1074] Rosenfeld, A. (1999) 'The Art of Energy Efficiency: Protecting the Environment with Better Technology', Annual Review of Energy and the Environment, Vol 24. pp. 33-82.

[1075] Rosenfeld, A. (1975) 'The Particle Data Group: Growth and Operations – Eighteen Years of Particle Physics', Annual Review of Nuclear Science, Vol 25, pp. 555-598.

School[1076]. By the nineteen-sixties, radicalism abounded. Physics professor Charles Schwartz had become involved in the anti-war movement, and alongside similarly motivated colleagues had announced the formation of Scientists and Engineers for Social and Political Action (SESPA) [1077]. The first meeting attracted around three hundred physicists, either opposed to, or seeking to defend, the militaristic use of their work[1078]. A year earlier Schwartz made an unsuccessfully attempt to persuade the American Physical Society (APS) to formally oppose the Vietnam War. Schwartz had been a junior member of the JASONS, the DOD's elite cadre of physicists, which led him led him to argue the APS was complicit in the ongoing Vietnam War[1079]. Schwartz began holding lunchtime meetings to discuss the moral and political implications of contemporary science. A move which provoked opposition from LBL's director Edwin McMillan, who sought to ban the meetings and fire Schwartz. Others were more sympathetic. The May 1971 issue of *Science for the People,* SESPA's journal, discussed Schwartz' case, and noted that Rosenfeld was a 'liberal' and a 'firmly committed to the cause'. Even Alvarez, a 'somewhat conservative member of the establishment' was commended for offering his 'occasional support'[1080]. The support of a Nobel winning physicist was not enough for McMillan, and later that year Schwartz was suspended from his job at the laboratory for 'flagrant and repeated defiance of authority'[1081]. The incident indicated both young and old physicists at Berkeley were sympathetic to those criticising the martial use of physics.

[1076] Rorabaugh, 1989.

[1077] Two weeks after an initial meeting 'Engineers' were added to the name, Moore, K. (2008) Disrupting Science: Social Movements, American Scientists, and the Politics of the Military, 1945-1975. Princeton University Press, p. 152.

[1078] Casper, B. (1974) 'Physicists and public policy: the "Forum" and the APS', Physics Today, Vol. 27, Iss. 5, pp. 31.

[1079] Moore, 2008, p. 152.

[1080] SESPA (1971: 23) 'Report from Berkeley SESPA', Science for the People, Vol. III, No. 2.

[1081] Aaserud, F. (1987) 'Oral History interview with Charles Leon Schwartz, 1987, May, 15.', American Institute of Physics, Niels Bohr Library Archives.

Rosenfeld never joined SESPA, but the 1973 oil embargo would somewhat radicalise him. As he explained, in November 1973, whilst queuing for gasoline after work, the result of Nixon's fuel allocation policies, he calculated that the laboratory's lighting would consume 100 gallons of fuel over the weekend, despite the fact the building would be empty. In 1967 German physicist Klaus Gottstein had noted that bubble chamber laboratories 'work around the clock, in shifts, day and night and weekends like a blast furnace, and the lights never go out'[1082]. Rosenfeld, realising the illogic of this arrangement during a period of energy crisis, attempted to switch the laboratories lights off. In doing so he discovered switches concealed behind filing cabinets, posters, and bookcases. Reflecting on this evident lack of concern over energy use, Rosenfeld reasoned that there was little or no correlation between energy use and economic welfare, as many economists claimed at the time (Chapter 8). But whilst visiting Switzerland's Centre Européen pour la Recherche Nucléaire (CERN), to collect the laboratory's Nobel Prize, he noticed no difference in the Swiss quality of life, despite their using half the electricity Americans did[1083]. Later, he remembered this realisation was as if he had 'stumbled upon the idea that per-capita energy use could be reduced without deprivation'[1084].

In fact, Rosenfeld's interest in conserving energy reflected a growing concern within the discipline generally. In 1971 the APS agreed to establish a new division, a 'Forum on Physics and Society', made up of younger physicists, to further the 'advancement and diffusion of knowledge regarding the interrelation of physics, physicists, and society'[1085]. The group was

[1082] Galison, 1992, p. 225.

[1083] Rosenfeld, 1999.

[1084] Rosenfeld, A., Poskanzer, D. (2009) 'A graph is worth a thousand Gigawatt-Hours', innovations, Fall, 2009, pp. 57-79.

[1085] Casper, 1974, p. 33.

intended to be a moderate counterweight to SESPA, whilst also an acknowledgement that the goals of physics did indeed require some re-orientation[1086]. The Forum was intended to address physicists' professional concerns, such as the employment of minorities, sexism, and the promotion of applied research. The Forum not only reflected the interests of physicists, but also the changing imperatives of federally funded science, hence Schwartz complained that the forum was an exercise in 'co-optation'[1087]. At the Forum's request the APS approved a proposed summer school study on 'reducing energy consumption at the point of use, and created a sub Committee on Energy Conservation[1088]. Two months before the embargo, at Los Almost, the APS Directorate agreed to fund three studies on the problem of energy demand, looking at reactors, 'energy technologies' such as superconductors, and – importantly - the 'technical aspects of energy conservation'[1089].

Princeton in New Jersey would eventually play host to the Summer School. It was one of a number of elite universities, alongside MIT, Johns Hopkins, and Stanford whose engineering departments were strongly embedded within the 'military-industrial-academic' nexus[1090]. The university had pioneered the new discipline of 'engineering science', a term the Dean Joseph Elgin coined to describe 'the science of engineering systems', a technologized approach to engineering that made use of computation and systems analysis, and which was increasingly applied to the engineering problems of the Cold War state, such as aerodynamics and

[1086] Cassidy, 2011, p. 140.

[1087] Bridger, 2015, p. 203.

[1088] Casper, 1974.

[1089] Forum on Physics and Society (1973) 'Newsletter: Council Approves Three APS-sponsored Energy Studies', FPS Newsletter, Vol. 2, Iss. 3, p. 5.

[1090] Leslie, S. (1994) The Cold War and American Science: The Military-Industrial Academic Complex at MIT and Stanford. Columbia University Press., p. 24: ft. 15.

hydrodynamics[1091]. For example, in 1952, the physicist and mathematician John von Neumann built a computer at the Institute for Advanced Study in Princeton, intended to aid military strategy by modelling hydrodynamic flows within the atmosphere[1092]. Neumann had also proposed the development of intercontinental ballistic weapons whilst at the university's mathematics department[1093]. Princeton physicists also had a reputation as engineers. In 1956 Gerald O'Neill, a young assistant professor, helped develop a new kind of particle accelerator on behalf of the AEC. The 'delay line inflector' focused two beams of particle into each other; the colliding streams would reveal information with greater efficiency, consuming less energy[1094].

Despite its 'establishment' reputation Princeton it was not free from radicalism. The Institute for Defence Analysis, the JASONS's home, had a branch at Princeton, located next to the engineering department. From 1967 onward, the office became the target of student protests, and by 1970 large-scale protests began across campus, with protesters demanding that engineering become a tool for social progress rather than warfare[1095]. In response, the University council agreed to assemble a review committee to review research. In a curious twist, it was Thomas Kuhn, Forman's former boss, who led the review. Kuhn noted that even seemingly benign research projects, such as one on 'Leaf Abscission and Senescence' could be linked to war. In this case, providing the biological science from which chemical defoliant could be developed for use in Vietnam. Kuhn was critical of this kind of 'drift' in research,

[1091] Wisnioski, M. (2012: 107) Engineers for Change: Competing Visions of Technology in 1960s America. MIT Press.

[1092] Cassidy, 2011, p. 151.

[1093] Bridger, 2015, p. 15.

[1094] O'Neil would later go on to develop a number of practical approaches toward space colonization, partly as a response to the evidence of terrestrial limits made increasingly apparent in the 1970s. McCray, P. (2012) The Visioneers: How a Group of Elite Scientists Pursued Space Colonies, Nanotechnologies, and a Limitless Future: Princeton University Press., p. 44-5.

[1095] Wisnioski, 2012.

and maintained some hope that research could remain 'pure' or at least applied to more benign ends[1096].

Physicist Robert Socolow (1937--), like Rosenfeld, would become somewhat radicalised by events at Princeton and elsewhere. Socolow had graduated from Harvard with a doctorate in high-energy physics in 1964, and gone on to briefly work on arms control for RAND[1097]. Two years later he had become a faculty member at Yale, teaching theoretical and nuclear physics. But this conventional career ended when he organised a campus 'day of reflection' in 1969. The intention was to allow students to reflect on, what he termed, the undesirable uses of 'the technology that our science has spawned'[1098]. Socolow's move was provoked by the military's planned anti-ballistic missile shield, which would have placed defensive missiles close to towns and cities across the United States[1099]. This, he reminisced, 'hastened my decision to switch my major professional interests from high energy physics to problems of more direct social relevance'[1100]. But Socolow's radicalism was moderate. His political activities had been 'responsible enough to irritate the more radical students'[1101]. But he had become sufficiently disenchanted with the direction his career was taking that, that same year, he chose not to accept a job working with a particle accelerator. Instead, he devoted his

[1096] Bridger, 2015: 214-8; see also Chapter 4.

[1097] Davidson, M. (2003) 'Portrait of Innovation: Robert H. Socolow', in Modella, A., Bedi, J. Inventing for the Environment. MIT Press

[1098] Sabin, P. (2013: 30) The Bet: Paul Ehrlich, Julian Simon, and our Gamble over Earth's Future. Yale University Press. See also Sokolow, [sic.] R. (1969) 'Questioning Science', Yale Daily News, February 25, 1969, p. 2.

[1099] See Moore (2008).

[1100] Letter to Steve Fels, Socolow, R. Homepage, available at: http://www.princeton.edu/mae/people/faculty/socolow/steve-fels-dec-1969-letter.pdf

[1101] Letter to student, Socolow, R. Homepage, available at: http://www.princeton.edu/mae/people/faculty/socolow/mit-letter-nov-1970.pdf

summer to an environmental impact study of Jamaica Bay, New York, where an airport was planned[1102].

In 1972, during a presentation on fast breeding nuclear power-plants, Socolow realised that reactors were being developed on the assumption that energy demand would be fifteen times its level at the time. It was the unfathomable environmental impact of this scale of energy production that he later believed had transformed the focus of his research[1103]. In 1972 Socolow moved to Princeton where the physics professor George T. Reynolds had successfully applied for RANN funding to create a 'Centre for Environmental Studies' in 1970. Reynolds had worked at Los Alamos during the war as a blast effects specialist. After the war, he directed the Princeton's high-energy physics laboratory, before becoming increasingly interested in biology and the environment via a research project on luminescence[1104]. The Centre for Environmental Studies was interdisciplinary, attracting lawyers, statisticians, and physicists. It combined the university's engineering competencies with a diverse approach to environmental sciences, which allowed the university to capitalise on the growing enthusiasm for environmentalism amongst the student body[1105].

From 1972 onward, Socolow and colleagues carried out experiments on increasing the energy efficiency of a rented house in Twin Rivers, New Jersey. By focusing on a single real house, unlike RAND or the ORNL's simulation studies, Socolow's work, in his words, 'strongly emphasized field studies'[1106]. Twin Rivers was a 'planned unit development' (a 'PUD'), a

[1102] Harte, J., Socolow, R. (1971) Patient Earth. New York, Holt Rinehart and Winston.

[1103] Socolow, R. (1986) 'Reflections on the 1974 APS Energy Study', Physics Today, Vol. 39, Iss. 1, pp. 60-68.

[1104] Gruner, S., Piroué, P, Socolow, R. (2005) 'Obituary: George T. Reynolds', Physics Today, October p. 102.

[1105] Landon, L. Ed. (1970) 'Princeton and the Environment', Princeton Alumni Weekly, Vol. 70, January 27.

[1106] Socolow, R., Sonderegger, R. (1976: 6) The Twin Rivers Program on Energy Conservation in Housing: Four Year Summary Report. Centre for Environmental Studies. Report no. 32. NSF-RANN Contract 6-35758. Princeton University.

site for homogenous, state-supported housing. Soon there would be three-thousand homes like Princeton's experimental one. The potential to identify savings was significant, as at the time domestic energy-use consisted of around twenty percent of America's total energy demand.

As families began to move in, researchers were, in the words of *Princeton Alumni Weekly*, 'quick to realize that a real-world laboratory was growing in Princeton's backyard'[1107]. In contrast to the abstraction of simulated studies, Socolow's team found the 'signature' of an actual house was marked by faults and leakages, and other unexpected sources of heat-loss. This data came from three 'highly instrumented townhouses' fitted with anemometer probes, infrared scans, oscilloscopes, and thermostats, that produced over two hundred channels of data, with the energy usage of individual appliances discerned via an 'Esterline-Angus, D-2-20TTY' data acquisition system, a device that transmitted information to the engineering department's IBM 360/91 computer, over ten-miles away, via the community's telephone lines[1108]. By transforming their house into a highly detailed source of information on energy use, Socolow's team concluded that 'houses are different enough from one another to require some on-site observation before sensible advice can be given'[1109]. In addition, the Twin Rivers experiment was able to show that the same number of individuals in the same type of home could end up using twice as much of certain fuels, in this case gas, as one another. This evidence suggested 'structural' improvements could only offer a certain level of energy savings, as the problem was fundamentally behavioural. Hence Socolow's team could evidently claim that 'computer programs that give unique energy consumption figures for a

[1107] Helitzer, F. (1973) 'The Quality of Our Lives', Princeton Alumni Weekly, Vol. 74., October 30., p. 6.

[1108] Socolow, R., Sonderegger, R. (1976: 6)

[1109] Ibid, 1976, p. 162.

building, based on its floor plan, do not correspond to reality'[1110]. In an interview with the *New York Times* in May 1973, Socolow explained that 'the problem [of energy conservation] is not simple. Just adding more insulation is not going to solve the energy crisis'[1111]. Faced with the complexities of actual housing stock and the vagaries of human behaviour, Socolow's mantra became 'disaggregate!'[1112].

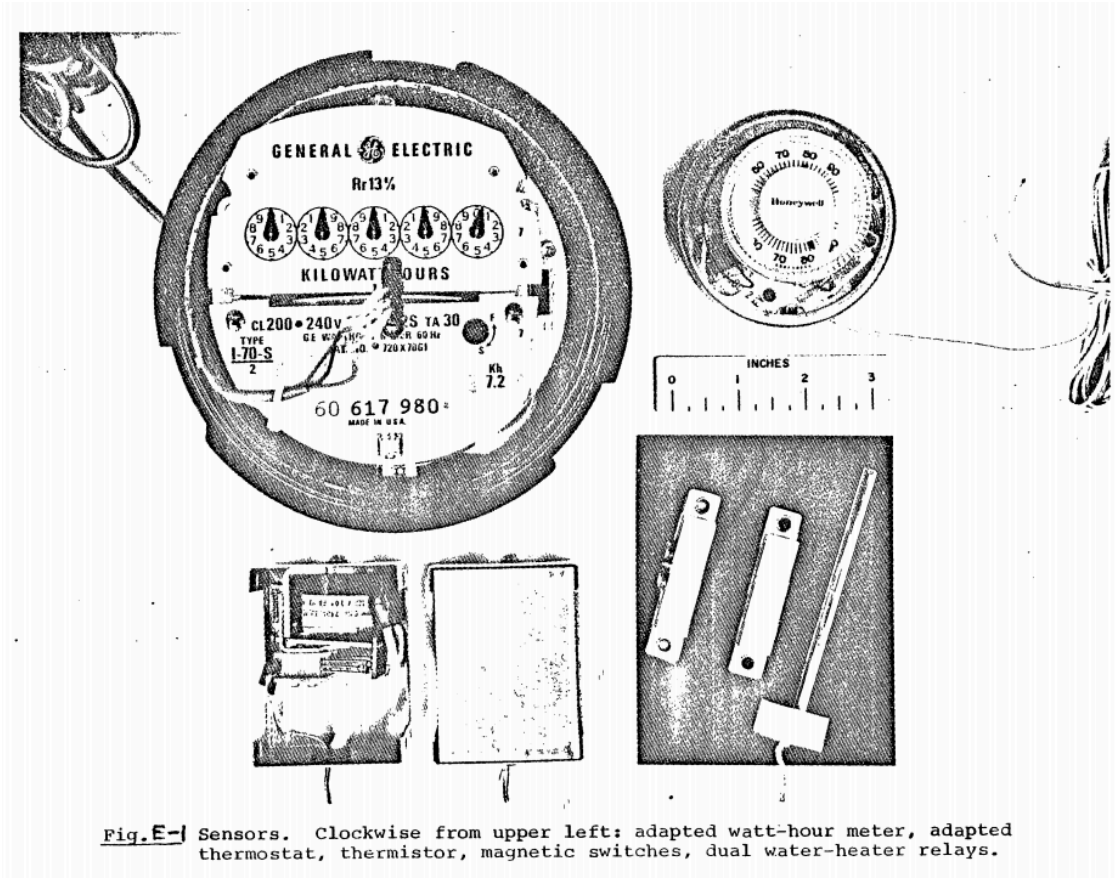

Figure 7.3. 'Highly instrumented townhouses'
Photograph detailed the sensors, meters, thermostat, thermistor, heater relays, and switches from Socolow's study in Twin Rivers, New Jersey (1977).

[1110] Harrje, Dutt, G., Socolow, R., Gadsby, K., Linteris [sic.] (1981) 'Two-to-one variation', in Wilson, T. ed. Home Remedies: A Guidebook for Residential Retrofit. As derived from the First National Retrofit Conference, June, 1980. Princeton University. Mid-Atlantic Solar Energy Association. Pennsylvania.

[1111] Bird, D. (1973) 'Energy in the Home Being Tested at Twin Rivers', The New York Times, May 27, p. 49.

[1112] Socolow, R. (1977) 'The Coming Age of Conservation', Annual Review of Energy, Vol. 2, pp. 239-289.

REDEFINING EFFICIENCY

In 1974 Rosenfeld and Socolow were chosen to lead the Forum on Physics and Society's summer school on the physics of energy conservation[1113]. Socolow and Rosenfeld would be joined by the more senior Daniel Hartley of Sandia Laboratory, Marc Ross from the University of Michigan, and Sam Berman, from the California Institute of Technology[1114]. As mentioned, given its reputation for engineering, Princeton had been chosen as the venue. In the preceding months, the student newspaper *The Daily Princetonian* gave some indication of the effects of the ongoing energy crisis on campus. Federal fuel allocations meant the university had been forced to revise its academic calendar, delaying the beginning of the semester. Also, Princeton's natural gas supply had been cut off and there were limited supplies of fuel-oil. As a result, a program of campus conservation measures implemented. Heating was limited to 68° in campus housing, and 60° to 65° in offices and classrooms. But the editors glibly assured readers that 'the university community has shown a remarkable degree of cooperation and good spirit'[1115].

That summer, seventy attendees, including physicists, chemists, utility company engineers, and employees of American industrial laboratories came to Princeton for five-weeks of study. Their stated intention was not to 'derogate *regulatory, economic,* or *persuasive* tools that may be brought to bear' on the problem of energy demand, but to simply 'present a unified overview of energy efficiency from the perspective of physics'[1116]. To do so attendees would

[1113] Rosenfeld, 1999. Alongside the Forum's support, also now had funding from the National Science Foundation, the Federal Energy Administration, and the Electric Power Research Institute.

[1114] Editorial. (1974) 'Summer Group Focuses on Efficient Energy Use', Physics Today, Vol. 27, Iss. 9, p. 75.

[1115] Editorial. (1973) 'Bundle Up for Energy', The Daily Princetonian, Vol. 97, No. 124, November 23 1973, p. 6.

[1116] Carnahan, W., Casper, B., Ford, K., Prosperetti, A., Rochlin, G., Rosenfeld, A., Ross, M., Rothberg, J., Seidel, G., Socolow, R. (1975) Efficient Use of Energy: A Physics Perspective. AIP Summer School. Study Group on Technical Aspects of Efficient Energy Utilisation. See also Socolow, R. et al. (1975) 'Efficient Use of Energy', Physics Today, Vol. 28, Iss. 8, pp. 23-33.

model energy using technologies as 'simplified thermodynamic systems'[1117]. These models would be used to calculate theoretical estimates of maximum possible efficiency. Recast in the language of physics, the scientists began to consider how, what their final report termed, the 'comprehensive and elegant insights of the past hundred and fifty years of physical science' might help alleviate the energy crisis. In looser language, Socolow later recollected that their intention had been to overturn the idea that 'real men don't study how to use less energy'[1118].



Figure 7.4. Directors of the APS Summer Study
L-R: Robert Socolow, Dan Hartley, Marc Ross, Sam Berman.
Physics Today (1974, p. 75)

[1117] Ibid, p. 16.

[1118] Socolow, 1986, p. 3. Even though well intentioned, in gendering energy analysis Socolow was unwittingly re-enforcing a propensity the anthropologist Laura Nader would document, when called upon by NASA to carry out an ethnography of energy policymaking in the latter half of the decade. See Nader, L. (1981) 'Barriers to thinking new about energy', Physics Today, Vol. 34, Iss. 2, pp. 99-104.

Recasting energy technologies in the abstract language of classical physics led to a number of ideas for reducing energy demand. As the School's proceedings put it: 'the viscoelastic flexing of rubber tyres, the pyrolysis of fuel droplets, the gas discharge in fluorescent bulbs, the behaviour of boundary layers at the surfaces of windows. This is where the physics, chemistry, and engineering of energy use lie'[1119]. As a result, it was argued that thermal diodes, fluorescent lighting, insulating window coatings and new conductive materials for electricity transfer could improve home energy use. As there were an estimated 60 million 'dwelling units' across America, small efficiency increases could potentially lead to vast savings, though the attendees hesitated from giving a total estimate as to what this might be[1120]. It was also proposed that research into dynamotors, batteries, flywheels, and viscoelastic materials could improve vehicle efficiency. As 'rubber-tired, internal combustion engine-powered' vehicles accounted for 18.5 per cent of the total U.S. energy consumption[1121] – with improvements in gearing, engine technology, rolling resistance, and aerodynamic drag, the attendees cautiously recommended that total demand for energy from transport could be reduced by between 4 and 9 per cent.[1122]. Though efforts were made to investigate energy efficiency in industry, the attendees did not propose an estimate for that sector, but given that industry used nearly a third of U.S. energy, potential savings in general processes could be expected to make a significant reduction in energy use[1123].

The school's major theoretical contribution was to redefine the nineteenth century concept of energy efficiency. The first 'conservation' law of thermodynamic dictates that change from

[1119] Carnahan et al., 1975, p. 22.

[1120] Socolow, R. et al. (1975).

[1121] Transport as a whole, including aviation, made up 25 per cent of national demand (Carnahan et al., 1975).

[1122] Carnahan et al., 1975: 99.

[1123] Carnahan et al., 1975, p. 18.

one state to another cannot involve a loss in energy, the first law must be upheld. Hence efficiency was originally measured as a ration of input to output (E1 = energy transferred/energy inputted). This provides an indication of the energy that has been *usefully* conserved, that is, transformed into work and that which has been wasted. In this context, an increase in efficiency means an increase in the ratio of conversion: i.e. the amount of energy transferred (conserved) increases. Defined this way, as it was for most of the nineteenth century, an increase in efficiency does not imply *less* fuel will be used, simply that energy use will be more productive in terms of producing work. It was this commonplace nineteenth century notion of efficiency on which Jevons had based his criticisms of the conservative capacity of efficiency increases (Chapter 2).

First Law Efficiency:

$$\eta = \frac{\text{energy transfer achieved}}{\text{energy input to device}}$$

In redefining efficiency, the APS attendees drew on an 1878 paper by American physicist Josiah Willard Gibbs (1839-1903). Gibbs, a physical chemist, had argued that 'the comprehension of the laws which govern any material system is greatly facilitated by considering the energy and entropy of the system in the various states of which it is capable'[1124]. In effect, he had proposed the analysis of energy, in his case that of chemicals, should differentiate between energy disqualified from use owing to entropy and energy 'available for use[1125]. According to this idea of 'available energy' the APS attendees

[1124] Gibbs, J. (1878) 'On The Equilibrium of Heterogeneous Substances', Transactions of the Connecticut Academy, Vol. III., pp. 108-248.
[1125] Ibid.

proposed that efficiency could be defined in a new way which accounted for this measure of availability.

The notion of 'Second Law Efficiency' was based on the idea that a quantity of energy has a certain potential to do useful work, and that increases in efficiency should work towards carrying out that useful work with the minimal expenditure of energy. Some energy is more useful than others, in so far as it is physically concentrated rather than diffuse[1126]. The difference between coal and warm air for example. Hence, in a measure of the usefulness of energy must take its 'quality' into account. Energy is considered to have useful quality when it is 'available' for human use. Useful energy is available for use, useless energy – from a human perspective – is that which has become unavailable, via the process of thermal diffusion known as entropy (the 'Second Law'). Every time energy is used usefully, some available energy is irretrievably lost as a result.

Second Law Efficiency:

$$\epsilon = \frac{\begin{array}{c}\text{actual heat or work}\\ \text{usefully transferred}\\ B\text{actual}\end{array}}{\begin{array}{c}B\text{min}\\ \text{theoretical maximum}\\ \text{heat or work}\\ \text{usefully transferred}\end{array}}$$

Considering energy use in terms of available energy had two implications. First, a theoretical *maximum* amount of available energy that could be obtained from a given process or fuel could be calculated ('maximum possible work extracted from a given quantity of fuel'). Second, for any energy-using task, the minimum amount of available energy ('minimum

[1126] Chapter 2.

work') needed to do that task could be calculated, again in theory. By dividing the second figure by the first (E2 = 'minimum work required'/'maximum possible work extracted from a given quantity of fuel'), a ratio called 'Second Law efficiency' could be determined. For a given task, if the available energy required could be reduced, then a corresponding quantity of available energy could, in some sense, be considered as 'conserved'. With this simple idea, the physicists believed they had transformed the objectives of engineering. Engineers would no longer be concerned with maximising the efficiency of energy input to output. In its place, they would seek to minimise the energy that it required to complete a task.

Redefining efficiency this way helped construct the ontology of ERC. In the proceedings of the Summer School, Socolow and his co-authors noted that 'Until recently, energy conservation at the point of extraction'[1127] which had motivated the regulation of extraction and supply industries (Chapter 4). Second law efficiency meant the end point of energy use was a potential site of conservation. Just as Landsberg had noted on behalf of *Resources for the Future* that year, the notion of conservation had been redefined (Chapter 5). Now, it was almost as if everyday appliances were considered a means for the supply of energy. As Rosenfeld later recollected, with the establishment of second law efficiency, and its applications to the major determinants of American energy demand, it was as if they had found 'a huge oil and gas field buried in our cities, factories, and roads'[1128]. Or, as Rosenfeld would later write, 'The reserves of energy created through conservation do not lie in the ground; rather they lie in the *end uses* of energy'[1129].

[1127] Carnahan et al., 1975, p. 21.

[1128] Rosenfeld, 1999.

[1129] Meier, A., Wright, J., Rosenfeld, A. (1983) Supplying Energy Through Greater Efficiency. The Potential for Conservation. University of California Press., p. viii.

There are a number of problems with these resource-ontological claims. First, the *maximum* amount of available energy that could be obtained from a given process or fuel was always *theoretical*. There was no perfectly efficient means to obtain work from fuel, so the value of the denominator was always a hypothetical ideal. Second, just because energy was categorised as 'available' in that it had not been consumed by completing the given task, this did not mean that this energy could necessarily be considered a 'resource'. To claim it was a resource would suggest that it could "got at" and "used", which clearly would not always be the case. In effect, it was as if the physicists had given an energy accounting convention the ontological status of a resource, without considering whether or not that resource could, in reality, be utilized.

As the heterodox economist and historian Philip Mirowski has pointed out, in order to make a measurement of Second Law Efficiency beyond the laboratory, or beyond the blackboard, the complexities of the actual energy using processes, and the various energy systems in which it was nested, like a China Doll, would mean the claim that there was some quantity of work held available in the system, and that this could be quantified and considered as a resource, would require solving an insuperable measurement problem:

> *'Of course, were one ever to seriously attempt to calculate such an index, one would rapidly learn that both the numerator and the denominator were so dependent on the particular context of use – that is, that the quantities involved are so path-dependent that the index has no meaning.'*[1130]

What kind of calculation could account for the manifold shifting relations of objects and forces that measurements of energy consist of when considered in their totality? There is no intrinsic property in a single *thing* which can be considered its energy, so energy calculation

[1130] Mirowski, P. (1988) 'Energy and Energetics in Economic Theory: A Review Essay', Journal of Economic Issues, Vol. 22, Iss. 3, p. 819.

would either have to be meaninglessly abstract of prohibitively complex[1131]. The reason being that thermodynamic theory means a system cannot be treated in isolation, but must be considered in terms of its relations to all other systems in which it is situated[1132]. Energy is a property of a system, not something that can be taken from that system. This suggests there was a considerably flaw to the idea of energy as a metrological resource; how could the use of available energy be practically achieved?

Ontological construction has always been a tool in physics, where conceptual objects are granted ontological status for analytical and theoretical purposes[1133]. For example, the concept of available energy, in Gibbs' statistical mechanics, was an analytical tool in order to describe the thermodynamic equilibrium, or all the possible states, of a given system, not a claim about the potential utility that could be derived from it[1134]. So to suggest there was an isolatable quantity of energy that could be quantified and considered a *resource* seems fanciful. The attendees had 'strongly recommend that this formulation, or a similar one, be widely adopted by the scientific and technical community[1135]. And it appears there was a brief vogue for measuring second law efficiencies, from heat pumps to chemical processes[1136].

[1131] Stenger's writes, cf. Clausius, the universe is the 'only "system" that, by definition, does not undergo exchange with an environment', to a true measure of available energy would have to begin at this scale. Stengers, 2010, p. 206.

[1132] Barry, A. (2015).

[1133] Stengers, I. (2010) Cosmopolitics I. University of Minnesota. Trans. Bononno, R.

[1134] Stengers, I. (2011) Cosmopolitics II. University of Minnesota. Trans. Bononno, R.

[1135] Carnahan et al., 1975.

[1136] Akau, R., Schoenhals, R. (1980) 'The Second Law Efficiency of a Heat Pump System, Energy, Vol. 5, pp. 855-863. See Ft's 1-10.

The idea of second-law efficiency was not new[1137], but the APS' very qualified claim that these savings might be achieved at the level of society was. But it was another, exaggerated use of this aspect of Summer School's findings, later published in *Foreign Affairs* which would prove most influential[1138]. Attendees had been enthusiastic about the savings that were possible at the level of a single task, but they were cautious about making any claim that these savings might be scaled up to a national level. In Chapter 9 we will discuss this popularisation of the physicists estimated level of energy demand reduction via the work of renegade physicist Amory Lovins.

FROM BUBBLES TO BUILDINGS

After the summer school Socolow remained at Princeton to continue his involvement in the Twin Rivers project[1139]. Rosenfeld returned to Berkeley, and to high-energy physics. Following the formation of a Californian Energy Commission in 1974[1140], Rosenfeld was drawn back to the science of energy conservation. He began teaching students about ERC, to an enthusiastic reception. As a result, in 1971 Berkeley established an interdisciplinary graduate 'Energy and Resources Group', headed by a young physicist called John Holdren[1141]. Soon after, Rosenfeld founded the Lawrence Berkeley Laboratory Centre for Building Science. There he developed a computer program, 'DOE1' which allowed detailed analysis of a building's energy demand[1142]. Around this time, Rosenfeld also began working

[1137] Denbigh, K. (1956) 'The Second-Law Efficiency of Chemical Processes', Chemical Engineering Science, Vol. 6, Iss.1.

[1138] Lovins, A. (1976) 'Energy Strategy: The Road Not Taken', Foreign Affairs, Vol. 55, Iss. 1, pp. 186-218.

[1139] Socolow, R. (1977) 'The Coming Age of Conservation', Annual Review of Energy, Vol. 2, pp. 239-289.

[1140] Wellock, T. (1998) Critical Masses: Opposition to Nuclear Power in California, 1958-1978. University of Wisconsin Press.

[1141] Rosenfeld, 1999, p. 38.

[1142] Cronin, J. ed. (2004: 278) Fermi Remembered. University of Chicago Press

with architect Edward Dean, to build 'TWOZONE', a computational model for evaluating the annual use of energy in a home in relation to the location, number, and size of windows[1143]. As a result of these efforts, by the end of the 1970s, the Lawrence Berkeley Laboratories largest division was that of 'Energy and the Environment'[1144]. There is perhaps no better indication of the shift in disciplinary prerogatives in the 1970s than one of the field's leading computational physicists shifting his labour from unravelling the secrets of the universe to the analysis of energy efficiency in the built environment. Just as Alvarez had overseen the transfer of computational technology from nuclear to high-energy physics, Rosenfeld would oversee its transfer to the science of ERC.

In many ways the analysis of the 'thermal characteristics of a building' was similar to the analysis of particles. The energy in particles and buildings was difficult to measure. Dean's description of the building analysis could equally have applied to the problems of isolating the properties of a particle: 'buildings operate as units. While we study components and systems as separate isolated subjects, in reality they are constantly working together and modifying the behaviour of one another'[1145]. This measurement problem, as argued above, could equally be applied to the notion of second law efficiency. Because as physicists increasingly refined their techniques of measuring, simulating and modelling energy *efficiency* in buildings and appliances, their estimates of rates of energy *conservation* could only be credibly made in reference to the specific system in question. Be it a house, engine, or lightbulb. To make such a claim applicable to society as a whole would appear prohibitively complex.

[1143] Dean, E., Rosenfeld, A. (1977) 'Modeling natural energy flow in houses', Energy and Buildings, Vol. 1, Iss. 1, pp. 19-26.

[1144] Heilbron, J., Seidel, R. (1989).

[1145] Dean, E. (1977) 'Introduction to the 1975 Berkeley Summer Study', Energy and Buildings, Vol. 1, Iss. 1, pp. 7-10.

The "macrosocial" implications of their micro-scale estimates of rates of conservation could not be assumed to occur at a societal level, or at least, physicists lacked the knowledge and authority to make such a claim. Societal dynamics lay outside of the domain of physics. The causal mechanism that translated the savings achieved in the laboratory, or the simulation of a house, into economy wide savings remained only a postulate. As we shall see in the next Chapter, it was economists who would appropriate the careful estimates of physicists as to rates of energy conservation and interpret them, within their own discipline's terms, as demonstrations of the 'elasticity' of energy demand at a societal level. Later in the decade, an entrepreneurial advocate for ERC would combine the work of physicists and economists with a countercultural gloss, to present an ambitious estimate of the possibilities for societal energy conservation in step with the *lebensphilosophie* of the nineteen-seventies. This will be discussed in Chapter 9.

CONCLUSION

Historian Paul Forman suggested that the last place we should look for the technologizing of science, and the epoch that this inferred, was the nation's high energy physics laboratories. This Chapter argues that it was these laboratories which were at the avant-garde of this cultural turn, and that ERC must be seen as an artefact of this. As Forman had written of quantum physics in the 1920s, in the 1970 physicists' growing interest in the science of energy conservation could be seen as the product of a 'hostile environment and [their] accommodation to its values'. Using Forman's approach, this chapter has detailed the circumstances under which scientists were swept up by contemporaneous intellectual currents. In an environment of funding cuts, disillusionment, and unemployment, the authority of physics remained intact, but it was applied to more prosaic goals, one of which

was the development of a properly physical science of energy conservation, employing careful measurement and simulation to show how ever greater efficiencies could be achieved in the use of energy.

By applying new computational methods, high levels of instrumentation in the built environment, and re-assessing the notion of efficiency itself, however improbable the reality of conserving energy at a societal scale, the result of these physicists' efforts was a reaffirmation of the ontology of conserved energy. It was as if measurement was itself a source of energy, a metrological resource, and as Rosenfeld later wrote 'Precisely because conserved energy is a novel source, the techniques used to estimate its reserves are almost as important as the estimates themselves'. The post-war authority of physicists had remained intact; it had simply been applied to a new form of scientific endeavour, the production of conserved energy as a resource.

And what of the forms of politics this new resource imposed? Clearly energy conservation was not as obviously ambitious as the exploration of space, or the development of nuclear weapons, nor was it a solution to the employment crisis, but this scaling back of ambitions was in step with a more general movement away from centralised, grand scale technological systems and toward small-scale, decentralised, networks of control[1146]. That a figure like Edward Teller, subject to the ire of radical scientists at the start of the decade[1147], could end it as an advocate for ERC, shows how, like in earlier periods, physics and the martial state were not easily disentangled. Socolow had stated that 'there are not many ways of rebelling and using more energy'[1148], but it was with some irony that reducing energy demand in fact

[1146] Kwa, C. (1993) 'Modelling technologies of control', Science as Culture, Vol. 4, Iss. 3, pp. 363-391.

[1147] Reiss, E. (1991) 'The Culture of Star Wars', Science as Culture, Vol. 2, Iss. 3, pp. 391-410.

[1148] Socolow, 1977.

became a small act of conformity in helping to maintain American hegemony, even when it was pursued for environmental or radical reasons. This hybridised politics of energy conservation will be discussed at length in Chapter 9.

Finally, as most of the physicists we have discussed would admit, they were not diagnosticians of the social implications of improved energy efficiency. This mantle would fall to economists, and it was their work which could provide an explanation of how increased energy efficiency at the scale of an appliance or an individual could have a material effect on societal energy use. In making such claims, the work of physicists, their careful estimates of the savings possible at a micro or system level, would bolster the later claims made by economists. Like the earlier work of RAND, the work of economists, in systematising the science of energy conservation into a general theory of political economy will be discussed in the next Chapter. But as late as 1979, physicists continued to believe that, as a second energy crisis loomed, as Iranian oil was nationalised, that they 'continue to be the professional community best qualified to advise and in some cases to work on this problem'[1149]

[1149] Anderson, P (1979) 'Statement for the APS', Newsletter of the Forum on Physics and Society. Vol. 8, No. 3, p. 4.

CHAPTER 8. THE ECONOMICS OF ENERGY RESOURCE CONSERVATION AFTER THE CRISIS (PART TWO)

In Chapter 4 it was demonstrated that for much of the twentieth century American petroleum conservation was something achieved via political intervention at the point of production. Pro-rationing and import licenses were intended to conserve domestic reserves. The aim of this Chapter is to demonstrate how, during the energy crises of the nineteen-seventies, the concept of fuel conservation was reinterpreted by economists to become a more all-encompassing notion of inter-fuel 'energy conservation'. The historian Timothy Mitchell argues that the crisis provided an opportunity for a new form of economics to gain credibility, which challenged interventionist economic policy. My argument extends Mitchell's, by suggesting that economist's adoption of the notion of conservation gave the profession means to argue for the deregulation of the fuel industries and the marketization of energy. Economists claimed such liberalisation was necessary in order to achieve of a form of societal structure which more closely resembled their econometric models of optimal resource allocation, all the while these claims were couched in the lexicon of conservation. This section is intended to follow on from Chapter 4, and the subsequent genealogy of Hotelling and Koopman's work is addressed. This Chapter concludes by arguing that in outlining a national or even a global mechanism for conserving energy, economists played a significant role in the ontological construction of ERC.

INTRODUCTION

As we saw in Chapter 2, the relationship between economic theory and the physics of energy were contested. The need to conserve exhaustible energy *resources* meant theories of political economy had long developed approaches to extending the use rate of resources. In Chapter 4 it was outlined that there were two dominant approaches to the economics of

petroleum conservation: the first implied that government should intervene to control production and importation in order to avoid wasteful oversupply; the second idea was that the market should be used to regulate the rate of petroleum extraction by letting interest rates dictate its price. As it was, for much of the pre and post-war period, both federal and state government tended to favour the regulatory approach, particularly following the oil glut and price crash of the nineteen-thirties. As it was, from the outset the market for oil had been fashioned by regulations rather than free competition[1150]. This meant the only evidence that advocates of a free market for fuel had were econometric models of the kind Harold Hotelling had proposed in 1931, or Koopmans algorithmic simulation of a perfectly competitive market, proposed in 1951. There was no empirical evidence to show how demand for petroleum would respond to price rises if the market were unregulated.

Irrespective of theory, the energy crises outlined in Chapter 5, would have a dramatic effect on the price of oil, which rose by 300 per cent between 1973 and 1974. Other goods rose in price alongside oil, and inflation rose by 13 per cent[1151]. The effect of price rises was magnified as the rising costs of foreign oil caused America's balance of foreign payments to fall. Initially the crisis seemed also to be a crisis for the economics profession. Following a 'golden age' of authority in the nineteen-sixties, MIT economist and management theorist Lester Thurow (1938--) observed economics – like other disciplines – was undergoing a degree of disestablishment, not only because of the energy crisis but also because of ongoing 'stagflation' (Chapter 4, p. 192) as 'economists neither predict these events nor seem to have cures for them'[1152].

[1150] Sabin, P. (2004) Crude Politics: The California Oil Market: 1900-1940. University of California Press.

[1151] Bernstein, M. (2001) A Perilous Progress: Economists and Public Purpose in Twentieth-Century America. Princeton University Press, Princeton and Oxford. p. 58.

[1152] Thurow, L. (1977) 'Economics 1977', Daedalus, Vol. 196, No. 4, pp. 79-94.

A rival discipline 'energy analysis', which stressed the primacy of energy as the source of value had slowly emerged, building on work carried out by heterodox geographers, anthropologists, and historians who had stressed the primacy of energy in human affairs. This nascent discipline seemed better suited to addressing the problem, as the subjective theory of value that defined neoclassical economics seemed to have reached an analytical impasse, , just as it had in the nineteen-thirties[1153]. Energy analysis, by contrast, implied the principles of physics, geology, and engineering were better able to explain both the crisis, and economic growth more generally[1154]. As a result, energy theories of value, and interventionist technocratic approaches to economic management would prove briefly in vogue[1155]. But after the Second World War, economics would gradually recover its authority, and economists would suggest the crises validated underlying economic principles, and that economics could become the leading discipline, and the economy the greatest contributor, to the science of ERC.

Before the energy crises, the economics of fuel, at this time, as the Jevons's and Zimmermann's work attested too, were grounded in geological and technological knowledge as much as economic theory. All three authors had provided a detailed geological account of the material circumstances of fuel distribution, and all had offered a lengthy discussion of the role of technological in both enabling and limiting rates of extraction. However, as historian Rüdiger Graf has noted, somewhat unexpectedly, the energy crises would encourage a new

[1153] Guyol, N. (1960) 'Energy Consumption and Economic Development', in Ginsburg, N. ed. (1960) Essays on Geography and Economic Development. Chicago University Press; Mirowski, P. (1988) 'Energy and Energetics in Economic Theory: a review essay', Journal of Economic Issues, Vol. 22, No. 3, pp. 811-830.

[1154] Berndt, E. (1981) 'From technocracy to net energy analysis: engineers, economists and recurring energy theories of value' Sloan School of Management, Working Papers, MIT. Research supported by the Department of Energy, under contract EX-76-01-2295.

[1155] In contrast to the oddly laissez faire technocratic approach advocated by RAND, Chapter 6.

form of 'petroknowledge', a form of expert knowledge regarding the properties of petroleum. This new form of knowledge took the shape of an economic theory that, as Graf notes, was 'largely disconnected from material fuel reserves'[1156]. Instead of taking account of the material and technological, as institutional economists - and to a lesser extent William Jevons - had done[1157], this new field of 'energy economics', would place abstract econometric principles at the core of its epistemological claims.

As Timothy Mitchell has similarly argued, despite the oil crisis partly resulting from an embargo, the economics profession reinterpreted events as an 'object lesson in the principles of neoclassical economics', leading to the development of a field known as 'resource economics'[1158]. Mitchell recounts the work of economist Robert Solow, who resurrected Hotelling's argument about the conservative capacities of the price mechanism in an unregulated market. Presenting this idea to the American Economic Association in 1973, he proposed that resource economics undermined the case for government intervention during the crisis, offering what Mitchell terms 'a neoliberal alternative: that the problem of the putative exhaustion of oil reserves can be overcome by market arrangements'[1159]. In response, this Chapter makes the following argument; Solow exemplified a more general tendency amongst economists to reframe two extant economic principles as 'energy conservation' mechanisms: the first was price 'elasticity', a neoclassical convention, which

[1156] Graf, R. (2014) 'Expert Estimates of Oil-Reserves and the Transformation of "Petroknowledge" in the Western World from the 1950s to the 1970s', in Uekötter, F., Lübken, U. eds. Managing the Unknown: Essays on Environmental Ignorance. Berghahn Books.

[1157] William Jevons had, as noted, given a detailed description of the material circumstances of coal in Britain, but as his marginal value theory suggested, it was the relation between this materiality and the psychophysiology of the consumer that determined value: value was not determined by *things* but by circumstance. See Chapter 2.

[1158] Mitchell, T. (2011) Carbon Democracy: Political Power in the Age of Oil. Verso. New York and London.

[1159] Ibid and Mitchell, T. (2010) 'The Resources of Economics', Journal of Cultural Economy, Vol. 3, Iss. 2. pp. 189-204., arguess this was key to overthrowing 'Keynesian' economics, but the economics of resource conservation, as we saw in Chapter 4, were explicitly Institutionalist.

when applied to 'energy' could be redefined as conservation; the second idea, based on econometric reasoning, was that the difference between a demand forecast in which fuels were optimally allocated and one of sub-optimal allocation could be considered as *conserved* energy. In this way, economics regained epistemic legitimacy, and claimed authoritative knowledge of an economy-wide, systemic means of conserving energy.

UNCERTAIN ELASTICITY

Before the crisis the economics of fuel were opaque. In 1960 a Resources for the Future ('RFF') study, led by resource economist Sam Schurr (1919-2003), former head of economics at RAND, claimed between the years 1950 to 1973 America's aggregate energy use had, and would continue to, grow by 3.5 per cent per year, closely mirroring the rate of growth of the economy, 3.7 per cent per year[1160]. There seemed to be clear relationship between increasing energy use and economic growth. But this relation had been achieved during a period of significant market intervention, including but not limited to: pro-rationing, petroleum import quotas, depletion allowances, indemnity for investments in nuclear power, coal extraction licenses, and federally controlled electricity and gas prices[1161]. With some irony during the Cold War, the American fuel industries were highly regulated and subject to centralised control; control over the energy industries, as we saw in Chapters -5-7, was a particularly useful means of combatting inflation[1162]. It was impossible to say if this coupling of energy use and economic growth indicated economic causation, or a policy-engineered correlation. Despite this lack of clarity, the majority of studies using data from the 1950s and 1960s came to the conclusion that energy consumption was roughly proportional to growth in

[1160] Schurr, S., Netschert, B. (1960) Energy in the American Economy, 1850-1975. An Economic Study of its History and Prospects. Resources for the Future, Johns Hopkins University Press.

[1161] Vietor R. (1984) Energy Policy in America since 1945. Cambridge University Press.

[1162] Prasad, M. (2006) The Politics of Free Markets: The Rise of Neoliberal Economic Policies, in Britain, France, Germany, & the United States. University of Chicago Press. Chicago, London.

national income, and that, accordingly, demand for energy was relatively inelastic[1163]. That is, demand did *not* decrease proportionately to increases in price[1164].

Though he offered no precise quantitative relation, the nineteenth-century Jevons had argued that there was no real substitute for coal's energy, and that if it were to become scarce this would irreparably *impede* Britain's economic growth (Chapter 2). Subsequently British economist Alfred Marshall (1842-1924) had refined the study of the effects of price on demand by introducing the notion of elasticity, defined as 'a percentage change in quantity demanded divided by the percentage change in price'. Marshall, unlike Jevons, believed others forms of energy could happily replace coal should its price rise[1165]. In accordance with this view, in the post-war period, economists termed the ratio between GNP and a general category of 'energy use' as 'the energy co-efficient': a measure of the percentage increase in energy use that goes with a one per cent increase in gross national product; the assumption being that a unit of GNP could use varying ratios of fuel[1166]. This coefficient provided a simple indication of the relationship between energy consumption and economic growth. The problem was that economists could not agree on a precise figure. In the 1960s, drawing on a variety of sources, it was estimated that the coefficient, or energy's elasticity[1167] ranged from 0.6 to 1[1168]. That is, energy was either directly coupled to economic growth in the case of a

[1163] Martin, J. (1981) 'Energy Demand Control in Energy Policy', in Amman, F., Wilson, R. eds. Energy Demand and Efficient Use. Proceedings of the Fourth International School on Energetics. Plenum Press. New York.

[1164] Adams, F., Miovic, P. (1968) 'On relative fuel efficiency and the output elasticity of energy consumption in Western Europe', The Journal of Industrial Economics, Vol. 117, pp. 41-56.

[1165] Reisman, D. (1987) Alfred Marshall: Progress and Politics. Macmillan London. p. 94.

[1166] Brookes, L. (1971) 'Energy and Economic Growth', Industrial marketing Management, No. 1, pp. 3-10.

[1167] Daly, H. (1976) 'Energy Demand forecasting: Prediction or Planning', Journal of the American Institute of Planners, Vol. 42, Iss. 1, pp. 4-15.

[1168] Brookes, 1971; Adams & Miovic, 1968.

coefficient of 1, or somewhat decoupled in the case of 0.6[1169]. The exact quantitative relation was open to debate.

The economics of energy supply were also contested. It was unclear whether energy supplies were dictated by demand or by the natural limits of materiality and geophysics. Energy resources were sometimes considered 'supply inelastic' in so far as rising prices were unable to elicit a proportionate increase in supply, nor did lower prices reduce the rate of supply[1170]. But given the scale of market intervention at the time, such thinking was purely speculative. As early as 1956, geologist Marion King Hubbert had suggested that the discovery of domestic crude oil in the United States would peak around 1971. This would decrease the energy available for economic growth. But Standard Oil Company economist John Ryan derided Hubbert's work for failing to account for the role prices would play in delaying and denuding the peak, as he believed oil was supply elastic, higher prices would increase supply be encouraging exploration and investment in the industry[1171], much like David Ricardo's reasoning a century earlier, advocates of supply elasticity indicated scarcity was something which could bring forth resources[1172].

Another aspect of this uncertainty was that even minor differences in estimates of energy's elasticity could lead to wildly divergent predictions of future demand. If demand was assumed inelastic, demand could be forecasted via 'pure extrapolation', as we saw in Chapter 6. Stanley Greenfield of RAND had criticized such forecasting as more a form of planning, it

[1169] The coefficient of 0.6 per cent came from Brookes' analysis of the British economy in the post-war period, which, he postulated, was a result of Britain's shift from low-efficiency coal to more efficient oil, Brookes, 1971.

[1170] Vietor, 1997: 6.

[1171] Bowden, G. (1985) 'The social construction of validity in estimates of US crude oil reserves', Social Studies of Science, Vol. 15, pp. 207-40

[1172] Chapter 2.

was 'self-fulfilling' as projected demand led to the construction of the plant required to meet the predicted capacity[1173]. Elasticities and coefficients were contested precisely because far-reaching decisions hinged on minute differences. If energy was considered inelastic, it made sense to invest in nuclear power and develop new power plants to meet demand. As Louisiana State economist Herman Daly had written: '*Prediction* sounds objective and scientific, while *planning* sounds subjective, arbitrary, and even socialistic. Hence we find the propensity to say *prediction* when one really means *planning*'[1174]. But as RAND researchers William Mooz and C.C. Mow remarked in 1972, as they developed their own demand forecasting method (Chapter 6), given the artificiality of the energy market 'informed subjective judgement is about all one has to go on'[1175]. Without clarity about energy's elasticity uncertainty reigned.

ELASTICITY CONFIRMED

The crisis of 1973 caused dramatic energy price increases. Even the belief in shortages the embargo triggered seemed to cause large price rises, suggesting that users could not easily switch to other forms of fuel, implying that petroleum was inelastic or even that it had a reverse elasticity: as the price went up, people seemed to buy more[1176]. Despite the exceptionality of the event, econometrician James Sweeney, of Stanford University's Energy Modelling Forum, established in 1976, suggested the energy crisis had provided 'a natural

[1173] Chapter 6, and Greenfield, S. (1970) Projection and Distribution of Waste Thermal Energy, RAND Corporation, P-4540.

[1174] Daly, H. (1976) 'Energy Demand forecasting: Prediction or Planning', Journal of the American Institute of Planners, Vol. 42, Iss. 1, pp. 4-15.

[1175] Mooz, W., Mow, C. (1972) The Growing Demand for Electrical Energy in California, RAND Corporation, R-IOB4-NSF/CSRA. P. 42.

[1176] Mabro, R. (1992) 'OPEC and the Price of Oil', The Energy Journal, Vol. 13, No. 2, pp. 1-17.

experiment […] allowing examination of sensitivity of energy consumption to prices'[1177]. Between 1973 and 1982 consumer prices increased 51 percent for gasoline, 139 percent for gas, and 23 percent for electricity. Utility companies paid 175 percent more for oil, 350 for gas, and 85 for coal. At the same time, oil, gas and electricity consumption fell at a rate of 1.4, 2.3, and 2.1 percent respectively, per year. As a reserve fuel, coal consumption increased by 2.6 percent. Alongside this, the economy grew only 1.8 percent year[1178]. This seemed to suggest the crisis caused demand for energy resources to fall, with concurrent economic contraction. It appeared that the energy analysts were correct, to some degree; energy use had determined economic growth. This fact, caused a wave of interest in heterodox energy-based theories of the economics of energy[1179]. Another interpretation was that price rises had not damaged the economy to the expected extent. As Brandies University economist Anne Carter remarked 'firms and final users are finding ways to reduce their consumption without necessarily curtailing their levels of operation', which meant assumed co-efficient ratios were no longer adequate[1180]. It was this second interpretation of the crisis would become most widely accepted amongst economists.

In part, this was due to new means of examining energy. In 1978 Schurr, still at RFF, would argue that the study of energy and the economy using formal econometrics was a 'new art, scarcely more than five years old', and that not only was it novel, it was transformative: first time, such models implied 'economic growth can be substantially separated from energy

[1177] Sweeney, J. (1983) 'The Response of Energy Demand to Higher Prices: What have we learned? Energy Modelling Forum, Stanford University. Paper presented at the 96th Annual Meeting of the America Economics Association, San Francisco, California.

[1178] Martin, J. (1981).

[1179] Nilsson, S., Kristofferson, L. (1976) 'Energy Analysis and Economics', Ambio, Vol. 5, Iss.1, pp. 27-29.

[1180] Carter, A. (1974) 'Applications of Input-output analysis to Energy Problems'. Science, Vol. 184, No. 4134, pp. 325-329., ten Raa, T., Baumol, W. (2011) 'Anne Carter and Input-Output: Technology Trade and Pollution', Oeconomia, Vol. 1, Iss. 1, pp. 59-72.

growth'. We saw how this was achieved in RAND's energy demand model in Chapter 6. Models allowed the depiction of unobservable theoretical entities[1181]: in this case, the global or national 'energy system'. It was no surprise that Tom Robertson, coordinator of the new University of Florida Energy Centre, described such models as 'new processes of perception'[1182], Such modelling was central to the systematisation of 'energy' as problem to managed by government, or by the market. And vitally, such modelling had demonstrated the possibility decoupling of energy from the economy at multiple sites, as Schurr noted: 'although the specific numerical findings differ from model to model, there appears to be consensus on the question of separation'. Though the 'true numerical values for this relationship' were ambiguous, because both before and after the crisis were periods of exception, given interventions and the embargo, the theoretical claim was clear: energy use could be decoupled from economic growth[1183]. It appeared that in some way, econometrics itself had enabled the realisation of the notion of decoupling.

Mitchell's account of the energy crisis also made the important point that economists' recast the complexities of fuel economy under the systemic rubric of 'energy'[1184], though as Chapters 5 and 6 argue, this systematisation had been ongoing for a number of years. But this section will argue that this process was aided by economists' discussion of the complex geographical, geological, technological, and behavioural determinants of energy use in the abstract language of econometrics. Econometrics, as its founding society had proposed, aimed at 'theoretical-quantitative and the empirical-quantitative' solutions to economic

[1181] Morgan, M., Knuuttila, T. (2012) 'Models and Modelling in Economics', in Måki, U. ed. Handbook of the Philosophy of Economics. V1. Handbook of the Philosophy of Science. Ed, Gabbay, D., Thagard, P., Woods, J.

[1182] Robertson, T. (1975) 'The System of Energy and the Energy of Systems', Sierra Club Bulletin, Vol. 60, March 1975; pp. 20-23.

[1183] Schurr, S. (1978) 'Modelling energy-economy interactions', Energy Policy, Vol. 6, Iss, 2., pp. 160-2.

[1184] Mitchell, 2011: 177.

problems[1185]; quantification was considered both a means of measurement and, importantly, theory formation. In practice, despite the fashionable rhetoric of 'application' economists had become increasingly concerned with the consequences of abstract assumptions rather than empirical specificity[1186]. As Lester Thurow observed 'econometrics shifted from being a tool for testing theories to being a tool for exhibiting theories'[1187]. In effect, messy reality was made to conform to abstract models, which in a return to neoclassical orthodoxy, took the optimising behaviour of individuals as the determinate law of economics[1188]. This would end the primacy of institutionalism in economic theory, and with it, the idea that conservation policy should be based on government intervention[1189].

Economics was also undergoing a related methodological transformation, thanks to the falling costs and the increased availability of computer power[1190]. In the 1950s, econometricians like Koopmans had developed calculative methods for minimising and maximising outputs in economic models. At the time, economy-wide analyses of these kinds had been too computationally demanding to carry out. In 1957 Koopmans proposed that computers would realise 'the full economic benefit of the new techniques' of linear programming[1191]. Though there had been computers for econometrics in earlier decades, with the advent of lower-cost and more powerful computers, such problems became

[1185] Louça, F. (2007) The Years of High Econometrics: A Short History of the Generation that Reinvented Economics. Routledge. p. 29.

[1186] Backhouse, R., Cherrier, B. (2014) 'Becoming applied: The Transformation of Economics after 1970', Working Paper, HOPE, Duke University.

[1187] Thurow p. 83.

[1188] Ruggles, N. (1970) Economics. Englewood Cliffs: Prentice-Hall.

[1189] Rutherford, M. (2001) 'Institutional Economics: Then and Now', Journal of Economic Perspectives, Vol. 15, No 3, pp. 173-194.

[1190] Backhouse, R., Cherrier, B. (2014) 'Becoming applied: The Transformation of Economics after 1970', Working Paper, HOPE, Duke University.

[1191] Koopmans, T. (1957) Three Essays on the State of Economic Science. McGraw Hill, New York

computationally assailable by multiple researchers[1192]. Whereas, in earlier years, when computers were scarce, economists and other types of modeller had been forced to constrain the granularity of their model to within the parameters of computational power, whereas now models could assume a level of complexity that contributed to a sense of their representativeness, objectivity, and explanatory power[1193], as we saw with RAND's energy demand model (Chapter 6).

Added to which, just as in other disciplines, 'applied economics' was in vogue, as part of wider federal enthusiasm for problem-led science. And under the provisions of the RANN programme, economic researchers could apply for federal funding for the first time (Chapter 5). It was no surprise when Solow, in his 1973 lecture to the AEA, noted as many as twelve economists were working on the same problem at the time: the economics of exhaustible resources[1194]. As Schurr had noted, this combination of computational power and problem-oriented research had led America's economists to the idea that energy use could be decoupled from economic growth. In fact, three of America's leading economists, Solow, William Nordhaus, and Koopmans, part of a tightly-clustered academic community, to the collective conclusion that demand for energy was elastic, and that were a market suitably liberalised, this would mean energy price rises - as a result of increased scarcity - would prompt a reduction in demand or encourage the use of substitute forms of power.

[1192] Backhouse, R., Cherrier (2014).

[1193] Erickson, P. et al. (2013) The Bounded Rationality of Cold War Operation's Research', in How Reason Almost Lost its Mind: The Strange Career of Cold War Rationality. Chicago.

[1194] Solow, R. (1974) 'The Economics of Resources or the Resources of Economics', Richard T Ely Lecture to the AEA 86th Annual Meeting, The American Economic Review, Vol. 64, Iss. 2, pp. 1-14.

MODELS OF OPTIMALITY

Solow, an influential professor at MIT, as Mitchell has written, essentially recycled Hotelling's argument, arguing that if energy prices were liberalised the vicissitudes of price would govern rates of extraction and conservation. His contention was that demand for energy was elastic, as consumers could find substitute forms of capital. Energy resources were a 'capital asset' like any other, and high energy prices would, according to the principle of 'optimal social management' cause the market to re-arrange the ratios of the different factors of production to develop a more optimal allocation of resources which would allow the maximisation of economic growth and the minimisation of costly energy inputs, just as the minimisation function of Koopmans linear programming model had demonstrated possible. Though Solow admitted the degree of substitution was an empirical question, the mathematics of optimality seemed to imply 'The world can, in effect, get along without natural resources'[1195]. Whereas, at the time, the incipient field of energy analysis was arguing entirely the opposite, and that the economics of energy must consider it a fixed, physical quantity rather than 'elastic monetary units'[1196]. Under the RANN program, economics would attract the greatest support from federal government[1197].

As an NSF grantee, Yale economist William Nordhaus advocated the use of markets to allocate scarce resources over time though he admitted that, given the crisis, it was an 'act of faith to believe that "the market" can somehow see the proper allocation [of energy] through this tangle of complexity, uncertainty, and politics'. Straining the limits of contemporary computing, he created an optimisation model of the energy economy of the entire non-

[1195] Ibid.

[1196] Berndt, 1981, p. 16.

[1197] Mata, T., Scheiding, T. (2012) 'National Science Foundation Patronage of Social Science, 1970s and 1980s: Congressional Scrutiny, Advocacy Network, and the Prestige of Economics', Minerva, Iss. 50, pp. 423-449.

communist world, which forecast demand for the next 200 hundred years. The model's objective was to calculate a set of energy resource prices 'to determine the allocation of energy resources (over time, space and different categories) that minimizes the discounted costs of meeting a set of final demands'. Unsurprisingly, given the underlying theory, 'The miraculous outcome of this procedure is that the calculated prices seem to be much the same as the market prices'[1198]. The modelling exercise appeared almost entirely tautological: according to the econometric principle of optimal allocation, the most optimal solution was that which came closest to the mathematical formalisation. As philosopher Ian Hacking has claimed, such social scientific claims, as 'looping effects', help solidify ontological claims[1199].

Koopmans, still based at Cowles, now recognised the coherence his approach when compared to that of Hotelling. Against contemporary concerns about limits to growth, or 'the model of possibly slow but inexorable and untimely catastrophic exhaustion', which was the 'subject of a protracted and continuing debate between economists and conservationists' (as documented in Chapter 3). Koopmans argued that an optimal theory of growth could be demonstrated which minimised the input of energy resources but maximised collective utility. Cast in the right way, there should be no conflict[1200]. The reason for this was, aside from the notions of elasticity and optimal allocation, the concept which bound all three of these studies was 'the future' as a means for making the market an optimal conservative mechanism. The scarcity of a resource, they argued, as Hotelling had done, in a freely

[1198] Nordhaus, W. (1973) 'The Allocation of Energy Resources', Brookings Papers on Economic Activity, 1973, Vol. 4, Issue 3, pp. 529-576

[1199] Hacking, I. (1995) 'The Looping Effects of Human Kinds', in Sperber, D., Premack, D., Premack, A. eds. Causal Cognition: A Multi-Disciplinary Debate. Clarendon Press.

[1200] Koopmans, T. (1973) 'Some Observations on 'Optimal' Economic Growth and Exhaustible Resources', Cowles Foundation Discussion Papers 356, Cowles Foundation, Yale University.

operating market, would be represented by the resource's price. But as Solow asked, 'who becomes the guardian of future interests'? He warned that ''one ought to be as suspicious of uncritical centralisation as of uncritical free-marketeering'.[1201] But despite this apparent reticence Solow, Nordhaus and Koopmans all advised the establishment of an 'organized futures trading in natural resource products'[1202].

Koopmans would win the economics Nobel in 1976 in recognition for his development of linear programming[1203]. Riding high, in 1977 he was selected by President Carter's government to lead a major simulation exercise 'Energy Modelling for an Uncertain Future' as part of a large-scale investigation, the Committee on Nuclear and Alternative Energy Systems (CONAES). This project was intended to show how America could reach the end of the century using energy in a more efficient and less strategically compromised way. The project took a pre-specified projection of future gross national product, and then used this as the basis for three different technological scenarios. In each of these scenarios the base data remained the same, other than price and income elasticities of demand, which were specific to each model. Within this basic framework, two operations were carried out. An optimisation algorithm, like the kind we encountered in Chapter 4, was used, in Koopmans' words 'to simulate the behaviour of a competitive market economy'. The other operation was to calculate out long-run analysis of elasticities of demand for energy consumers over time, as a function income, prices, and quantities of energy consumed: in this way, the economy became a device for producing conserved energy as a metrological resource.

[1201] Solow, p. 12.

[1202] Ibid, p. 13. Nordhaus, p. 534, Solow. p. 12.

[1203] He would only accept the award on the condition that Leonid Kantorovich, a Soviet economist who had developed a very similar model, was co-awarded the prize. Düppe, T., Weintraub, R. (2014) Finding Equilibrium: Arrow, Debreu, McKenzie and the Problem of Scientific Credit. Princeton University Press.

The exercise indicated that between 1975 and 2010 America could reduce its energy demand by 10 to 20 per-cent whilst only reducing GNP growth by 1 or 2 per cent. In this way, the CONAES model demonstrated how energy demand could be dramatically decoupled from economic growth with little effect on economic growth. Even reductions of 60 per cent of energy use in 2010 could be estimated to reduce GNP by between 2 and 20 percent, depending on whether a price elasticity of demand of between 0.5 and 0.25 was selected[1204]. In order to achieve this reduction 'energy prices are calculated so as to be in balance with an efficient path of the technology mix into the future, and thereby to induce the right amount of energy saving'[1205]. This normative language expressed in Koopmans' model, like that of Solow and Nordhaus, would optimally recalibrate the amount of energy the economy required as energy prices increased. As prices rose, alternative ratios of production inputs would be established which, contrary to the 'engineering literature' which stressed a persistent relationship between energy use and GNP', if energy prices were allowed to rise, the energy use is projected to grow less than proportionally'[1206]. In this way, the most effective way of decoupling energy from economic growth was to allow prices to rise.

Addressing the AEA in 1979, Koopmans view was that CONAES, and models like it, such as the recently completed Ford Foundation study on future energy demand[1207], demonstrated an 'important trait of the neoclassical model', which was that 'it does not postulate one sole primary resource'. In fact, 'any primary input to production can be substituted to some extent

[1204] Modelling Energy Group (1978) Energy Modelling for an Uncertain Future, Report Prepared for the Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences. Martin, J. (1981) 'Energy Demand Control in Energy Policy', in Amman, F., Wilson, R. eds. Energy Demand and Efficient Use. Proceedings of the Fourth International School on Energetics. Plenum Press. New York.

[1205] Koopmans, T. (1979) 'Economics amongst the sciences'', The American Economic Review, Vol. 69, No. 1, p. 9

[1206] Ibid.

[1207] Hudson, E., Jorgenson, D. (1974) 'U.S. Energy Policy and Economic Growth, 1975-2000', The Bell Journal of Economics and Management Science, Vol, 5., No. 2, pp. 461-514.

for any other'. 'In this view "the energy problem" is not one of just saving energy", regardless of the cost of other resources. It is rather one of seeing to it that the increasing real cost of domestic energy extraction and supply, and the increased market power of OPEC, are – over time – reflected in the real prices of primary energy forms relative to other primary inputs'[1208]. Here was a clear statement of the systemic nature of the problem of energy demand, the problem was not so much shortages of specific fuels or even non-fuel resources, but the ability of the market to reconfigure the different components of the economy to accommodate any shortages in a specific input.

If we think back to Chapter 2, we can now appreciate that the energy crises had the remarkable effect of returning economic theory to the position it had held in Ricardo and McCulloch's time. So rather than expressing a neoclassical trait, Koopmans model had returned to the argument of classical economics, and the pre-Jevonian argument for resource conservation, though expressed in the language of econometrics. Ricardo had argued that shortages in energy could be overcome via the substitution of alternate analogous forms of labour and capital. Koopmans, similarly, considered it an 'an empirical fact' that 'any primary input to production can be substituted to some extent for any other'[1209]. There was nothing special about energy as a factor of production; thus energy price rises would, in a freely operating market, allow demand for energy to be met by substitutes. The consumption of energy would eventually reduce at little cost to economic growth if two fundamental conditions were in allowed to occur: First, the price of energy must be allowed to rise in proportion to demand; second, nothing should hinder the substitution of other factors of

[1208] Koopmans 1979.

[1209] Ibid.

production in place of energy[1210]. Both of these conditions were contingent on the liberalisation of energy markets, and the removal of the post-war system of price controls.

CONCLUSION

In Jevons' work, unregulated markets were considered as a means for assuring exponential increases in coal consumption. But as this Chapter has sought to demonstrate, owing to developments in econometrics, the market was now seen as the primary means for regulating resource use in a homeostatic way; a means of ensuring logarithmic rather than geometric growth[1211]. As the crisis had shown that demand for energy resources had been shown to be elastic, according to the principle of optimal allocation, a liberalised market could absorb this elasticity without unduly damaging economic growth, as energy price rises would encourage the entire economy's ratio of productive inputs to be reconfigured to ensure that resources allocated in an optimal way; in effect, energy could be decoupled from economic growth. This has led to a new ontological statement about the existence of conserved energy as a resource: the difference in energy use in a forecast of sup-optimal resource allocation, and one of optimal allocation could be considered conserved. Sub-optimal futures could be contrasted with efficient ones, and the difference between them treated as if it were a resource. In this way, estimated quantities of conserved energy could be made in reference to a hypothetical, though never achieved profligate future.

The onus to conserve had shifted from producer to consumer, as Zimmermann had claimed would be necessary (Chapter 4). Thanks to the evidence proffered by econometricians, it was argued that individuals would not lose out on potential energy-derived utility. In fact, it was

[1210] Martin, J. (1981).

[1211] A similar argument is made in relation to economic indicators in Mitchell, T. (2014) 'Economentality: how the future entered government', Critical Inquiry, Summer, 2014, pp. 479-507.

argued, individual acts of conservation would bring them the economy close to the levels of growth that would have been achieved with profligate energy use. This idea prompted a radical reconsideration of the role of government in the political economy of energy. As aside from ensuring the market operated effectively, and that some kind of futures market for energy existed, the government's role was to rescind upon the high levels of market intervention that had been in place since the Second World War. As we will see in the next Chapter, this chimed with a declining faith in centralised political authority.

CHAPTER 9. COLD WAR TECHNOCRACY OR LOW ENERGY SUBCULTURE?

This chapter addresses a misconception regarding the history of ERC. From the 1970s onward, commentators have associated energy conservation with the diverse and often radical social movements collectively known as 'the counter-culture'. Following the previous Chapters, this association seems incongruous. It was argued researchers working in leading American research organisations and universities developed an applied science of ERC, which drew on systems theory, computer simulation, statistical mechanics, and econometrics. The science that emerged was intended to meet the resource needs and geopolitical objectives of the Cold War state during a period of supposed détente, and to improve economic productivity during a period of 'stagflation'. In contrast, the counter-culture were cast as 'technocracy's children', opposed to the strictures of post-war industrial society and continued American political hegemony. Despite this, ERC and counter-cultural politics were, and continue to be, conflated. In order to explain this curious hybridisation, this chapter documents the reception of the science of ERC within the counter-culture, as represented by the 'underground press', the media of this oppositional culture. This reveals the counter-culture was far from unanimous in supporting ERC, and yet, thanks to the one activist, a coherent theory of ERC emerged which seemingly combined counter-cultural politics and the applied science of ERC.

TECHNOCRATS OR TECHNOCRACY'S CHILDREN?

In describing the scientific implications of the Second World War historian of science Andrew Pickering borrowed a line from Thomas Pynchon's (1937) novel *Gravity's Rainbow* (1973). He suggested we must see 'the war itself as a *laboratory'* in which a new relation between science and the state was tested. Clearly, the science of ERC can be seen as product

of this new relation, a science of policy[1212]. But Pynchon's work is of further relevance to the history of ERC. *Gravity's Rainbow* captured the central concern of this chapter, it pitted a psychedelic and often paranoid, 'counterforce', including a talking lightbulb called Byron, against a totalitarian 'Elect', represented by an omnipresent V-2 rocket. Pynchon's narrative, as several reviewers noted[1213], explored the extent to which an oppositional culture can subvert an authoritarian regime. Also, the implications of open and closed energy systems were central to the novel's plot[1214]. Late in the novel, Friedrich Kekulé, the nineteenth century German organic chemist (1829-1896), hallucinates under the influence of benzene, and envisions the nightmarish consequences of untrammelled energy use:

> *'Taking and not giving back, demanding that "productivity" and "earnings" keep on increasing with time, the System removing from the rest of the World these vast quantities of energy to keep its own tiny fraction showing a profit: and not only most of humanity – most of the World, animal, vegetable and mineral, is laid waste in the process. The system may or may not understand that it's only buying time. And that time is an artificial resource to begin with, of no value to anyone or anything but the System which sooner or later must crash to its death, when its addiction to energy has become more than the World can supply, dragging with it innocent souls all along the chain of life.'*[1215].

This quotation, in which, as literary theorist Thomas Moore points out, Pynchon 'atypically, moralizes directly'[1216], gives some indication of the deep cultural significance that energy use took on at this time, and the anxieties that the energy status-quo provoked. Pynchon's account of 'the system' provides a good entry point into the cultural history of ERC in this period.

[1212] Thomas, W. (2015) Rational Action. The Sciences of Policy in Britain and America, 1940-1960. MIT Press.

[1213] Freer. J. (2014) Thomas Pynchon and American counter-culture. Cambridge University Press.

[1214] Seed, D. (1981) 'Order in Thomas Pynchon's "Entropy", Journal of Narrative Technique, Vol. 11, No. 1, pp. 135-153.

[1215] Pynchon, T. (1973) Gravity's Rainbow. Viking Press., p. 412.

[1216] Moore, K. (2008) Disrupting Science: Social Movements, American Scientists, and the Politics of the Military, 1945-1975. Princeton University Press., p. 175.

The preceding Chapters described the institutional and intellectual development of a science of ERC. By revisiting the work of the RAND Corporation, the nation's physicists and economists, and the Federal government itself (in the case of the 'CONAES' model, discussed in Chapter 8), it was shown how the calculative work of estimating efficiency savings could be carried out by combining engineering analysis and computer simulations, helping to establish conserved energy as a *metrological resource*. The energy infrastructure would act as a control mechanism, maintaining iterative reductions in energy use, meaning the growth rate of energy demand would decrease whilst the economy continued to grow. However, as Chapter 8 outline, in order for this decoupling to occur, the post-war political economy of energy, in which prices were controlled and government intervention was common, had to be liberalised.

Despite this association with ideas later termed 'neoliberal', ERC is often described as if it was an artefact of counter-cultural politics, which is itself cast as anti-technocratic[1217]. Californian historian Theodore Roszak (1913-2011) in his 1968 book *The Making of the Counter-culture,* took the term technocracy to mean 'a society in which those who govern justify themselves by appeal to technical experts, who in turn justify themselves by appeals to scientific forms of knowledge'[1218]. Energy resource conservation can be described as technocratic, in so far as its advocates suggested energy could be conserved only by applying scientific principles to problems that were normally addressed in political terms. In the United States, the term 'technocracy' had been briefly prominent thanks to support for Harold Scott's movement of that name, who in the midst of the 1930s depression had called

[1217] Davies, W. (2014) The Limits of Neoliberalism: Authority, Sovereignty, and the Logic of Competition. Sage, London

[1218] Roszak, T. (1968) The Making of a counter-culture: Reflections on the Technocratic Society and its Youthful Opposition. New York Double Day., p. 8.

for a new government, the 'Technate', to run America according to engineering principles[1219]. Though this movement was short-lived, aspects of technocratic thought were apparent in the post-war 'managerial revolution', though largely confined to industry (Chapter 3)[1220]. Energy conservation, as a national policy, represented a significant exception to this rule, in that it constituted, in the words of ORNL Director Alvin Weinberg[1221], a call for organising the country's economy upon 'thermodynamic imperatives'[1222]. The principles of ERC implied, in Habermas' phrase, the 'scientization' of political economy (Chapter 5).

Successive Presidents, Nixon, Ford and Carter pushed energy conservation as a means of reducing dependence on foreign oil, there moves can be seen as a détente era response to Arab states' deployment of the 'oil weapon'. As described in Chapter 7, in response, America's national laboratories, which had formerly developed nuclear weapons, now began to develop means for conserving energy resources. Similarly, researchers at RAND, such as 'C.C.' Mooz, who had formerly designed bombing systems, now proposed simulations as a means of saving energy. Cold War strategists like James Schlesinger (1929-2014), who had overseen combat operations in Vietnam, began to promote conservation as a means to exert geopolitical pressure on Middle Eastern countries. But perhaps the most prominent evidence of the use of ERC as a détente weapon was President Carter's 1977 reference to acts of energy asceticism, even simply lowering thermostats, as the 'moral equivalent of war'. Seen as a part of détente geopolitics, energy research conservation, to borrow Pynchon's term, appeared to be a means of perpetuating 'the system' of American hegemony and capitalist industry, rather than rejecting it.

[1219] Segal, H. (1985) Technological Utopianism in American Culture. Syracuse University Press., p. 128.

[1220] Elsner, H. (1967) The Technocrats, Prophets of Automation. Syracuse University Press., p. 213-19

[1221] Discussed in Chapter 7.

[1222] Weinberg, A. (1978) 'Reflections on the Energy Wars', American Scientist, Vol. 66., No. 2., pp. 153-158.

Aside from reducing demand for nuclear power, and reducing the fissile material available for nuclear weapon development, the politics of energy conservation seemingly had little to do with the values of the counter-culture, who Roszak had described as 'technocracy's children' in recognition of their rejection of post-war industrial society in favour of 'oriental mysticism, psychedelic drugs and communitarian experiments'[1223]. In light of this dissonance, the purpose of this chapter is to explain how the science of ERC and the politics of the counter-culture came to be conflated.

THE AMERICAN COUNTER-CULTURE

The size of the American counter-culture is contested. Some suggest there were anywhere between two- and fifty-thousand communes, populated by either a few thousand or seven-hundred and fifty-thousand people[1224]. Others suggest it is wrong even to see the counter-culture as a 'movement' to be quantified, rather than 'an inherently unstable collection of attitudes, tendencies, postures, gestures, "lifestyles", visions, hedonistic pleasures, moralisms, negations, and affirmations'[1225]. A recent account describes it as 'An inchoate collection of individuals, interests, and ideologies'[1226]. Irrespective of its size or solidity, the significance of this community or attitudinal event has been consistently affirmed. Geographer David Harvey described the counter-culture as a harbinger of postmodernity and the avant-garde of the decline of Western post-war industrial society[1227]. Historian Jon Agar described it as a network of diverse social movements, whose efforts contributed to a wider societal

[1223] Roszak, 1968: xii

[1224] Miller, T. (1999) The 60's Communes: Hippies and Beyond. Syracuse University Press., p. xix

[1225] Braunstein, P., Doyle, M. (2001) Imagine Nation: The American counter-culture of the 1960's and 70's. Routledge.

[1226] Kaiser, D., McCray, P. eds. (2016) Groovy Science: Knowledge, Innovation, and American counter-culture. University of Chicago Press.

[1227] Harvey, D. (1989) The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change. Wiley.

transformation by subjecting the fundamental concepts of Western modernity to an 'oppositional tone'; concepts such as 'authority', the 'hierarchy, 'establishment' and the 'system' were redefined[1228].

But most ambitiously, French sociologists Luc Boltanksi and Éve Chiapello saw the counter-culture as the avant garde of a new spirit of capitalism, which they term 'connexionist' or 'networked'. In contrast to the class-based management hierarchies of the late 1960s, connextionist capitalism promoted individual autonomy was promoted as an ideal. Individuals were encouraged to operate in a non-hierarchical networks of relations, rather than according to traditional class factions. The result, Boltanski and Chiapello claim, was a new 'postmodern, post-Fordist, re-engineered' capitalism, in which old distinctions between work/leisure, factory/home, and public/private were cast aside in favour of the individual pursuit of wealth. Dictates of economic control, formally authoritarian and statist, were internalised[1229]. Energy resource conservation, in meshing counter-cultural principles with a new economic theory, seems to embody this new spirit.

The association made between ERC and the counter-culture was first made by the established energy utility industries, and was intended to disparage the claim that energy could be conserved. Unfortunately, historians of this period have repeated and reaffirmed this misattribution. For example, in his history of electricity deregulation David Hirsh describes how energy conservation, 'once viewed as a cause pursued largely by counter-culture environmental zealots' became 'mainstream' by the end of the 1970s[1230]. And historian

[1228] Agar, J. (2008) 'What Happened in the Sixties?', The British Journal for the History of Science, Vol. 41, Iss. 4.

[1229] Boltanksi, L., Chiapello, E. (2006). New Spirit of Capitalism. London, Verso.

[1230] Hirsh, R. (1999) Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System. MIT Press., p. 4.

Thomas Wellock, in recounting the history of Californian's opposition to nuclear power, memorably claimed the state legislature underwent an 'Aquarian takeover' in 1975, as 'new age' ideologues opposed the development of a proposed nuclear power plant in Southern California, on the basis that energy could be conserved, which obviated the need for new plant[1231]. In attributing the development of ERC to the counter-culture, these historians mirror the association first made by the energy industry, and obscure the true history of this unusual resource.

So far, this thesis has argued there was no way to simply characterise the politics of ERC. RAND-based environmentalists argued that conservation could end the need for nuclear power, a totem of American technocratic government, but they did so by employing the very methods which legitimised technocratic policymaking[1232]. Similarly, members of the American Physical Society (APS), in redefining energy efficiency, believed their actions were politically radical, and a means to move away from nuclear power and its associated political authoritarianism (Chapter 7). At the same time, military strategists would employ estimates of conservation savings as a strategic détente 'weapon'. Energy conservation also provide da rationale for liberalising energy markets, and economies generally. Given these ambiguities, this Chapter adds to the contradictory picture by suggesting the counter-culture were far from unanimous in their enthusiasm for ERC. However, from this plurality of opinion, a theory of energy conservation emerged which combined mainstream and counter-cultural values and went on to prove highly influential. In many ways, by the end of the decade, energy conservation manifest many of the characteristics which, much later, media theorists Richard Barbrook and Andrew Cameron, in their critique of the political economy

[1231] Wellock, T. (1998) Critical Masses: Opposition to Nuclear Power in California, 1958-1978. University of Wisconsin Press., p. 189.
[1232] Ibid.

of the internet, derided as 'the Californian ideology'. A political philosophy involving an 'unexpected collision of right-wing neo-liberalism, counter-culture radicalism and technological determinism'[1233].

LOW ENERGY SUBCULTURES

In 1976, ecologist Howard Odum (1924-2002) and his wife Elizabeth published a popular guide to the science and politics of energy. Like other ecologists, Howard's interest in energy had been prompted, in part, by earlier work in radioecology, carried out on behalf of the Atomic Energy Commission[1234]. By 1976 the Odums had become increasingly occupied with promoting a low-energy society. Imbued with a sober asceticism, they argued that their vision was different to that being espoused by, what they termed, a 'low-energy subculture'. Young people who had assumed unconventional lifestyles to 'avoid the excesses of the high-energy growth period'[1235]. The Odums expressed some scepticism about this subculture's commitment to using less energy, cautioning that it would require hard work – an attribute they presumed lacking[1236]. This accusation seemed ungrounded, New England's 'Clamshell Alliance' were an example of such a low-energy subculture. Veterans of the anti-Vietnam war movement, and they believed nuclear power represented a threat to human survival. The same year as the Odums' book was published, they occupied the site of a proposed nuclear development in Seabrook, New Hampshire, planting pine and maple saplings, and refusing to move like their eponymous mollusc. Some were members of a rural commune called Montague Farm, founded in Massachusetts in 1968, who long before the energy crisis had

[1233] Barbrook, R., Cameron, A. (1995) 'The Californian Ideology', Science as Culture, Vol. 6, Iss. 1., pp. 44-72.
[1234] Melosi, M. (2012) Atomic Age America. Prentice Hall.
[1235] Odum, H., Odum, E. (1976) Energy Basis for Man and Nature. McGraw Hill., p. 251.
[1236] Ibid.

advocated the use of solar power and the adoption of lifestyles which required only low-levels of energy use[1237].



Figure 9.1. The Clamshell occupation of Seabrook in 1976.
Still from the documentary 'The Last Resort' (1979**)**
Directed by Daniel Keller, Green Mountain Post Films ©

In 1978, Alvin Weinberg, head of Oak Ridge National Laboratory (ORNL), described the Seabrook protest as part of an ongoing 'energy war', in which the future of energy use had become a fight over cultural values. 'On one side' he wrote 'are the energy "radicals" and 'on the other, the energy "conservatives" - the Energy Establishment and the nuclear people'[1238]. Radicals similarly employed martial language, associating nuclear power with the existential threat of nuclear bombs[1239]; and in some cases, anti-nuclear protests had become violent, or

[1237] Slonecker, B. (2012) A New Dawn for the New Left. Liberation News Service, Montague Farm and the Long Sixties. Palgrave., p. 128; Downey, G. (1986) 'Ideology and Clamshell Identity: Organisational Dilemmas in the Anti-Nuclear Power Movement', Social Problems, Vol. 33, No. 5, pp. 357-373.

[1238] Weinberg, A. (1978) 'Reflections on the Energy Wars', *American Scientist*, Vol. 66., No. 2., pp. 153-158.

[1239] Nelkin, 1981.

destructive: in 1974, an organic farmer called Samuel Lovejoy tore down a five-hundred-foot tower, erected in Montague, to assist the siting of a proposed nuclear power plant. For anti-nuclear activists this sabotage became a symbolic event, and Lovejoy a folk-hero in a conflict increasingly known as the 'energy war'[1240]. This war was fought internationally, as across Europe anti-nuclear radicals clashed with the state, in an effort to curtail the development of nuclear power. For example, in Creys-Malvilles, France, in 1975, sixty-thousand people had protested at the site of the 'Super-Phenix' nuclear development. It had culminated in pitched battles fought with the policy. A thirty-one-year-old protestor, Vital Michalon, was killed as his lungs collapsed under the force of a grenade[1241]. And in 1974 in Whyl, North West Germany in 1974, thirty-thousand protestors occupied a proposed nuclear development site for nine months. This protest was peaceful, but relation between nuclear power and nuclear weapons gave their campaign a sense of apocalyptic urgency, as West Germans felt they were on the frontline of the Cold War[1242]. By contrast, the American energy war was relatively peaceful. As a RAND investigation noted, one of the most prominent factions, the Clamshell alliance, refused violence[1243]. Not forgetting that RAND researchers had themselves made the case against nuclear power development (Chapter 6).

As the head of the ORNL, though his laboratory worked on reducing energy demand, , Weinberg defended 'energy conservatives' and their continued support for nuclear power. The problem with the radical position, he argued, was that 'thermodynamic imperatives are

[1240] Wasserman, H. (1979) *The Energy War: Reports from the Front*. Independent Publishers Group, California.

[1241] Nelkin, D., Pollak, M. (1980) The Atom Besieged: Extraparliamentary Dissent in France and Germany. The MIT Press.

[1242] Barkan, S. (1979) 'Strategic, Tactical and Organisational Dilemmas of the Protest Movement against Nuclear Power', Social Problems, Vol. 27, Iss, 1.

[1243] Daubert, V. (1985) Origins, Goals and Tactics of the US Anti-Nuclear Protest Movement. RAND Corporation, California.

elevated to sacred dogma'[1244]. Weinberg suggested a fundamentalist advocacy for energy conservation, above all else, undermined the guiding principles of modern society[1245]. But Weinberg presented America's 'energy radicals' as a homogenous group, as the Odums had disparagingly done, in fact, as we shall the assumption that the counter-culture advocated ERC, and that it was in some way radical, was a convenient untruth.

THE UNDERGROUND PRESS

In order to understand the counter-culture's approach to energy, this chapter looks at the 'underground press' of the late 1960s and 1970s, rather than relying on the perspective of members of the 'energy establishment'. Boltanski and Theivenot, in their study of capitalism's new spirit, studied the textbooks of management theory, but here, the underground press might be thought of as a means of accessing a different form of 'moral education'[1246].The underground press was a diverse print medium for new social movements to articulate their views. For example, Montague Farm was not only commune, but also a hub of journalistic activity. Its members had split from the Harlem based *Liberation News Service,* an agency founded in 1967, which collated ('clipped') and posted packets of news stories of pertinent to counter-culture concerns. In 1968, the commune split. Disgruntled Leftist radicals stole *Liberation News Service's* printing press and began producing their own publication, though eventually ceding control back to the more politically agnostic, 'back to the land' Harlem group[1247]. This episode illustrates two points. First, the counter-culture was not politically homogenous. Second, this heterogeneity found expression in the movements' publications.

[1244] Weinberg, 1978: 154.

[1245] Ibid.

[1246] Boltanksi, L., Chiapello, E. (2006).

[1247] Slonecker, 2012, p. 3.

As an early issue of *Liberation News* noted, the underground press had developed from 'rough-hewn rags, extolling the virtues of dope and goodness' to become 'a synthesis of the cultural and political aspects of making a revolution in this country'[1248]. *Liberation News* considered itself as a 'new media' which undermined 'bourgeois conceptions of "objectivity" and re-evaluated 'established notions about the nature of news'[1249]. Another aspect of this new media was its scale; though individual journals were generally published in small numbers, the total number of 'underground' publications reached around 500 by 1969, with an estimated circulation of around 333 thousand[1250]. By the mid-1970s, at the height of its popularity *Liberation News* alone estimated a total readership at 4.6 million[1251]. Historian of American socialism Joseph Conlin argues readers should avoid jumping to any conclusions when such figures are cited, as publication numbers and circulation figures could mislead, and history had taught him that 'it is by no means frivolous to suggest that the movements, parties, factions, and tendencies that make up American radical history were actually subsidiary to their organs'[1252]. So, though the underground press been smaller and its readership more aspirational than they might like to suggest, the medium offers some evidence of the development and diversity of oppositional counter-cultural politics[1253].

ALTERNATIVE TECHNOLOGY

For counter cultural groups, certain technologies had become known as 'alternative' in recognition of their perceived contribution to oppositional counter-cultural life. Members of

[1248] Dreyer, T., Smith, V. (1969) 'The movement and the new media', Liberation News Service, March 1.

[1249] Ibid.

[1250] Conlin, J. ed. (1974) The American Radical Press, 1880-1960. Greenwood, Connecticut & London., p. 6.

[1251] 2 per cent of the total U.S. population in 1974.

[1252] Conlin, J. ed. (1974)., p. 7.

[1253] Dreyer & Smith, 1969.

groups such as the New Alchemy Institute, founded in 1969 by biologist John Todd in Massachusetts, and the Farralones Institute, founded in California the same year by the architect Sim Van der Ryn, vocally advocated alternative technologies. Partly drawing on the self-reliant principles of American settlers, alternative technologists also drew on British economist Ernst Schumacher's 'appropriate technology' movement. Schumacher's followers had developed the idea of 'intermediate-technology', simple, human-powered technologies intended to help former British colonies to develop in a more sustainable and less energy-intensive manner than that of the West[1254]. Such was the concern with the political implications of certain technologies in the 1970s sociologist Langdon Winner claimed that in that decade 'the subject of technology has finally come alive'[1255].

Technology was the subject of the *Whole Earth Catalog*. In 1968, Stewart Brand (1938), a biologist who had studied under Paul Ehrlich (1932), author of the *Population Bomb*, published the first issue of *Whole Earth*, a directory of technologies intended to appeal to the counter-culture. The *Catalog* began with a hubristic statement of humanity's technological power: 'We are as gods, and might as well get good at it'[1256]. In both Britain and the United States, and elsewhere, a younger generation had begun to discuss how science and technology might be appropriated as a means for social transformation. In contrast to the supposed rejection of technology that Roszak claimed, the counter-culture actively engaged with science and technology as a means for transforming their relation to the environment and each other.

[1254] Pursell, counter-culture. (1993) 'The rise and fall of the appropriate technology movement in the United States, 1965-1985', SHOT Presidential Address. Technology and Culture, Iss. 34. pp. 629-637.; Winner, L. (1979) 'The Political Philosophy of Alternative technology: historical roots and present prospects', Technology and Society, Vol. 1, Iss. 1, pp. 1-86.

[1255] Winner, 1979, p. 75.

[1256] Brand, S. et al. (1968) The First Whole Earth Catalog. The Whole Earth Press.

A recent spate of revisionist history has drawn attention to this counter cultural technophilia. Historian Andrew Kirk has argued the counter-culture transformed environmental politics, shifting the movement from an anti-technological or 'anti-modernist' position toward a vision of technologically enhanced sociality and human-environment symbiosis[1257]. Media historian Fred Turner has noted the counter-culture's enthusiasm for computers and the 'cybernetic rhetoric of systems and information' helped contribute to the rise of personal computing and the internet[1258]. Cybernetics, loosely interpreted by counter-culture ideologues like psychedelic guru Timothy Leary and media theorist Marshall McLuhan, rather than appearing technocratic as they had to an earlier generation, appeared to offer a theory of non-hierarchical control that appealed to counter-culture sensibilities[1259]. Given that this thesis has argued that the science of ERC was partly based on cybernetic principles, systems analysis, and the idea that information could in some way act as a supplement for energy, it could be assumed the counter-culture would be highly receptive to the idea. However, this assumption misleads.

COUNTER-CULTURE ENERGY

In order to understand the diversity of counter-cultural opinion toward ERC it is perhaps best to start with the *Whole Earth Catalog*, the publication central to Kirk and Turner's technophiliac accounts[1260]. Since the magazine's inception in 1968, the term 'energy' had been highly prevalent, but in a variety of senses far beyond the thermodynamic. It was used

[1257] Kirk, A. (2007) counter-culture Green: The Whole Earth Catalog and American Environmentalism. University Press of Kansas.

[1258] Turner, F. (2006) From counter-culture to Cyberculture: Stewart Brand, The Whole Earth Network, And the Rise of Digital Utopianism. University of Chicago Press., p. 4.

[1259] Eglash, R. (1998) 'Cybernetics and American Youth Subculture', Cultural Studies, Vol. 12, Iss. 1., pp. 382-409.

[1260] Kaiser, D., McCray, P. (2016).

to describe the poetry of architect Buckminster Fuller, Jungian psychology, yogic practices, and, most memorably, by physiologist John Lilly who described the effects of self-experimentation with flotation tanks and LSD in terms of 'white noise energy'[1261]. But the OAPEC embargo was transformative, as Brand noted at the end of the decade: 'Since 1973 we have been given an energy x-ray of our economy by the historic events around oil pricing'[1262]. As a result, energy was increasingly discussed in terms of alternative energy technologies, means of breaking free from the strictures of conventional energy dependent society.

In this context, the *Whole Earth's* advertisements for 'Dunlite' wind-powered electricity generators, methane digesters and solar stills offered readers the possibility not only of detachment, but also a means to re-envision a community as a system. In New Mexico, *Whole Earth's* co-editor John Baldwin, an engineer, developed 'Alloy', a self-contained commune of geodesic domes, intended to operate as an autonomous system, collecting and generating all the resources that were required. These 'Arks' were to be self-reliant in energy, and Baldwin and others employed Howard Odum's systems analytic approach to ecosystems to set out how this might be achieved in the built environment. Odum had carried out exploratory research work for NASA, in order to develop means for long-term space travel. He had suggested space travellers would be best supported by the creation of a simple, self-sufficient, ecosystem[1263]. The New Alchemists attempted this on earth, as they hoped capturing geothermal heat, wind, and solar power, the idea was that the Ark could use and

[1261] Brand et al, 1968.

[1262] Brand, S. et al. (1980) The Next Whole Earth Catalog. The Whole Earth Press., p. 172 ,

[1263] Bryant, W. (2006) Whole System, Whole Earth: The Convergence of Technology and Ecology in Twentieth-Century American Culture. Unpublished Doctoral thesis.

recycle resources in a feedback system open to alternative energy supplies but closed to conventional hydrocarbon derived sources of power[1264].

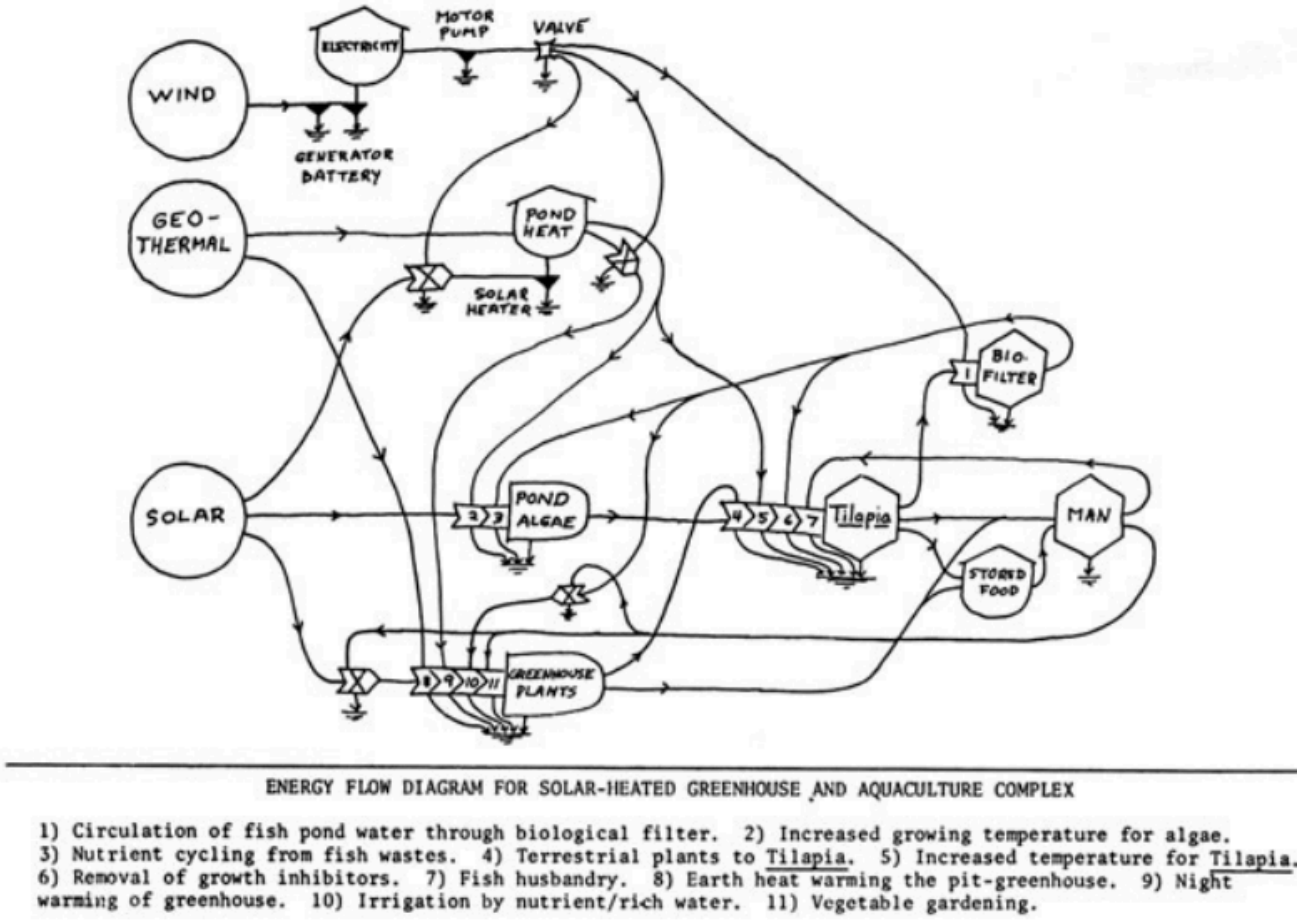

Figure 9.2, Energy Flow Diagram for an 'Ark'
Journal of the New Alchemists 2, Reprinted in Kirk 2016: 158.

In the 1974 edition, under the banner of 'soft technology', the *Catalog* contained thirteen pages of 'soft' energy technologies[1265]. Soft technology, as Brand wrote, was 'gentle on its surroundings, responds to it, incorporates it, feeds it'[1266]. The emphasis was an alternative

[1264] Kirk, A. (2016) 'Alloyed: Countercultural Bricoleurs and the Design Science Revival', in Kaiser, D., McCray, P. eds. (2016) Groovy Science: Knowledge, Innovation, and American counter-culture. University of Chicago Press.

[1265] in contrast to just two pages in 1968.

[1266] Brand, S. et al. (1974a) Whole Earth Catalog - Epilog. The Whole Earth Press., p. 526.

forms of supply rather than, as the conventional science of ERC, reducing energy demand. The 1974 issue contained only one section on 'energy efficiency' which mentioned only cycling[1267]. As the *Catalog's* technology editor, Alloy's Baldwin admitted there was 'a lot of work to be done in reducing the NEED for energy; and that 'except for a very few projects, most work has only lightly touched on that'[1268].

The 'soft technology' philosophy was markedly distinct from the science of ERC outlined in previous Chapters. The authors of the *Energy Primer,* a collaboration between *Whole Earth* and the *New Alchemists*, suggested the onus to save energy was on the individual rather than a potential property of the system as a whole:

> '[L]*owered thermostats, simple appliances and efficient insulation are all important methods of reducing energy consumption. But by themselves they mean little unless they become part of a personal plan to change our standard of living, recycle our materials, and make do with less'*[1269]

Whereas RAND's approach to energy conservation, outlined in Chapter 6, had called for 'strategies of restriction' whose success would depend 'on the strength of the prohibition and the degree to which it is enforced', which seemingly implied a fairly authoritarian approach to conserving energy resources[1270]. This was significantly different from the autonomous, individualist system of energy use proposed by the counter-culture. So, in *Whole Earth* at least, alternative energy meant an independent and renewable supply, or the use of low-energy consuming technologies, not the optimisation of the allocation of energy in the conventional energy system.

[1267] Brand, S. et al. (1974b) The (Updated) Last Whole Catalog. The Whole Earth Press., p. 638.

[1268] Baldwin, J., Brand, S. (1978) Soft~Tech. A Co-evolution book. Published by the Whole Earth Catalogue., p. 527.

[1269] Merrill, R. (1978) Energy Primer: Solar, Water, Wind and Biofuels. Portola Insitute.

[1270] Chapter 6.

THE ENERGY LEFT

The technophile *Whole Earth Catalog* and related journals of the *New Alchemists* and *Mother Earth News* have dominated counter-cultural revisionism[1271]. This has presented a somewhat homogenous view of counter-cultural technological politics, which is pro-technology and anti- engagement in conventional politics[1272]. However, a left-wing movement had persisted in America, despite the collapse of the Communist Party in the 1950s. A 'New left' had even emerged in the nineteen-sixties, which defined itself in opposition to doctrinaire Marxism and the Soviet Union. In 1962, a group called Students for a Democratic Society (SDS) had published what became known as the Port Huron statement, the movement's founding document, authored by twenty-two year-old student Tom Hayden (1939-), it had called for a renewed 'participatory democracy' in which each citizen would oppose inequality, racism and the militant culture of America, rather than hoping organised labour, or capitalism's internal contradictions would lead to societal transformation[1273]. Little has been written of the New Left's approach toward energy. And for some, environmentalism was considered a bourgeois distraction from the real work of political activism[1274]. But the statement had, surprisingly, called for an *increase* in energy provision, particularly in the developing world, where 'atomic power plants must spring up to make electrical energy available'[1275]. Here the emergence of an 'energy left' is re-affirmed, and their approach to ERC outlined.

[1271] Kaiser, D., McCray, P. eds. (2016)

[1272] Barbrook & Cameron, 1995; Kirk, 2002; Turner, 2006.

[1273] Mattson, K. (2002) Intellectuals in Action: The Origins of the New Left and Radical Liberalism, 1945-1970. Pennsylvania University Press.

[1274] Gottlieb, R. (2005) Forcing the Spring: The Transformation of the American Environmental Movement. Island Press.

[1275] SDS (1962) 'Port Huron Statement of the Students for a Democratic Society', Available at: http://www.sds-1960s.org/PortHuronStatement-draft.htm

Barry Commoner (1917-2012), professor of plant physiology at Washington University, would emerge as the energy left's leader, as an ideologue who linked left-wing politics, shaped by his involvement with the post-war New York labour movement, with emerging concerns about the politics of nuclear energy. In the late 1950s, Commoner, was a member of the St Louis' *Committee on Nuclear Information* (CNI). A program at Washington University, led by doctors Louise and Eric Reiss, who were increasingly concerned with the biological effects of nuclear radiation. They led a campaign to collect and test babies' teeth for the presence of radioisotope Strontium-90. The 'Baby Tooth Survey', which continued until 1968, was both a form of data collection and also an affective means of raising public awareness about the potential relationship between nuclear weaponry and power and incidences of cancer[1276].

In 1971, Commoner wrote *The Closing Circle.* Using the example of nuclear radiation, he suggested the public's lack of awareness of the risks and externalities of science and technology was an inevitable effect of capitalism, as risk, as a form of labour, was 'subsidized by society'[1277]. The *Closing Circle* also attacked fellow biologist Paul Ehrlich's *Population Bomb* (1968)[1278], as Commoner argued population crisis, like the environmental crisis, was the product of the contradictions of capitalism, rather than birth rates, themselves the product rather than cause of poverty[1279]. Like Ehrlich, Commoner's work was informed

[1276] Egan, M. (2007) Barry Commoner and the Science of Survival: The Remaking of American Environmentalism. MIT Press.

[1277] Commoner, B. (1971) The Closing Circle: Nature, Man and Technology. Random House.

[1278] Chapter 5.

[1279] Egan, 2007.

by systems theory[1280]. But unlike Ehrlich, Commoner took systems theory as a demonstration of the need for cooperative and redistributive politics rather than population control[1281].

Commoner's next book *The Poverty of Power* (1976) described the energy crisis in similarly politicised terms. It was the result of a 'mindless chain of events' conditioned by an economic system which had 'concentrated the physical power of energy and the social power of the resultant wealth into ever fewer, larger corporations; that has fed this power on a diet of unemployment and poverty'[1282]. Reiterating a causal relation between energy and labour, as technocrats had (Chapter 3), Commoner argued the use of fossil and nuclear fuels have to be reconsidered, and the public needed to ask why the 'system has been designed to waste energy so blatantly'[1283]. Systemic energy waste, he argued, resulted from thousands of decisions based upon profit maximisation, and the use of cheap mineral energy rather than more costly human labour, which blocked the development of 'a rational, thermodynamically sound energy system'[1284].

Commoner's proposed solution drew on RANN funded research, as outlined in the previous three Chapters. Throughout his book he cited the 1974 American Physical Society (APS) study, and their attempt to redefine efficiency (Chapter 7) which Commoner suggested, was 'an extremely important study'[1285]. He also cited Eric Hirst's work on reducing energy demand at Oak Ridge National Laboratory, and the industrial engineer Charles Berg's

[1280] Turner, 2005, p. 44.

[1281] Lewis, D. (2012) 'Scientist, Candidate and Planet Earth's Lifeguard', New York Times, October 1., p. A1.

[1282] Commoner, B. (1976) The Poverty of Power: Energy and the Economic Crisis. Random House., p. 264.

[1283] Ibid, p. 5.

[1284] Ibid, p. 258.

[1285] Ibid, p. 270.

work[1286]. On the basis of this and other research Commoner suggested as much as thirty-five per cent of U.S. energy use could be saved if suitable reforms were made[1287]. For Commoner, the potential to reduce energy demand offered a path to radical political change, the value of labour could be re-enshrined, and the use of fossil fuels could be rendered more costly through the demand for greater responsibility in their use.

A RADICAL SCIENCE?

As outlined in Chapters 5 and 7, a younger generation had become increasingly disillusioned with the trajectory and patronage of scientific research. Solidifying this discontent, in 1969, physicist Charles Schwartz had formed Scientists and Engineers for Social and Political Action (SESPA), an attempt to reorient the objectives of scientific work toward more socially progressive ends. Chapter 7 described how SESPA member Robert Socolow, from Princeton, and radical sympathiser Arthur Rosenfeld, of Berkeley, were central to the development of a science ERC. Recasting efficiency in terms of the second rather than first law of thermodynamics, they were able to reconceive of energy-using appliances as points of energy availability rather than energy use. For Socolow in particular, conservation was not only a means to protect the environment, but also to disengage from the development of nuclear technologies. Amongst radical scientists, support for ERC often intersected with other political views. For example Commoner decried 'the waste produced by a nuclear power plant' not only for reasons of environmental damage and risk, but also because nuclear power also threated to magnify the wasteful excesses of capitalism[1288]. And for Amory Lovins, ERC would reduce the need for nuclear power, which would end the subsidised production of

[1286] Ibid, p. 289, ft. 157.

[1287] Ibid, p. 39.

[1288] Moore, 2008; Egan, 2007, p. 159.

fissile material for nuclear weapons, contributing to a 'durable peace' rather than mutually assured destruction[1289].

But not all radicals believed ERC was politically radical. In 1974, following the energy crisis, SESPA's Boston 'teaching group' produced a pamphlet on energy, republished in *Science for the People*. It argued the seven major oil companies had become a 'private government of energy' in which the American government was a 'willing junior partner'. This oligopoly used power over energy supply to exploit both oil producing nations and the American consumer[1290]. Its author, Harvard physicist David Jhirad (1939-2013) suggested ERC offered *some* potential as a democratic technology, owing to the decentralisation of control it implied. However, he argued the burden to conserve was unfairly placed on individuals rather than industry or those in charge of governing the energy infrastructure.

Jhirad came to this conclusion based on his reading of *The Potential for Energy Conservation* (1972), a report for the *Committee on Emergency Preparedness* collated on behalf of Democratic Senator Henry Jackson (1912-1983), head of the Energy Committee of the Senate Interior and Insular Affairs Committee[1291]. Jackson had compiled the work of the RANN funded projects, including those detailed in Chapters 6, 7, and 8. On this basis, he suggested energy conservation measures could reduce American energy demand by 7.3 million barrels a day by 1980, through what it described as a range of 'belt tightening' and 'leak plugging' measures[1292]. But Jhirad believed consumers were being asked by

[1289] Lovins, A. (1977) Soft Energy Paths: Towards a Durable Peace. San Francisco: Friends of the Earth International/Ballinger.

[1290] Jhirad, D. (1974) 'Energy', *Science for the People*, 1974, Vol. 6, No. 1, p. 7.

[1291] Jhirad, 1974, p.11, ft. 13.

[1292] USGPO (1972) The Potential for Energy Conservation: A Staff Study. October. Executive Office of the President, Office of Emergency Preparedness.

government to subsidise the 'structural waste of energy'[1293] on behalf of industry. As the accompanying cartoon suggested, the radical scientist's clenched fist, normally depicted upright and grasping a test-tube, was compromised by the suggestion that efficient energy consumerism was revolutionary.



Figure 9.3 '**All power to the people!'**
Science for the People, 1974, Vol. 6, No. 1, p. 7
Artist: Ron Cobb.

This scepticism toward ERC was reiterated in a later essay by SESPA founding member and physicist Al Weinrub[1294]. He described conservation as a 'subterfuge', which obscured the fact growing energy use went hand-in-hand with increased energy efficiency, a Jevonian dynamic, though he did not use the term, which helped capitalists to increase industrial

[1293] Ibid, p. 10.

[1294] Moore, 2008, p. 62.

productivity at the expense of the worker. Weinrub argued that the current energy situation enabled the concentration of capital in the hands of industrialist. He argued that calls for conservation meant 'capitalists are demanding sacrifices from working people', but that their sacrifice would simply perpetuate their own exploitation[1295]. Far from being embraced by radical scientists, these publications give plenty of evidence that ERC was far from unanimously supported amongst this diversity of counter-cultural opinions. But a new ideologue had emerged who would ardently promote ERC, and portray it as something seemingly allied to some of the objectives of the counter-culture. However, this would not remain the case.

THE SOFT PATH

In 1977, in a biographical sketch in the *New York Times*, 29-year-old physicist Amory Lovins, whom we encountered in Chapter 7, was described as the '*enfant terrible* of the energy left', presumably meaning he was of the left rather than terroriser of the left. Or perhaps the ambiguity was intentional, as the piece noted he was a 'paradoxical man, an environmentalist and an intellectual who can also sound like an oilman asking for higher prices or a monetarist calling for a freer market'[1296]. It was this political ambiguity that had allowed Lovins' proposed energy conservation policies to appeal to both counter-cultural and mainstream society. A year earlier he had come to prominence by advocating for energy conservation policy in the conservative periodical *Foreign Affairs*. Founded in 1910, the journal had original been known as the *The Journal for Race Development,* and it had

[1295] Weinrub, A. ("NY SESPA") (1975) 'Energy Crisis: Oiling the Profit Making Machinery', Science for the People, Vo. 12, No. 1, pp. 8-17.

[1296] Parisi, A. (1977) 'Soft Energy, Hard Choices: the critics spotlight', New York Times, October 16., p. 1.

become the pre-eminent journal in conservative foreign policy[1297]. After the 1973 embargo, the journal became increasingly focused on energy.

The title of Lovins' article titled 'Energy Strategy: The Road Not Taken' borrowed a stanza from Robert Frost's poem, 'The Road Not Taken'. '[T]wo roads diverged in a wood, and I -/I took the one less travelled by'[1298]. The protagonist of Frost's poem illustrated Lovins' argument that America faced two mutually exclusive energy futures. The 'hard path' would be marked by increasing centralisation of supply and increasing use of coal, nuclear, and gas. Essentially, as Lovins noted, 'an extrapolation of the recent past'. The 'soft path', by contrast, would require 'serious commitment to efficient use of energy' and involve considerable decentralisation as the 'rapid development of renewable energy sources'. Importantly, he argued this scenario need not mean economic contraction. In fact, he argued, like economists did (Chapter 8), that increasing the efficiency of energy use would allow the economy to grow using considerably less energy. As Lovins put it 'we could have steadily increasing economic activity with approximately constant primary energy use for the next few decades'[1299].

In the article, Lovins admitted that his estimates of the scale of energy conservation were 'shamelessly recycled' from the work of others, the 'hundreds of technical and semi-technical analyses of both kinds of conservation [that] have been done; in the last two years

[1297] Vitalis, R. (2016) White World Order, Black Power Politics. The Birth of American International Relations. Cornell University Press.

[1298] Smil, V. (2010) Energy Myths and Realities: Bringing Science to the Energy Policy Debate. AEI Press., p. 46. In fact, Lovins was not the first to use Frost's poem to outline alternative environmental futures. In fact, Rachel Carson had done so in her 1962 book *Silent Spring,* Chapter 17, 'The Other Road'. In in his cultural flourishes, Lovins seemed to have had a self-acknowledge propensity to recycle the ideas of others.

[1299] Lovins, 1976, p. 64.

especially'[1300]. Like Commoner and Jhirad, Lovins lent heavily on RANN funded research. For example, drawing on the APS Summer School research, he suggested 'technical fixes *alone* in the United States could probably improve energy efficiency by a factor of at least three to four', so much so that the efficiency of energy use could, he claimed, be doubled by the end of the century ('end use efficiency')[1301]. Lovins exaggerated their careful claim (Chapter 7), as he suggested this would equate to a thirty or forty percent reduction in national energy use, decoupling on a dramatic scale. The APS attendees had suggested such efficiency increases were *theoretically* possible, but they had made efforts not to claim such savings could be assumed at the scale of society in general[1302].

In fact, Lovins' claims were positively utopian. Using thirty or forty percent less energy, as he confidently suggested was possible, would also, he suggested, save billions of dollars, protect the environment, reduce air pollution, decrease inflation, and reduce the 'alarming dependence on OPEC oil'[1303]. Not only that, but reducing the need for energy would reduce the need for nuclear plant, meaning the soft path could even limit the proliferation of nuclear weapons[1304].

[1300] Ibid, p. 66.

[1301] Ibid.

[1302] Ross, M., Williams, R. (1975) Assessing the Potential for Fuel Conservation. Institute for Public Policy Alternatives.

[1303] Lovins, 1976, p. 88.

[1304] Lovins, 1976, p. 89.

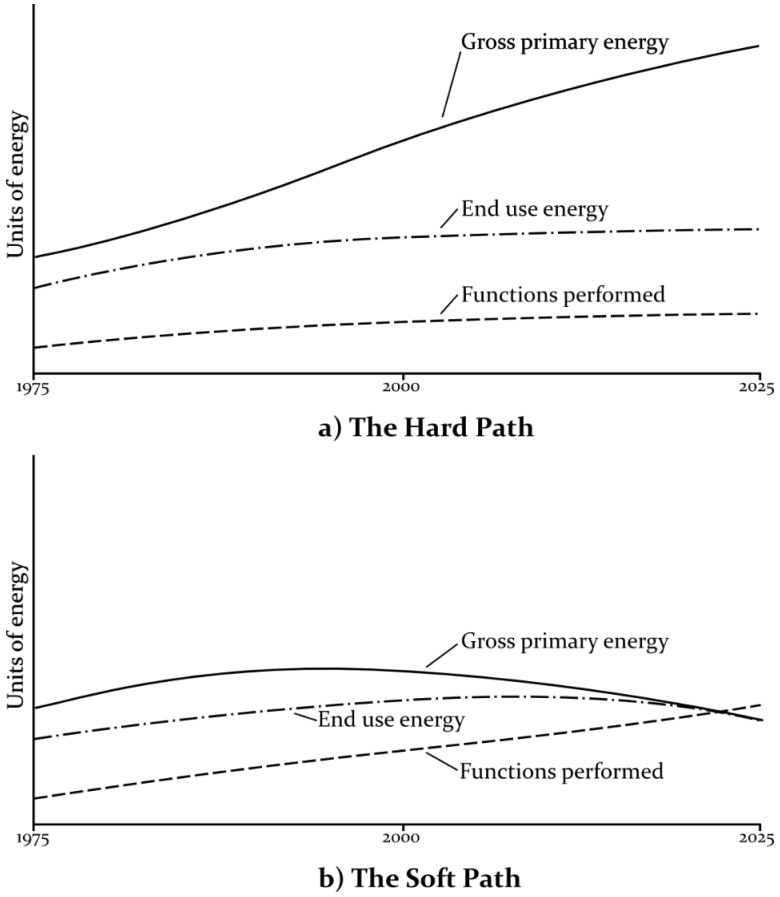

Figure 9.4., Lovins' 'Soft' and 'Hard' paths
Adapted from Lovins (1977).

In the next *Foreign Affairs,* Cornell physicist Hans Bethe (1906-2005) accused Lovins of '"soft" arithmetic' in estimating the potential contribution that solar energy could make to American energy demand[1305]. Next issue, Bertram Wolfe, Vice President of the General Electric Utility Company dismissed the soft path as an 'energy Shangri-La' which overestimated the costs of 'hard' technologies and used unrealistically low costs for 'soft' technologies[1306]. So began a sustained critique of his work. Most comprehensively, in 1977 a communications consultancy, a client of utility companies, Charles Yulish Associates Inc., published a collection of critical essays in response to the article: Dr Ian Forbes, from utility company affiliate organisation, the Energy Research group (ERG), compared the 'soft path'

[1305] Bethe, H. (1977) 'Letter to the editor', Foreign Affairs, 55. p. 637.

[1306] Wolfe, B. (1977) 'Energy Revisited', Foreign Affairs, Vol. 55, No. 4, p. 891-900.

to the utopias proposed by English socialists William Cobbett and William Morris; Yulish himself accused Lovins of promoting 'friendly collectivism'; and Sheldon Butt, of Olin Brass Company, a utility subsidiary, suggested Lovins' work appealed to those 'who have elected to drop out of society'[1307].

Yulish claimed to have self-funded the collection of disparaging essays, as he found the author's 'political manifesto' so upsetting[1308]. He had been an early advocate of nuclear power, and in 1953, whilst a high school student, he had set up a radioisotope laboratory at his school in Florida, with radioactive material obtained from Oak Ridge National Laboratory[1309]. Irrespective of funding source, the book was clearly a vitriolic public relations exercise on behalf of the established energy industries. To which Lovins responded in kind, suggesting 'Mr Yulish's authors substitute character assassination and demagoguery for the normal mechanisms of criticisms', a sign of 'a siege mentality'[1310].

Lovins published a book length version of his argument in 1977 titled *Soft Energy Paths: Towards a Durable Peace,* a review from the ORNL's Alvin Weinberg's added to the image that he was radical[1311]. In the book, he suggested conservation would also radically transform society, as it:

> *'simultaneously offers jobs for the unemployed, capital for businesspeople, environmental protection for conservationists, enhanced national security for the military, opportunities for small businesses to innovate and for big business to recycle itself, exciting technologies for the secular, a rebirth of spiritual values for the religious, traditional virtues for the old, radical reforms for the young, world order*

[1307] Yulish, C. (1977) Soft vs. Hard Energy Paths: 10 Critical Essays on Amory Lovins' Energy Strategy. Charles Yulish Associates.

[1308] Hammond, A. (1977) "Soft Technology" Energy Debate: Limits to Growth Revisited?' Science, Vol. 196, Iss. 4293, pp. 959-961.

[1309] Popular Mechanics (1955) 'High-School Atom Lab', October 1955, p. 133.

[1310] Lovins, A., Nash, H. (1979) The Energy Controversy: Soft Path, Questions and Answers. Friends of the Earth.

[1311] Weinberg, A. (1978) 'Review: Soft energy paths: toward a durable peace - by A. B. Lovins', Energy Policy, Vol. 6, Iss. 1. pp. 85-87

and equity for globalists, energy independence for isolationists, civil rights for liberals, states' rights for conservatives'[1312].

Seemingly promising a solution to all of America's foreign and domestic policy problems in one fell swoop, Lovins' article provoked interest across the political spectrum.

Given such pronouncements, unsurprisingly, the establishment figure Alvin Weinberg suggested that 'Lovins is a revolutionary in the tradition, though not with the doctrinal cast, of Karl Marx. Unlike Marx he is a neo-Jeffersonian who sees in decentralized energy systems the true way to Utopia'[1313]. Weinberg suggested the *Soft Path* seemed to have emerged from a Jeffersonian, back-to-the-land counter-culture. And in fact, to the technophile counter-culture associated with *Whole Earth,* this seemed broadly correct. He was the 'redoubtable' Lovins, the one 'with the documentation', to persuasively demonstrate the feasibility of a low, alternative energy society[1314]. In 1978 Stewart Brand, editor of *Whole Earth,* suggested it was he who had reintroduced the 'soft energy' approach, which had British origins, to the United States[1315].

Brand was right that the term 'soft technology' had British origins. In 1968, following a conference on chemical warfare at Imperial College, a group of young scientists had established the British Society for Social Responsibility in Science (BSSRS), an attempt to form a new 'scientific left', akin to the American radical science movement[1316]. But true to the spirit of the times, the BSSRS soon splintered into factions, representing the plurality of

[1312] Lovins, 1977, p. 125.

[1313] Brand, S. et al. (1980) The Next Whole Earth Catalog. The Whole Earth Press. p. 371.

[1314] Weinberg, A. (1978).

[1315] Baldwin, J., Brand, S. (1978) Soft~Tech. A Co-evolution book. Published by the Whole Earth Catalogue.

[1316] Werskey, G. (1978) The Visible College. London, Allen Lane.

'new left' ideas and, increasingly, those of the less conventionally categorised counter-culture[1317]. One faction grouped around Robin Clarke, a science journalist. In 1971, Clarke became the editor of *Undercurrents*, a journal for 'people who believe that radical views on scientific and technological subjects need a medium in which they can be aired'[1318]. In an 'energy special' he and his partner Jennifer outlined what he termed as 'soft technology', an idea he had devised in 1968, which he hoped a commune in Wales could pioneer. He suggested the adjective 'soft', was 'copied with ironic intent' from detergent advertisements, Clarke's intention was the 'ultimate defeat of the Big by the Small, aided by the holy trinity of Sun, Wind and Shit'[1319]. But Clarke hoped 'soft', and other forms of 'alternative' technology would be the means for a radical new society with an 'eco-socialist morality'[1320] . The politics of this movement differed greatly from that of Lovins, whom an *Undercurrents* reviewer described as 'a bourgeois liberal still trying very much to work within the system'[1321].

As if confirming the conventionality of Lovins' thinking, his soft approach would be re-iterated in the journal *Harvard Business Review* that year, where the resource ontological claim was made that the soft path meant 'The United States can, in effect, quickly produce millions of barrels per day of conservation energy'[1322]. Seemingly the renegade physicist had

[1317] Ravetz, J. (1979) 'Anti-establishment science in some British Journals', Counter Movements in the Sciences, The Sociology of Alternatives to Big Science. Nowotony., H, Rose, H. Eds.

[1318] Clarke, R. (1972) 'Science with a Human Face', Undercurrents, February, Vol. 1, Iss. 1, p. 2.

[1319] Clarke, R., Clarke, J. (1972) 'soft technology – blueprint for a research community', Undercurrents, 1973, No. 2, Winter.

[1320] Clarke, R. (1975) 'Where is AT at?', New Scientist, Vol. 68, No. 979. 11 December., p. 651.

[1321] Hutton-Squire, counter-culture. (1975) 'Review of World Energy Strategies', Undercurrents, September 1975.

[1322] Stobaugh, R., Yergin, D. (1979) Energy Future: report of the energy project at Harvard Business School. Random House.

melded counter- and conventional culture in his vision of America's energy future, even if this was at odds with more political radical ideals.

In fact, given the preceding Chapters, Lovins' approach was clearly derived from the work of America's leading research organisations. RAND had earlier shown how energy demand might be decoupled from energy use. In fact, the *Soft Energy Path* argued that in order for energy to be conserved, just as in the RAND model, reductions in energy use had to take place within a closed system; or, as he phrased it, the 'whole energy system'. He went on to argue that 'in energy strategy as in system dynamics, the structure of the system matters far more to its behaviours than the exact values assumed for its coefficients.[1323]' This belief in the determinate nature of structures was a key tenet of systemic cybernetic thought. Three decades earlier Norbert Wiener had declared that 'the structure of the machine or of the organism is an index of the performance that may be expected from it'[1324]. According to this systematic cybernetic view Lovins argued, as RAND mathematician Fred Roberts had, society should be restructured to optimise the input and transmission of energy and information.

The *Soft Energy Path* suggested energy could be conserved by harnessing the calculative capacities of the consumer, employing 'pluralistic consumer choice' and 'a myriad of small devices and refinements' to transmit information on energy supply and demand[1325]. Accordingly, energy supply and demand had to be structured to allow information on the

[1323] Lovins, 1977, p. 147.

[1324] Wiener, N. (1950, [1989]) The Human Use of Human Beings: Cybernetics and Society. Free Association Books, London., p. 57.

[1325] Lovins, 1977, p. 54.

quantity and supply of energy at given points in the market to be fed-back to users. This would require some reconfiguration of the energy economy:

> '*The first* […] *is correcting the institutional barriers that now impede conservation and rational supply technologies* [...] *The second step is removing subsidies now given to conventional fuel and power industries* [...] *The third step is gradually making energy prices consistent with what it will cost in the long run to replace our dwindling stocks of cheap fuels.'*[1326]

Lovins' scenario clearly espoused the idea that a liberalised, non-interventionist energy market in would enable the accurate relay of price information. And, in line with the econometric approach outlined in Chapter 8, he called for 'long-run marginal pricing of energy' as a means of conservation. This demonstrated how far the science of ERC had come from Jevons' period, when marginal pricing was seen as anything but resource conservative.

The similarity between Koopmans' thesis and that of Lovins is clear (Chapter 8). Both looked at markets whose freedom was compromised. The market for energy, at the time, was replete with government interventions. Both Koopmans and he advocated the use of price as a means to stimulate efficiency, and both suggested that in an imperfect market, a more accurate price could be simulated via the decentralisation of decision making. In a long list of acknowledgements in the *Soft Path* Koopmans is thanked. In effect, Lovins had presented the latest research by econometricians like Koopmans and the careful work of physicists with a counter-cultural gloss.

The conventionality of his argument became apparent when, in October 1977, Lovins met President Carter, James Schlesinger, and other White House staff to discuss the concept of the 'soft path'. According to Carter's diary the meeting lasted only thirty minutes. It was

[1326] Lovins, 1977, p. 19.

unlikely his ideas had any significant influence in that time, more likely, the meeting acknowledged the coherence between his work and the principles already established by federally funded research[1327]. Earlier that year, Carter had delivered a televised speech in which he had declared energy conservation the 'the quickest, cheapest, most practical source of energy'[1328]. Carter's advisors, led by Schlesinger, had estimated that the amount of energy American's wasted was greater than the total amount of oil that the country imported. Two days later he had announced a National Energy Plan in which he declared that 'the foundation of a national energy plan must be the conservation of energy'[1329].

Conservation, the plan suggested, could save the equivalent of four million barrels of oil per day by 1985, but to do so would require government intervention at many levels of society: including mandatory efficiency standards for cars and appliances, insulation regulations for all new buildings, and a system of tax credits. But Carter's plan, like Lovins', was also strongly deregulatory. It was based on the principle that 'Energy prices should move toward a level that reflects the true value of energy in order for market systems to work in harmony with conservation policy'[1330]. These regulations were, at the time, seen as overly interventionist by free-market advocates. But what this kind of criticism missed was that these kinds of policy were intended to transform reality into an informational structure in which the market for energy could be fed with an unrestricted flow of information with regard to energy supply and demand. Regulation was intended to make reality conform more closely to the market model depicted in econometric models of energy allocation.

[1327] Horowitz, D. (2005) Jimmy Carter and the Energy Crisis of the 1970s: The 'Crisis of Confidence Speech of July, 15, 1979. A brief histroy with documents. Bedford Press. New York, Boston.

[1328] Horowitz, D. (2005).

[1329] Office of Staff (1977: 19) National Energy Plan, Secretary Series, Presidential Files; Folder: 4/20/77, [2] Container 16.

[1330] Ibid.

Whatever the intention, by 1980 Carter's Presidency was replaced by Reagan's. For many, Reagan's presidency is normally taken as the end point of counter-cultural energy policy[1331]. But it is not as clear cut as it seems. Whilst his presidency was marked by dramatic funding cuts for the Department of Energy's Conservation and Renewable Energy (CORE) program[1332], in many ways Reagan's presidency realised Lovins' vision. Aside from nuclear power, which Reagan's government renewed investment in, his presidency was marked by shift toward the market management of energy resources; though market interventions proposed by Carter, such as labelling appliance efficiency to assist consumers, were cut[1333], and federal expenditure on energy research fell by a third[1334]. As Reagan's 1981 report *Securing America's Energy Future* starkly suggested, 'the very nature of conservation implies that it be undertaken voluntarily out of the self-interest of individuals and businesses. There is little need for Federal participation beyond helping to ensure that the marketplace provides realistic price signals to consumers'[1335]. As Reagan quipped 'Our problem isn't a shortage of oil, it is a surplus of government'[1336]. Accordingly, oil and gas price controls were finally removed January 1981, their removal was expected to *save* around 50 to 100 thousand barrels of oil a day as the cost of oil increased[1337]. In a remarkable turn of events,

[1331] Winner, L. (1986) The Whale and the Reactor: A Search for Limits in an era of High Technology. University of Chicago Press. Chicago and London.

[1332] Ibid.

[1333] Hays, S. (1987) Beauty, Health, and Permanence: Environmental Politics in the United States, 1955 - 1985. Cambridge University Press.

[1334] Rosenfeld, 1999.

[1335] Narum, D. (1992) 'A troublesome legacy: The Reagan Administration's Conservation and Renewable Energy Policy', Energy Policy, Vol. 20, Iss. 1, pp. 40-53.

[1336] Schaller, M. (2007) Right Turn: American Life in the Reagan-Bush Era, 1980 - 1992. Oxford University Press, New York: Oxford.

[1337] Katz, J. (1984) 'US Energy Policy: Impact of the Reagan Administration', Energy Policy, Vol. 12, Iss. 2, pp. 135-145. Feinmark, P. (1982) 'Reagan's Energy Plan: Leave it to the Marketplace', Ambio, Vol. 11, No. 1, pp. 20-23. Hershey, R. (1981) 'President abolishes last price controls on US produced Oil', New York Times, Jan. 29.

considering the interventionist rationale for petroleum conservation in the first half of the twentieth century, ERC had been recast as an anti-statist, liberalisation policy.

CONCLUSION

This Chapter began by suggesting the science and policies of ERC and the disparate group of oppositional movements known as the counter-culture have, in some way, been conflated. Historians have given the impression that alternative energy technologies, and low-energy technologies, were associated with a subcultural, anti-authoritarian movement. Whilst, to some extent, this is true: as we saw in previous Chapters, scientists developing ERC were often somewhat radical and affiliated with oppositional groups. Some developed ERC as a means of averting the need for nuclear power, and the authoritarian politics it was associated with. The research took place at some of America's leading research laboratories, and was funded by federal government, in pursuit of productivity gains, unlimited economic growth, and geopolitical security. ERC must be seen as a progenitor of cold war science, even if it is of the détente kind. As a result, it appears there is no easy way to categorise the politics of energy conservation.

The relation between this applied federally-funded science and 'counter-cultural politics appears to have been made by the energy establishment themselves, in an attempt to denigrate the idea that America was not reliant upon continued growth in energy demand. Historians later re-iterated this conflation. In doing so, the heterogeneous composition of the counter-culture was ignored. In fact, amongst the 'Energy Left' considered ERC a ruse, intended to capitalise upon individual self-sacrifice, in order to perpetuate the business practices of American oil and utility companies. Added to which, early commune-dwellers were more interested in energy self-sufficiency, rather than engaging in networked systemic

energy conservation of the kind outlined in RANN funded work. But in the work of Amory Lovins, which lent heavily on this federal research, the state science of ERC gained a popular counter-cultural gloss.

Boltanksi and Chiapello argued that in the nineteen-seventies, the 'spirit' of capitalism changed significantly. In this new age, competition was cast as a new form of control. Centralised, state authority was denigrated. From both the right and the left. These changes, involving an emphasis on self-expression, decentralised and non-hierarchical systems of control, and the integration of utopianism in capitalist thought, they suggest, helped obstruct any resistance to this new form of capitalism. It has been suggested that ERC was part of this new spirit, which thanks to its counter-cultural gloss, appeared to emerge from outside the conventional, centralised, sites of the post-war economy of knowledge. Just as think-tanks seemed to offer a form of objectivity, given their interstitial relation to government, counter-culture ideologues could claim similar independence from received opinion. The counter-cultural gloss that ERC gained, was of political consequence: it helped engage an oppositional constituency in the project of market liberalisation.

CHAPTER 10. ENERGY RESOURCE CONSERVATION IN BRITAIN: FUTUROLOGY, FEEDBACK, AND FAILURE.

This Chapter suggests the energy crises had a profound impact on British political economy in the nineteen-seventies. As a result of fuel scarcities, due to domestic miners' strikes and the Middle Eastern oil embargo, the British government's approach to the fuel policy was transformed when Conservative Prime Minister Edward Heath's government [1970-1974] turned its attention to ERC. Drawing on the advances made in American 'energy policy', outlined in previous chapters, Heath's government concluded that Britain's demand for energy could be significantly reduced. If less energy were used, Britain would be less at the mercy of the National Union of Mineworkers and Arab oil producing states. But to do so would involve a dramatic shift in Britain's post-war political economy, as in order for energy to be conserved, policy-makers suggested price controls, and the underlying rationale for a nationalised energy supply more generally, would have to be brought to a close. In developing this idea, Heath's 'think-tank', the Central Policy Review Staff (CPRS) drew on the research outlined in the previous chapters, and the work of the government's new 'futurology' department, the World Future Trends Committee (WFTC). As a result, from this mangle of ideas, a term which expresses processes of intellectual resistance and accommodation, a clear and somewhat surprising argument emerged: the best way for the British government to conserve energy, and to overcome the energy crises, was for it to liberalise the energy market.

INTRODUCTION

In Britain the energy crises are widely accepted to have been an embarrassing failure for Edward Heath's Conservative government (1970-1974). By crises, I refer to both the restrictions placed on coal output by the National Union of Mineworkers (NUM) from 1971

onward, as part of an ongoing wage dispute, and the increased price and five per cent reduction in oil exports imposed by Organisation of Arab Petroleum Exporting Countries (OAPEC) in 1973[1338].These events were linked by their protagonists' intention to impose distinct political relations by controlling access to energy. As outlined in this thesis's introduction, controlling energy to enforce particular forms of social relations was a recurrent event in the twentieth century, a propensity which historian Timothy Mitchell names 'carbon democracy'[1339]. This relation between energy and politics is readily apparent in Heath's case. Having come to power promising a 'quiet revolution', in which the planned interventions of socialism would be overturned by the dynamism of competition[1340], his government had introduced a swathe of pro-market policies[1341]: wage and price controls would be scrapped, taxes cut, and the welfare state's budget would be cut. Industrial relations, which had accommodated the demands of organised Labour since the Second World War would be radically restricted and union's power constrained by law. But Heath's planned liberalisation was derailed by the intentional restriction of energy supplies. Both fuel shortages exacerbated ongoing inflation, eventually causing a humiliating return to wage and price controls and market intervention. This ideological 'U-turn', it is widely suggested, was the reason Heath lost the 1974 election[1342]. However, in this Chapter, it will be argued the relation between these energy crises and Heath's experiment in economic liberalisation was not as clear cut as some suggest.

[1338] Hughes, R. (2012) 'Governing in Hard Times', The Heath Government and Civil Emergencies – the 1972 and the 1974 Miners' Strike. PHD Thesis. QMUL. On oil see, Venn, F. (2002) The Oil Crisis. Longman.

[1339] Mitchell, T (2011) Carbon Democracy: Political Power in the Age of Oil, London, Verso.

[1340] CPO (1970) A Better Tomorrow, Conservative Party Manifesto, 1970 Election.

[1341] Cairncross, A. (1996) 'The Heath Government and the British Economy', Seldon, A., Ball, S. The Heath Government: A Reappraisal. Routledge.

[1342] Taylor, R. (1996) 'The Heath Government, Industrial policy and the 'new capitalism', in Ball, S., Seldon, A. eds. The Heath Government, 1970-1974: a reappraisal. Longman. New York and London.

The role of the energy crises in Heath's failed government has provoked debate. Heath's biographer John Campbell suggested twin oil and coal crises created 'a lethal combination' which brought the government to defeat[1343]. Whereas historian Martin Holmes argued 'the oil crisis' was 'an unconvincing alibi for a government whose economic strategy had already long since come off the rails'[1344]. Indisputably, the crisis led to five more years of Labour rule, derailing Conservative's plans for further economic liberalisation. Unsurprisingly the left saw Heath's fall as 'a humiliating and demoralizing a defeat' for conservatism[1345]. The 'new right' of the Conservative party agreed. Nigel Lawson (1932--), a minor party figure in the 1970s, later suggested the crises had demonstrated that control over energy was critical to the left's strength, and left him 'determined to break the *dirigiste* mentality' of the energy industries[1346].

In 1981, as Conservative Prime Minister Margaret Thatcher's Energy Secretary, Lawson was able to fulfil this ambition by taking the first steps toward the privatisation of the publicly owned Central Electricity Generating Board (CEGB). But in contrast to these rather broad-brush conclusions, based on the principles of ERC developed in preceding Chapters, it is argued an emphasis on party politics misses a subtler but more pervasive consequence of the energy crises. In fact, Lawson's later move toward a free-market in energy occurred, in part, on the basis that liberalisation was considered a better means of conserving energy than forms of interventionist conservation policy. By focusing on the British government's reception to the American science of ERC, this chapter argues that, as a result of the energy

[1343] Campbell, J. (1993) Edward Heath: A Biography. Random House

[1344] Holmes, M. (1987) The Failure of the Heath Government. Macmillan.

[1345] Milne, S. (1994) The Enemy Within: MI5, Maxwell and the Scargill Affair. Verso.

[1346] Lawson, N. (1992) The View From No. 11: Memoirs of a Tory Radical. Bantam.

crises, a cross-party, technocratic rationale for energy market liberalisation gained an early foothold in British political thought.

The origins of energy market privatisation are normally dated to around 1979, when Thatcher formed a Conservative government, whose members proposed the 'privatisation' of nationalised industry. Though it was not until 1989 that a bill was passed effectively privatising the electricity industry[1347]. As outlined in the previous Chapters, in America the science of ERC was increasingly considered contingent upon market liberalisation, in order to achieve up-to-the-minute price information and accurate forecasting of future rates of demand, attributes considered absent from centralised, state-owned industries in which prices were controlled and the rate of supply dictated by government rather than the market. But as energy shortages became apparent in the 1970s, and were framed against a wider fear of global 'limits to growth', the principles of ERC found increasing influence in British policy-making. As a result, the history of ERC in Britain suggests advocacy for energy market liberalisation were established in government long before Thatcher. Accordingly, the history of ERC in Britain suggests the energy crises were less a victory for the left than an early victory for proponents of ideas later known as 'neoliberal'[1348].

As outlined in Chapter 4, for much of the post-war period, the pursuit of fuel efficiency in Britain was a state-science, pursued by a government funded research corps, as a means of encouraging both private and publicly owned industries to use fuel more efficiently. But the rationales of ERC outlined in the previous Chapters were not unknown in Britain. The American science of ERC built on a native British interest in managerial science, future

[1347] Meek, J. (2012) 'How We Happened to Sell Off our Electricity, London Review of Books, Vol. 34, No. 17, pp. 3-12.

[1348] Davies, W. (2014) The Limits of Neoliberalism: Authority, Sovereignty And The Logic Of Competition. Sage.

studies, systems theory, and computational econometrics[1349]. But similar to the impact had in the United States, the energy crises provided an opportunity for a new generation of ideologues and political administrators, schooled in these disciplines, to make the argument that the market possessed a superior capacity to allocate energy resources, from within government[1350].

PRONE TO ARCHAISM?

In order to understand the reception that the science of ERC received in Britain, it is necessary to understand the political culture of nineteen-seventies Britain. In December 1974, a year after Heath's government fell, American think-tank the Hudson Institute published a futurological study which forecast Britain's 'relative decline' as compared to its European neighbours. A gloomy portent given the recent accession to the European Economic Community. The Hudson's report, titled *The United Kingdom in 1980*, suggested Britain's forecast decline was the product of 'a peculiarly British problem': the nation's political class were 'prone to archaism' and 'flights into pre-socialist, pre-capitalist fantasy'. The country was stunted by a factional class system and an aversion to technology and entrepreneurialism. To avoid national decline Hudson prescribed a 'shift in national style', which would require the establishment of a 'Planning Commission' consisting of 'Britain's best economists and administrators and engineers', who would implement a six-year economic plan based on long-term social and economic forecasts[1351]. Hudson had outlined the need for a highly technocratic, interventionist government.

[1349] Mirowski, P. (2002) Machine Dreams: Economics as a Cyborg Science. Cambridge University Press, Cambridge.

[1350] Jacobs, M. (2008) 'The Conservative Struggle and the Energy Crisis.' In Rightward Bound: Making America Conservative in the 1970s, Schulman, B., Zelizer, J. Eds. Harvard University Press.

[1351] Stillman, E., Bellini, J., Pfaff, W., Schloesing, L., Barth, M. (1974) The United Kingdom in 1980: The Hudson Report. Hudson Europe. Association Business Programmes Ltd.

The press responded vehemently to Hudson's report. *The Times* wrote it was 'more a prolonged attempt to shake the national psyche than a piece of original research' and the *Daily Mail,* that it was an unhelpful mix of 'the obvious and the speculative'[1352]. Even the reviewer in *Futures,* a journal dedicated to this kind of work, criticised the report's 'shallow argumentation and spotty treatment'[1353]. The Hudson Institute's authors were braced for such criticism. Its sole British contributor, James Bellini, dismissed this response as the 'self-serving denigration' of the national press, who were themselves archaic[1354]. Even before the report's publication, Bellini had written of Britain's 'profound domestic intellectual resentment of economic and socio-political forecasting'[1355]. In the final report, lead-author, political analyst Edmund Stillman had similarly warned 'attempts to make serious assessments of future developments in Britain's society and economy, as we ourselves have discovered, have been greeted, certainly in many academic and administrative quarters, with reactions ranging from dismissive scepticism to utter hostility'[1356]. For Hudson's researchers, British hostility served only to reinforce their argument. But despite the critical reception, the book reached number five in that month's bestsellers' list, and was discussed in Parliament[1357].

The Hudson Institute had been established in New York in 1961 by Cold War systems analyst Herman Kahn (1922-1983), who had established a reputation as a policy analyst,

[1352] Klimeš, I. (1975) 'Journalism in forecasting and vice versa', Futures, Vol. 7, Iss. 1. p. 2.

[1353] Dror, Y. (1975) 'The Misfired Report', Futures, Vol 7, Iss. 1, pp. 64-68.

[1354] Bellini, J. (1975) 'The Hudson Report: a personal view', Futures, Vol. 7, Iss. 2, pp. 165-169.

[1355] Ibid.

[1356] Stillman, E., Bellini, J., Pfaff, W., Schloesing, L., Barth, M. (1974) The United Kingdom in 1980: The Hudson Report. Hudson Europe. Association Business Programmes Ltd.

[1357] Klimes, 1975; Bellini, 1975.

primarily by developing pre-emptive and reactive strategies in case of thermonuclear war[1358]. In the 1940s Kahn had worked at RAND, home of rationalised policy analysis, and later home of energy conservation research (Chapter 6). There Kahn helped develop 'futurological' methods, a supposedly scientific approach to social forecasting which, advocates claimed, allowed policymakers to 'deal with socio-economic and political problems as confidently as we do with problems in physics and chemistry'[1359]. Futurology, as outlined in Chapter 6, generally used mathematical extrapolation from existing demographic or technological trends, or looser discursive techniques such as the Delphi technique[1360]. More broadly, futurology was grounded in the post-war science of cybernetics, and the notion of feedback: the idea that the future conduct of a machine, organism, or even a polity, could be controlled via the transmission of informational signals, which employing some kind of receiving device, could be used to calculate an appropriate modification to present behaviour, in response to external disturbance[1361]. Rather than an unknown, futurologists suggested the future could be conditioned by the intentions of the present[1362].

Betraying its Cold War origins, Hudson's questions and answers were marked by pessimism. The organisation specialised in offering answers to uncomfortable questions which policymakers avoided[1363]. Hudson had established a European office in 1973, with the expectation that the uncertainties following the end of the Bretton Woods and the expansion

[1358] Ghamari-Tabrizi, S. (2005) The Worlds of Herman Kahn: The Intuitive Science of Thermonuclear War. Harvard.

[1359] Andersson, J. (2012) 'The Great Future Debate and the Struggle for the World', American Historical Review, Vol. 117, Iss. 5, pp. 1411-1430.

[1360] Chapter 6.

[1361] Mayr, O. (1970) The Origins of Feedback Control. MIT Press; Schmidt-Gernig A (2002) The Cybernetic Society. Western future studies of the 1960s and 1970s and their predictions for the year 2000. In: Cooper RN, Layard PRG (eds) What the future holds. Insights from social science. MIT Press, Cambridge.

[1362] Luhmann, N. (1976) 'The Future Cannot Begin: Temporal Structures in Modern Society', Social Research, Vol. 42, Iss. 1.

[1363] Ghamari-Tabrizi, S. (2005).

of the EEC might prove profitable[1364]. The French government had indeed commissioned a report into their nation's prospects. But Hudson's gloomy British report was the result of a failed attempt to gain a similar contract from Heath's government. The final report was self-funded and derived much of its content from the French report[1365].

Hudson's findings can be seen as archetypical of the 'declinist' genre, a post-war genre of political analysis marked by a tendency to denigrate British policymaking for lacking technical expertise and expressing a national disdain for science and technology. Contrary to appearances, historian David Edgerton has suggested declinist narratives were a sign Britain was in fact profoundly technological, and such literature was self-serving rhetoric for those seeking to benefit from increased investment in science and technology[1366]. Extending Edgerton's argument, it is clear the poor reception the Hudson report received ignored that critical ire was more often directed at the method and quality of the work rather than futurology in general[1367]. In fact, in line with Edgerton's declinist revisionism, the following section illustrates nineteen-seventies Britain was profoundly futurological.

BRITISH FUTUROLOGY

During World War Two, Britain, alongside America, had developed a science of Operations Research ('OR') in which the mathematics of optimisation was applied to managerial decisions[1368]. In peacetime OR was enthusiastically adopted by newly nationalised industries such as the National Coal Board, and private industries such as United Steel and IPC

[1364] Bellini, 1975.

[1365] Dror, 1975.

[1366] Edgerton, D. (2006) Warfare State: Britain, 1920-1970. Cambridge University Press.

[1367] Price, T. (1975) 'The British Economy: A Call for National Planning', Futures, Vol. 7, No. 3, pp. 258-260.

[1368] Thomas, W. (2015) Rational Action: The Sciences of Policy in Britain and America, 1940-1960. MIT Press.

Media[1369]. In 1952, some of those trained in OR established the 'Ratio Club', a group of scientists inspired by their work's congruence with the ideas outlined in Norbert Wiener's 1948 book *Cybernetics*[1370]. One member of the Club, psychiatrist Ross Ashby (1903-1972) argued that price controls, of the kind instituted after the Second World War, ran contrary to the cybernetic principle of homeostasis, and he forecast an economically unstable future as a result[1371]. This was an argument, as we have seen, that would re-emerge in later decades with regard to the political economy of energy.

However, in 1959, Britain's most prominent cybernetician, Stafford Beer (1926-2002) combined OR with cybernetics to create the new field of 'management cybernetics'[1372]. Beer's premise was that 'all future events are improbable; but these improbabilities can be measured and manipulated and from them a strategy can be scientifically contrived'[1373]. He even made an ambitious attempt to manage the Chilean economy using cybernetic principles[1374]. Far from a propensity to archaism, as the Hudson Institute had suggested, futurology permeated both public and private British industry. So much so that there was a thriving futurological scene by the start of the 1970s, as a survey by Political and Economic Planning ('P.E.P'), a policy research organisation suggested, it identified over thirty futurological organisations in Britain[1375].

[1369] Kirby, M. (2003) Operational Research in War and Peace: the British experience from the 1930s to 1970. Imperial College Press.

[1370] Holland, O., Husbands, P. (2011) 'The origins of British Cybernetics: the Ratio Club', Kybernetes, Vol. 40, Iss. 1. pp. 110-123.

[1371] Ashby, R. (1945) "effects of control on stability' Nature, 155, pp. 242-243. Cited in Pickering, A. (2011) The Cybernetic Brain: Sketches of Another Future. University of Chicago Press, Chicago and London.

[1372] Beer, S. (1959) Cybernetics and Management. London University Press.

[1373] Beer, S. (1966) Decision and Control: The meaning of operational research and management cybernetics. John Wiley & Sons, Ltd.

[1374] Medina, E. (2011) Cybernetic Revolutionaries: Technology and Politics in Allende's Chile. Massachusetts Institute of Technology.

[1375] Political and Economic Planning (1971) '…and now the future', A PEP Survey of Futures Studies, Vol. 37, Broadsheet 529.

Britain's leading political parties had also become increasingly futurological. At the 1963 Labour party conference, opposition Labour leader Harold Wilson warned 'there is no room for luddites in the Socialist Party', and set out his party's response to the imminent, though long-forecasted, 'automative age', the replacement of human physical and cognitive labour with that of machines. He suggested that, with suitable foreknowledge, planned automation could 'provide undreamed of living standards and the possibility of leisure ultimately on an unbelievable scale'[1376]. In 1964, once in power, Wilson's government attempted to apply 'science to socialism and socialism to science' via a large-scale programme of investment in science and technology, carried out in the centrally-planned Ministry of Technology ('MINTECH')[1377]. This 'super-ministry' was envisioned as a means of rationalising government, and usurping the languid, aristocratic decision-making familiar to Whitehall[1378].The Ministry of Fuel and Power, established in 1955, had become part of this new technocratic organisation, whose aim, in Wilson's words, was to 'increase Britain's productive power'[1379].

One way of making socialism more scientific, Wilson's government decided, was to fund research on the basis of forecasted needs rather than on the basis of speculation or the interests of private industry. Though largely forgotten today, a MINTECH 'Programmes Analysis Unit' (PAU) was established in Harwell outside Oxford, at the same site as the Atomic Energy Agency, to carry out 'exploratory forecasts' and 'temporal extrapolation',

[1376] Labour Party Archive (1963) 'Labour's Plan for Science', Speech by Rt Hon. Harold Wilson, MP, at the Labour Party Annual Conference Scarborough, Oct. 1.

[1377] Gummett, P. (1980) Scientists in Whitehall. Manchester University Press.

[1378] Edgerton, 2006, p. 247.

[1379] Edgerton, D. (1996) 'The White Heat revisited: British Government and Technology in the 1960s', Twentieth Century British History, Vol. 7, pp. 53-82.

according to Derek Medford, the unit's head. Medford suggested there was a distinct "Britishness" to this state-funded forecasting, distinguished from the 'pseudo-science' of Kahn and other 'hubristic' American futurologists. As such, Medford called on Britain's futurologists to 'contribute and denigrate' current methods, lest, in a memorable phrase, 'they may awake too late and become the chattels of business school graduates'[1380].

THE THINK TANK

In opposition, Edward Heath's Conservative Party were similarly intrigued by the promises of futurology, but of the American kind. In 1966 Heath issued a pamphlet proposing a 'Central Cost Effectiveness Department' should his party form a government, which would apply the latest methods of 'American management science' to the problems of public spending. Heath suggested the most useful method was 'the Systems Analysis approach'[1381]. Somewhat imprecisely Heath outlined applying linear programming to government expenditure[1382]. As outlined in Chapter 4, econometric programming promised to optimise decision-making via the computation of numerous coefficients representing each stage in the production of a commodity or commodities; given sufficient conditions, a mathematically optimum decision could be formally demonstrated; suggesting government expenditure could be minimised will the effectiveness of government was maximised[1383].

[1380] Medford, D. (1969) 'The new thaumaturgy of governmental research and development', Futures, Vol. 1, Iss. 6, pp. 510-526.

[1381] CPA CCO 20/26/7, Conservative Systems Research Centre [undated].

[1382] 'This has three main steps. First, the clear definition of the total objective … then every alternative method of achieving the total objective is listed. Each alternative is then fully evaluated in terms of feasibility, if necessary using mathematical models to simulate activities with the help of a computer' (Heath, 1966).

[1383] Brentjes, S. (1994) 'Linear Optimisation', Grattan-Guinness, I. ed. Companion Encyclopedia of the History & Philosophy of the Mathematical Sciences. Volume 2. Johns Hopkins University Press.

Such methods were increasingly appealing as they allowed the development of policy in a scientific manner. Hence, whilst still in opposition, in 1968 a Conservative Systems Research Centre (CSRC) was launched at the Party's head office. The CSRC's aim was to create a computer-based forecasting tool 'for scrutinising, comparing and discussing ranges of policy alternatives before rather than after the event'[1384]. Led by Conservative MP Mervyn Pike, the organisation had four staff, including a systems analyst on loan from I.B.M. With their help, the Conservative Party installed a video terminal, linked via the telephone network, to a time-sharing computer, 'the SIA 6600', installed a few miles away in Victoria, operated by Service in Informatics and Analysis (SIA Ltd.). The 6600 was the most powerful computer in the world at the time[1385], and access to its calculative power allowed party programmers to develop a 'Policy and Information Control System', a program containing a linear programming matrix for forecasting the effects of tax adjustments and government spending[1386]. Though never used for actual policymaking, the system demonstrated the Conservative party's early interest in computational forecasting.

[1384] CPA, CCO 20/26/7 Heath to Pike, 28 March 1969.

[1385] CPA, CCO 20/26/7 CSRC [undated] Bodleian Library, Oxford.

[1386] CPA, CCO, CSRC files, as above. See also Spicer, 1970



Figure. 10.1. The Control Data 210 Video Display Unit.
CPA, CCO 20/26/7 CSRC [undated]

For Conservatives, new forms of management were seen as the antidote to the perceived inefficiencies of the public sector. As such, a 'Public Sector Research Unit' (PSRU) was set-up in 1967 to apply the principles of business management to government. Executives from Royal Dutch Shell and Sainsbury's, amongst other companies, were invited to submit ideas for public sector reform based on their experience of competition. As two contemporary sociologists observed, Heath's party 'intended to do for government what corporate planning did for business'[1387]. In accord with this new approach, a PSRU researcher called David Howell came across the idea of 'reprivatisation' in American management theorist Peter

[1387] Heclo, H., Wildavsky, A. (1974) The Private Government of Public Money. Macmillan, London.

Drucker's 1969 book *The Age of Discontinuity*[1388]. Drucker argued 'reprivatisation' would reintroduce them to the competitive forces of the market, transforming nationalised industries into future-oriented sources of unparalleled productivity[1389]. In 1970, Howell used Drucker's term to describe the party's 'new style of government'. 'Reprivatisation', or better 'privatisation', he suggested, captured the 'process of transferring functions and activities back to the private sector or running them down altogether'[1390]. Once in power Howell drafted a white paper, *The Reorganisation of Central Government,* which set out plans for a 'central capability unit', drawing on Heath's original idea of a conduit for private-sector practices to enter the public sector[1391].

Even before Heath came to power, there was a widespread opinion that government lacked technical expertise. The 1965 Fulton Committee had investigated Civil Service reform, and concluded bureaucratic modernisation of the 'machinery of government', in Haldane's old term (Chapter 3), was necessary, and that 'new modes of specialised analysis' such as 'linear programming and cost-benefit analysis' should be applied to government[1392]. There was clearly a thread of technocratic reform running from Haldane's time to this period. Though the ideas as to how this reform should be managed had changed, as we shall see. Given such sentiments, the Civil Service Head Burke Trend was sympathetic to Howell's idea of a 'Central Capability Unit'. Heath wanted to call it 'the think-tank', in recognition of the American organisations he wished to emulate, but Trend proposed the name Central Policy

[1388] Davis, J. (2007) Prime Ministers and Whitehall, 1960-1974. Hambledon Continuum, First Ed. London.

[1389] Drucker, P. (1969) Age of Discontinuity. See Davis, 2007.

[1390] Meek, 2012. See also Howell, D. (1970) A New Style of Government. Conservative Political Centre. No. 463. Crawley.

[1391] HMSO (1970) The Reorganisation of Central Government. White Paper presented to parliament by the Prime Minister. Her Majesty's Stationary Office.

[1392]HMSO (1968) The Civil Service, Vol. 1, Report of the Committee, 1966-1968. Chairman: Lord Fulton. Her Majesty's Stationary Office,

Review Staff (CPRS), as he felt it better described the unit's intended role, it was to review the efficacy of government policy not act as an independent research organisation on behalf of government[1393]. Irrespective 'the think-tank' became the organisation's colloquial name, and was perhaps a more accurate description of its style of administration than Trend hoped.

American think-tank's authority derived from the belief their ideas were more objective than those of government because they had been fashioned competitively in a 'marketplace of ideas'[1394]. Unsurprisingly, think-tanks are often associated with neoliberal thought, a political theory marked by the assumption that all institutions can and should be reformed according to principles of competiveness, private ownership, and economic evaluation[1395]. The authority of think-tanks were also on the rise in the nineteen-seventies, in part, as both the new right and the new left, often in a 'counter-cultural' guise, had grown suspicious of centralized forms of state-derived knowledge[1396]. Given its rationale, the idea of an intra-governmental think-tank seems idiosyncratic. But the CPRS' role was somewhat anti-statist, as it was seen as a means for bringing market-derived reasoning into British policymaking. As such, it would come as no surprise that the CPRS' advice to the British government during the energy crises would suggest the reformation of Britain's energy economy on market-based lines[1397]. However, at the time, there was an intellectual current in government which ran against such thinking.

[1393] Hennessy, P. (1985) Routine Punctuated by Orgies: The Central Policy Review Staff, 1970-1983. Strathclyde Papers On Government and Politics.

[1394] Ricci, D. (1993) The Transformation of American Politics: The New Washington and the Rise of the Think Tank. Yale.

[1395] Mirowksi, P., Plewhe, D. eds. (2009) The Road From Mont Pelerin: The Making of the Neoliberal Thought Collective. Harvard University Press.

[1396] Medvetz, T. (2012) Think Tanks in America. University of Chicago Press. Chicago. London., Davies, 2014. See also Chapter 9.

[1397] Another example was the CPRS role in the reformation of science and technology funding on a 'contractor' basis see Agar, J. (2011) 'Thatcher, Scientist', Notes & Records, of the Royal Society of London, Vol. 65, Iss. 3, pp. 215-232.

HEATH'S LIMITS TO GROWTH

In June 1971, Heath's Chief Scientific Officer, metallurgist Alan Cottrell, two months into his job, travelled to MIT at the invitation of American systems theorist Jay Forrester (1918-2016)[1398]. Forrester had developed the field of 'industrial dynamics', in which he simulated the determinant factors of a given industry via a mathematical model of its correlated variables, described as 'feedback-loops', with the intention that the observable industrial dynamics could inform managerial decision-making[1399]. Through the 1960s Forrester's models grew in complexity, from simulating a city to the World as a whole. His 'World1' model appealed to the agenda of the Club of Rome, a research organisation, who had begun a major project with the help of a quarter of a million dollar donation from the Volkswagen Foundation[1400].

Founded in 1968 by an economist and executive at the Fiat and Olivetti companies, Aurelio Peccei, and Alexander King, scientific director of the Organisation for Economic Cooperative Development (OECD), the Club consisted of seventy-five industrialists, policymakers, and futurologists, who shared a concern with the collective future of humanity[1401]. In 1971 some of the Club's members had travelled to MIT, along with Cottrell, to see if Forrester's model might provide some indication of the effects of continued levels of resource consumption. A preliminary run of 'World1' indicated deleterious resource shortages, pollution, and

[1398] CAB 168/291, Cottrell to Zuckerman, 28 July 1971, and Smallman, R.E. and Knott, J.F. (2013) 'Sir Alan Cottrell FREng. 17 July 1919-15 February 2012', Biographical Memoirs of Fellows of the Royal Society, Vol. 59, pp. 93-124.

[1399] Forrester, J. (1961) Industrial Dynamics. MIT Press, New York. See also Thomas, W., Williams, L. (2009) 'The Epistemologies of Non-Forecasting Simulations, Part 1: Industrial Dynamics and Management Pedagogy at MIT', Science in Context, Vol. 22, Iss. 2, pp. 245-270. Golub, R., Townsend, J. (1977) 'Malthus, Multinationals, and the Club of Rome', Social Studies of Science, Vol. 7, pp. 201-222.

[1400] Gillette, R. (1972) 'The Limits to Growth: Hard Sell for a Computer View of Doomsday', Science, Vol. 175, No. 4026, pp. 1088-1092.

[1401] Albrecht, counter-culture. (2014) 'The Atlantic Community in a Global Context': Global Crisis and Atlanticism within the context of the Club of Rome, 1960s to 1970s', GHI Bulletin, Supp. No. 10.

overcrowding within decades[1402]. The Club were impressed and commissioned Forrester to expand the model, with the aim of answering a simple question: when would Earth reach limits to growth?

Cottrell had been similarly impressed, and wrote to Heath to propose that the British government establish something similar, stating in no uncertain terms that he believed 'Forrester's approach is the most important development of its kind since Keynes' General theory'.[1403] Cottrell believed he had been employed to introduce just this kind of technocratic thinking into British policymaking[1404]. And Heath, similarly enthused by such forms of future-oriented analysis, gave his permission for a scoping study to assess the feasibility of a British environmental systems analytical model. In September, Cottrell held a meeting at the Cabinet Office and told assembled Civil Servants about Forrester's model. He suggested that for the Civil Service to establish something similar would require £50,000 a year and four employees. Though one Civil Servant countered that the Treasury already had a sophisticated econometric model suitable for forecasting[1405]. Officially the Treasury adopted computerised forecasting in 1971, but they had produced experimental computer forecasts since the late 1960s[1406]. Irrespective, there was general support for this newer idea and a further study was proposed.

At a second meeting in November 1971, Forrester's lead researcher, Dennis Meadows, was flown to Britain to explain the World model. His visit provoked considerable interest,

[1402] Forrester, J. (1971) World Dynamics. Wright Allen Press.

[1403] CAB 168/291, Cottrell to Zuckerman, 28 July 1971

[1404] Lean, T. (2009) An Oral History of British Science: Sir Alan Cottrell.

[1405] CAB 134/3584, 'Future World Trends', 9 September 1971

[1406] Evans, R. (1999: 14) Macroeconomic Forecasting: A Sociological Appraisal. Routledge.

encouraging even senior Treasury economist James Mead, a pupil of Keynes, to wryly request an audience with the 'computer forecasts of doom'[1407]. Speaking to a significantly larger group of Civil Servants, Meadows explained that the model's 'numerical values [...] were of little importance. Much more critical was the structure'. Here again was a fundamental tenet of cybernetics, structure rather than variables determined a system's behaviour[1408]. Accordingly, the structure of the World Model indicated that continued economic growth would cause population to 'overshoot', meaning large-scale famine, societal decline, and possibly even the breakdown of government. Given the severity of the message, there were understandable concerns raised. The World model, a Civil Servant pointed out, failed to account for economic dynamics in a sophisticated way. But generally Meadows' apocalyptic warning was taken seriously. Meadows defended his approach by suggesting he had come to Britain because 'anticipatory action' needed to be taken by politicians. Meadows also warned the assembled Civil Servants that further results of their study would be published in 1972, and this might lead the press to 'alarmist conclusions'[1409].

As warned, in March 1972 *Limits* was published at an event at the Smithsonian, Washington. Peccei had hired an American public relations company, Calvin Kyle Associates, to heighten its impact. In preparation they had contacted major newspapers worldwide and distributed twelve-thousand copies of the report in six languages to world leaders[1410]. The report described Earth as a system of feedback loops: 'Whereas positive feedback loops generate runaway growth, negative feedback loops tend to regulate growth and to hold a system in some stable state.' But a growing imbalance meant 'if present growth trends […] continue

[1407] CAB 168/291, note, Meade to Cottrell, 30 September 1971

[1408] See Chapter 6.

[1409] CAB 168/291, 'Future World Trends, November 24 1971

[1410] Gillette, R. (1972) 'The Limits to Growth: Hard Sell for a Computer View of Doomsday', Science, Vol. 175, No. 4026, pp. 1088-1092.

unchanged, the limits to growth on this planet will be reached sometime in the next one hundred years'[1411]. Unlike RAND's earlier systems analysis approach, the conclusion was 'neo-Malthusian'[1412]. This message, and the concerted public relations effort, provoked widespread debate in the press, the warning resonating with a maturing 'environmentalist movement'[1413].

The publication of *Limits* would encourage the government to develop their own environmental simulation[1414]. In February 1972, Peter Walker, Heath's Environment Secretary, wrote to the Prime Minister to draw his attention to the recent publication of 'Blueprint for Survival', a pamphlet published in January by British ecologist Edward Goldsmith, based upon leaked results from Forrester's study. Along with *Limits,* Goldsmith, Walker noted to Heath, had argued 'a severe breakdown in social systems' was likely, and though Walker dismissed aspects of their thesis as 'extreme, apocalyptic, and naïve', he agreed with Forrester and Goldsmith's general theses, that reaching environmental limits 'could be real and serious'[1415].

A sense of crisis already pervaded Heath's Government. Four days earlier, thanks to the ongoing miners' strike, Heath had declared a state of national emergency. The third of five such declarations during his government, this time the emergency was prompted by picketing at a coke depot in Birmingham, which had prompted shortages of electricity, and required

[1411] Meadows, D., Meadows, D., Randers, J., Behrens W. (1972) The Limits to Growth. A Report for the Club of Rome's Project on the Predicament of Mankind, Potomac Books.

[1412] Harvey, 1974.

[1413] Sandbach, F. (1978) 'The Rise and Fall of the Limits to Growth Debate', Social Studies of Science, Vol. 8, pp. 495-520.

[1414] Bardi (2011), according to personal communication with Meadows, suggests one million copies were sold.

[1415] CAB 164/1083 Walker to Heath et al, February 13 1972. Walker was trusted by Heath, having helped mastermind his election campaign. See Campbell (1996).

drastic restrictions on the use of electricity in commercial buildings[1416]. Alongside such events, Walker suggested government should study the MIT project on resource limits and produce its own forecast, as a matter of some urgency owing to 'a mounting tide of public interest[1417]. Walker was presumably unaware of Cottrell's project, but on his advice Heath agreed to establish a new steering committee that would expand Cottrell's earlier investigation to assess the veracity of both the *Limits'* and *Ecologist's* forecasts, and, ultimately, consider what political decisions might need to be made to avert British limits to growth[1418].

In June 1972, the United Nations convened the first global meeting on the environment in Stockholm[1419]. *Limits* dominated the agenda[1420]. Walker used this opportunity to publicly announce the British government's intention to form an 'environmental forecasting' group. He told assembled journalists that Britain's government was 'not persuaded by everything that has been said about these matters lately', but he also warned of the potential need for unprecedented government intervention to avoid environmental catastrophe, as he suggested 'if research teaches us that a tendency we now see could lead to devastation in 30 years, the fact that it can only be averted by unprecedented response is irrelevant'. Heath's government appeared conforming to what historian Jacob Darwin-Hamblin would later term 'catastrophic environmentalism', the idea that environmental problems legitimised unparalleled levels of government intervention, just as the threat of thermonuclear war had in earlier years[1421].

[1416] Hughes

[1417] CAB 164/1083 Walker to Heath et al, February 13 1972

[1418] CAB 164/1083 Heath to Walker et al, February 28 1972

[1419] Chapter 5.

[1420] Harvey, D. (1974a) 'Population, Resources, and the Ideology of Science', Economic Geography, Vol. 50, pp. 256-77

[1421] Darwin Hamblin, J. (2013) Arming Mother Nature: the birth of catastrophic environmentalism. OUP.

Unsurprisingly, the British press dubbed the proposed group the 'limits-to-growth unit' and 'Department of Energy futurology team'[1422].

So there were now three intellectual currents in Heath's government when it came to the question of resource limits. The first, represented by the CPRS, was that productivity stemmed from privatisation and market forces. On the other hand, *Limits* had encouraged the idea that unprecedented government intervention might be necessary to avert catastrophic resource limits being reached. Thirdly, the Department of Trade and Industry (DTI), heirs to MINTECH's Ministry of Power, would propose an approach to energy conservation more in step with the post-war fuel efficiency policies of the nationalised industries. It was these various approaches, which will be outlined in the next section, from which a British approach to ERC would emerge.

CORPORATE FUTUROLOGY

Heath's government may have been receptive to the idea of environmental limits not just because of the ongoing miners' strike but also because the CPRS had proposed such an idea in February 1971. That month, Victor Rothschild (1910-1990), the recently retired director of research at Royal Dutch Shell, had been hired to lead the intra-governmental think-tank[1423]. Rothschild hired fifteen civil servants, mostly economists, and some on secondment from business[1424]. Significantly, as two members noted, there was 'a continuous line of CPRS members from one or other of the major oil companies'[1425]. In fact, the CPRS was so close to oil companies that it would provide the conduit through which oil industry warnings of oil

[1422] Tinker, J. (1972) 'Britain to Start a Limits to Growth Unit', New Scientist, June 15.

[1423] Agar, 2011.

[1424] Fox, J. (1973) 'The brains behind the throne', The Sunday Times Magazine, March 25, pp. 46-56.

[1425] Blackstone, T., Plowden, W. (1988) Inside the Think Tank: advising the Cabinet, 1971-1983. Heinemann, London.

scarcity would reach government ears. Oil companies, like the Club of Rome, were carrying out their own futurological studies, similarly pointing to imminent scarcity, but the policies they would propose in response were much different.

In 1970 David Barran, a director at Shell, had commissioned a forecast of the oil industry in 1985. His forecast suggested Shell's 'dependence on Middle East Supplies will not diminish for some 10-15 years and there is a strong likelihood of a sellers' cartel for energy developing'[1426]. In September 1971, Rothschild, now working for the British government, saw his former employer's report. He wrote to Robert Carr, Heath's Secretary of State, to suggest Shell's warning of the potential formation of a Middle Eastern oil cartel was political 'dynamite', and requested that Barran meet with Heath in order to explain the situation. At the time, both the Treasury and DTI were operating on the belief that oil prices were likely to decrease in the Seventies as new sources of supply appeared and wells were extracted with increasing efficiency[1427]. Barran met with Heath in October 1971, and warned the Prime Minister that 'there was likely to be a major world energy crisis between ten and twenty five years from now'[1428].

Shell's forecast was one example of a growing body of catastrophic oil industry forecasts. Around 1971 forecasts of abundance were dropped in favour of those predicting scarcity[1429]. Heath was not alone amongst European leaders in receiving Shell's warning[1430]. And other oil companies made similar claims. That year Erik Drake, Chairman of BP, also warned

[1426] PREM 15/595, 'The Oil Demand and Supply Position'

[1427] PREM 15/595, Rothschild to Carr. 21 September 1971; PREM 15/407, Cabinet, Government Strategy []

[1428] PREM 15/595 Minutes from Barran Heath meeting, October 5 1971

[1429] Parra, F. (2004) Oil Politics: A Modern History of Petroleum. Tauris. London.

[1430] Sluyterman, K. (2007) Keeping Competitive in Turbulent Markets, 1973-2007: A History of Royal Dutch Shell. Oxford University Press.

Heath that oil was becoming 'a political problem for Governments, not a commercial problem for companies'[1431]. Like the later arguments of *Limits,* oil companies' warnings were designed to raise the prospect of unprecedented government intervention, though in defence of their industry rather than on the environment's behalf.

From the perspective of major oil companies, some of whom were a century old, negotiations that had taken place in Tehran in 1971, during which companies were forced to agree to price rises with Organisation of Petroleum Exporting Countries ('OPEC'), appeared to be the latest stage in a fifty-year history of oil re-nationalisation. Russia had nationalised its reserves in 1918, followed by Mexico, Iran, Iraq, Argentina and Peru. By 1970, ten oil-producing country's industries were fully nationalised[1432]. The future looked worse. In 1967 Shell commissioned Hudson to forecast the industry's prospects up to the year 2000. Their report warned 'present dirigiste tendencies in many industrial countries, as well as the major producing areas, cast some doubts as to the degree of profitability of the private international oil business in the longer term'[1433]. Given these companies' overriding fear of nationalists' seizure of their primary product, their attempts to warn Western governments of a Middle Eastern oil cartel must be taken as articulations of corporate strategy.

A month after Heath's meeting with Barran, Rothschild wrote to Heath to complain about the Government's 'degree of complacency'. Rothschild noted that the effects of an embargo would 'diffuse through the whole energy pattern of the country' and would 'raise the

[1431] Kuiken, J. (2014) 'Caught in Transition: Britain's Oil Policy in the face of impending crisis, 1967-1973', Historical Social Research, Vol, 39, Iss 4. pp 272-290.

[1432] Kobrin, S. (1984) 'The Nationalisation of Oil Production, 1918-1980', in Pearce, D. Siebert, H. Walter, I. Eds. Risk and the Political Economy of Resource Development. London.

[1433] Royal Dutch Shell (1967) Strictly Confidential: Post Objectives Period: A Special Survey of energy in the World Political and Economic Environment for the years 1985-2000. Studies and Policy Division PL/2 Dec. 1967. Oxford Futures Library.

question whether our coal industry should be run down at the rate envisaged by the DTI'[1434]. Given Heath's anti-inflationary budget was contingent upon limiting expenditure on nationalised industries, the idea that the coal industry might need to be ran-up rather than down had significant political implications beyond the immediate problem of energy supply.

Seizing the initiative, Rothschild prepared an abridged version of the Shell report to circulate to Ministers. Rothschild's briefing suggested each percentage increase in the price of oil negotiated by oil-producing countries would cause a dramatic decrease in the ratio of Britain's balance of payments. Just as in America (Chapter 5) a large differential between the value of Britain's imports and its exports risked dramatic currency devaluation. As the cost of oil went up, Britain's tax revenue would not. For example, a 0.5 per cent increase in producer revenue equated to a £600 million loss in exchange rate value. This meant even minor increases in the price of oil would significantly worsen inflation. Rothschild suggested a number of strategies to limit the effect of an oil embargo. This included proposing an increased reliance on coal, speeding up the exploitation of North Sea oil and gas, investing in nuclear power, and reducing petrol use through mandatory vehicle speed restrictions[1435].

In response to Rothschild, Heath suggested a forthcoming DTI study on 'Energy Policy' would in fact be the basis of any future policy, and it was best Rothschild did not confuse Ministers by offering different advice. As a result, Rothschild's memo was not circulated[1436]. Though the next year, 1972, Heath agreed the CPRS could produce its own energy policy forecast to accompany the DTI's[1437]. Meaning Heath's government now had three different

[1434] PREM 15/595, Rothschild to Heath November 1971

[1435] PREM 15/595, Rothschild, CPRS Memo: Oil Economics and Supplies, November 10 1971.

[1436] PREM 15/595, Armstrong to Rothschild, November 24 1971

[1437] CAB 184/58 Rothschild to Heath, Memo circulated in April 1972 []

groups looking into the future of energy and resources. The DTI, the CPRS and Cottrell's *Limits* inspired 'Future World Trends Committee' (WFTC). Each had a different intellectual orientation. The DTI was heir to MINTECH, oriented toward the nationalised industries. The CPRS was a think-tank within government, bringing the insights of private industry. Most novel of all, the WFTC was explicitly 'futurological': its aim, to assess the veracity of the claims made in *Limits.* It was out of this mangle of ideas, both accommodating and oppositional, from which the government's approach to ERC would solidify[1438].



Figure 10.2. The Central Policy Review Staff, or the 'think-tank'
Lord Rothschild in foreground, Fox (1973)[1439]

[1438] Pickering, A. (1995) 'Cyborg History and the World War II Regime', Perspectives on Science, Vol. 3, No. 1, pp. 1-48.

[1439] Fox, J. (1973)'The brains behind the throne', The Sunday Times Magazine, March 25, pp. 46-56.

WORLD FUTURE TRENDS COMMITTEE

Cottrell's WFTC held their first meeting in July 1972. As Jon Agar has recently shown, this committee would be one of the first British governmental committees in which climate change emerged as a political concern[1440]. They would also become central to the establishment of ERC in Britain. Fifteen Civil Servants would work in two units, 'Research' and 'Policy', based within the Department of the Environment. Their aim was to provide a corrective to recent forecasts, which Cottrell noted were the work of 'strongly-motivated enthusiasts' or based on 'inadequate evidence'. At the meeting, Joe Lyons[1441], the units director, announced the findings of the preliminary assessment of *Limits*. He noted the World model failed to account for the 'existence of strong stabilising forces' of the market, which could re-allocate and curtail demand via increases in resource price[1442]. This emphasis on market forces would prove the government's recurrent criticism of Forrester's work. By the Fifth meeting of the World Trends Committee's fifth meeting in October 1972, Lyons described how new 'feedback loops' could be added to the model, the first of which was 'Market forces acting to stimulate substitution'[1443].

Where had this idea of market forces, dressed in the language of cybernetics, come from? When Heath had spoken of 'market power' in his 1970 manifesto he meant it negatively, to describe how a monopolistic economy might develop[1444]. Enoch Powell, a far-right Conservative politician, was more immediately associated with the term, as he had long

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UTUR[1440] Agar, J. (2015) 'Future Forecast – Changeable and Probably Getting Worse': The UK Government's Early Response to Anthropogenic Climate Change', Twentieth Century British History, Vol. 26, No. 4., pp. 602-628.

[1441] In 1967 Lyons became infamous for recommending the stricken oil tanker the Torrey Canyon, adrift off the coast of Cornwall, be bombed to contain any damage Turnill, R. (2011) 'Dennis Lyons Obituary, 1916-2011', Guardian, April 17.

[1442] CAB 134/3584 Minutes WT (July 1972) 1st meeting.

[1443] CAB 134/3584 Minutes WT (October 18 1972) 5th meeting.

[1444] CPO, 1970.

proposed a return to Victorian liberalism and market-led policy[1445]. But perhaps the most vocal advocates of market forces were the pamphleteers of free-market think-tank, the Institute of Economic Affairs (IEA), who since 1955 had encouraged the liberalisation of nationalised industries such as telephony and fuel[1446]. There was a clear distinction between the IEA's advocacy of market forces as a substitute for government ownership, and Heath's idea of market competitiveness as a means to improve government-owned industries[1447]. Equally, the World Trends Committee's advocacy for market forces could likely have come from Jeremy Bray, the only active British member of the Club of Rome[1448], who had continually raised the absence of market forces in the *Limits* model. Bray's correspondence with Forrester had informed a significant part of the World Trends Committee's research[1449]. Though Bray was not an MP at the time, no doubt his involvement with the Club lent authority to his criticisms.

ENERGY RESOURCE CONSERVATION ARRIVES IN BRITAIN

In fact, the way the idea that market forces conserved energy entered government is clearly documented in the Cabinet archives. In February 1973 Rothschild visited America. On his return he wrote to William Armstrong, head of the Civil Service, noting he 'was stimulated to suggest' an solution to the ongoing energy crises as a result of 'some knowledge I acquired

[1445] Schoen, D. (1977) Enoch Powell and the Powellites. Macmillan, London.

[1446] Cockett, R. (1995) Thinking The Unthinkable: Think-tanks and the economic counter revolution, 1931-1983. Fontana Press. London.

[1447] Payne, counter-culture. (2012) The Consumer, Credit and Neoliberalism: Governing the Modern Economy. Routledge.Heath planned so that British Companies could be more efficient, whereas the IEA meant a state of consumer sovereignty.

[1448] The biologist Conrad Waddington, of Edinburgh University, was also a member, though he played little role in *Limits*, unlike Bray who was a vociferous critic of the project. See Turnbull, T. (forthcoming) 'Britain's Sole British Member of the Club of Rome', in Agar, J., Ward, J, eds. Technology, Environment and Modern Britain. University College London Press

[1449] This assumption is supported by the fact that Bray's letter had been filed alongside the minutes of the Meadows meeting in the Heath government's files, as submitted to the National Archive. They are marked by hand, suggesting Bray's criticisms had been noted

on holiday about what is going on in this field in the United States where I think there is a far more coordinated attack on this aspect of the energy problem than there is in the United Kingdom'[1450]. Rothschild's advice clearly influenced Heath who, two days later, circulated a high-level memorandum stating that 'we now need to put more effort into ways and means of conserving energy', in order to 'reduce our present demands for the exhaustible fossil fuels'[1451]. Given the memory of the 1972 miners' strike and Shell's forecasted oil embargo, and the ongoing furore over *Limits*, the attraction of ERC was clear, and Heath described ERC in suitably strategic terms, noting 'this attack will need to be developed on two main fronts: the first, 'greater efficiency in the exploitation of the inexhaustible sources of energy', such as solar energy, wind-power, and waterpower; the second, 'greater efficiency in the use of all forms of energy'[1452].

What knowledge had Rothschild acquired? Heath had made a very distinct claim; the CPRS were to report on the potential for greater efficiency in the use of energy in order to reduce demand for exhaustible fuels. The idea that increased efficiency of energy use could reduce rather than increase demand was a radical departure from Jevons' neoclassical argument (Chapter 2), in which demand was induced by efficiency-increases owing to the human propensity to maximise 'utility'. Equally, the idea that efficiency could reduce energy demand was also distinct from the concept of 'fuel efficiency' advocated by the post-war National Industrial Fuel Efficiency Service (Chapter 3). NIFES had made the case for fuel efficiency as a means of reducing costs, and the Fuel Research Board had similarly never advocated such an idea. In America, the idea of conserving the productive capacity of fuel

[1450] CAB 184/113 Rothschild to Armstrong, February 26 1973.

[1451] CAB 184/113 Heath to Rothschild, February 28 1973.

[1452] Heath listed a number of examples, 'improved vehicle efficiency, alternatives to the internal combustion engine, better public transport […]; improved efficiency of heating and lighting…' CAB 184/113 Heath to Rothschild, February 28 1973.

wells was only considered possible for most of the post-war period via a system of 'production rationing' licences (Chapter 4). The idea that efficient energy use could *conserve* energy, reducing demand whilst the economy grew was, as Rothschild suggested, a new and American idea.

What has been termed the science of energy resource conservation (ERC), as previous Chapters demonstrate, was formalised by RAND in abstract graph theoretical terms. Who had shown that, over time, the difference between optimality and sub-optimal rates of energy use could be considered 'conserved' (Chapter 6). The American Physical Association had made a similar claim, based on the idea that systems of energy use, used with greater efficiency, could be considered as reservoirs of available energy (Chapter 7). And America's economists had argued energy was price elastic, and as such economic growth was not contingent on geometric growth in energy use (Chapter 8). In Amory Lovins work, these ideas had been amalgamated, and received a provocative and popular counter-cultural gloss (Chapter 9). This was the science of ERC which had redefined the notion of conservation. As economist Hans Landsberg had suggested in 1974, the term now meant efficiency in use rather than leaving resources in the ground[1453].

Rothschild did not seem to have visited RAND that winter. But his daughter Emma was living in New York[1454]. Having recently finished a master's at MIT, where she worked with economist Robert Solow (Chapter 8), Emma was now working on a book titled *Paradise Lost,* documenting the decline of the American automotive industry[1455]. In criticising the

[1453] Chapter 5.

[1454] She later became a historian, though in these years, like many others, she was preoccupied with problem of energy supply. See, for example, "What is the Energy Crisis?', The New York Review of Books, July 19, 1973, pp. 23-28

[1455] Bender, M. (1973) The Roaring of a 'Mouse' is Heard in Auto Land', New York Times, November 3, p. 35.

efficiency of the automotive industry she repeatedly cited a recent report by the United States' Government Office of Emergency Preparedness ('USGPO'), in outlining how productive processes might be improved, or alternative modes of transport, such as mass transport systems, might be envisioned[1456]. The report, *The Potential for Energy Conservation*, was that commissioned by Democratic Senator Henry Jackson, and was based on a variety of studies produced under the RANN Programme, as outlined in Chapters 5, 6, and 7. The same report radical physicist David Jhirad had critiqued from the view of the energy left (Chapter 9)[1457]. Emma's book was not published until November, but if Rothschild visited her whilst in America, not unthinkable as it was Christmas, she may have introduced him to the USGPO report, and with it, the American science of ERC. Given the clear distinction between this idea, the nineteenth century notion of Jevons' Paradox, and the post-war concept of fuel efficiency, perhaps the work of Rothschild's daughter explains how the principles of ERC entered British political thought.

How novel was the science of ERC in Britain? Owing to its contemporary orthodoxy, its historical novelty is difficult to appreciate. But in 1970s Britain conservation via efficient use was a distinctly new idea. Wilson's 1967 *White Paper on Fuel Policy*, produced by the Ministry of Power, then part of MINTECH, had made no mention of conservation, only increased productivity and supply, despite marked increases in the efficiency of electricity production and train engines, in its time[1458]. The *Ecologist'*s 'Blueprint' had called for 'maximum conservation of materials and energy', but had referred to this as 'an economy of

[1456] Rothschild, E. (1973) Paradise Lost: The Decline of the Auto-Industrial Age. London: Allen Lane, p. 10; 216; 256.

[1457] USGPO (1972) The Potential for Energy Conservation, A Staff Study. U.S. Office of Emergency Preparedness. Washington.

[1458] Bending R., Eden, R. (1984) UK Energy: Structure, Prospects, and Policies. Cambridge Energy Research Group.

stock rather than flow'. This clearly referred to the older 'conservationist' notion of leaving resources in the ground, hence Goldsmith's suggestion that the re-allocation of demand for these resources would be restricted by a 'raw materials tax'[1459]. In contrast, the American theory suggested resource taxation would *inhibit* conservation, as it would distort the price of resources, leading to suboptimal resource allocation in the market as a whole (Chapter 8). Conservation via optimal allocation and the taxation of energy resources were considered incompatible.

Limits had made no reference to ERC. In fact, the report suggested 'the application of technology to apparent problems of resource depletion or pollution or food shortage has no impact on the *essential* problem, which is exponential growth in a finite and complex system'[1460]. In the *Limits* model increased efficiency of energy use would in fact lead to increased 'efficiency of capital', following Jevonian reasoning. Without 'deliberate checks on growth', this would simply increase the rate of per capita industrial output; accelerating rather than delaying societal collapse[1461]. Thinking back to Roberts' model for RAND (Chapter 6), the efficiency of production (here 'capital') was classed as a positive feedback, hence, unless the entire energy system were suitably reconfigured, efficient production would accelerate rather than decrease the rate of energy use. Similarly, Meadows and his co-authors argued 'technological optimism is the most common and most dangerous reaction to our findings from the world model'[1462]. And the idea that scarce energy resources could be conserved via their efficient use was something been absent from British theories of political

[1459] Goldsmith, E. et al. (1972) The Ecologist: A Blueprint for Survival. Penguin. First published as Vol. 2, No. 1 of the The Ecologist Magazine.

[1460] Meadows, D., Meadows, D. et al. (1972) The Limits to Growth. New York Books

[1461] Ibid.

[1462] Ibid, p.154.

economy, at least since the demise of Ricardian political thought in the nineteenth century (Chapter 2).

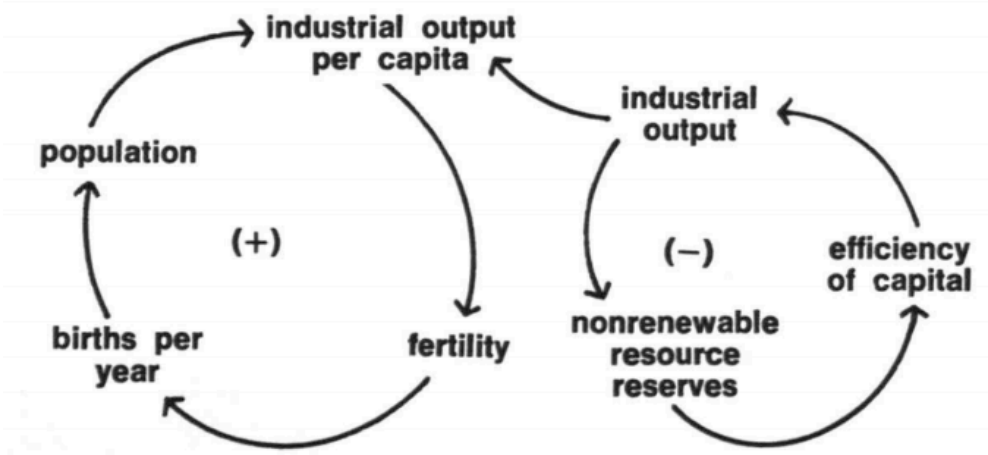

Figure 10.3. The Relationship between Population, Efficiency, and Industrial Output in *Limits*
Meadows et al, 1972, p. 101.

AN ENERGY POLICY FOR BRITAIN

Before the energy crises, British policymakers had spoked of 'fuel policy' but given the apparent interrelation of fuel types, a newer, more systemic 'energy policy' was increasingly deemed necessary by the government; a Department of Energy would be formed in January 1974. But one of the problems, or opportunities, of grouping policies under such a diffuse term, was that almost any area of government jurisdiction, even theories of economy themselves, could be considered energy policy[1463]. As we will see, the pursuit of British energy policy would propose, accordingly, a radical transformation in British political economy.

[1463] Chapter 6 and Patterson, W. (1978) 'Energy: Towards The All-Purpose Policy', International Affairs, Vol. 54, Iss.1, pp. 3

Following Heath's acknowledgement of the idea of ERC, Rothschild began a preliminary inquiry into suitable policies. CPRS member Ian Read, on secondment from Rothschild's former employer Shell, was selected to lead the project[1464]. His first report 'Why Conserve Energy?' was written in March 1973, and suggested the main aim of conservation was to 'lessen the risk that the growth of GNP will be constrained by the availability of energy', a definition that clearly conveyed the concept of ERC formulated under the RANN programme. Read suggested a second reason why conservation was important; the insecurity of Middle Eastern oil supply. Though no mention was made of possible alleviation of coal dependency. The third 'indirect' benefit noted by Read was 'to the environment'[1465]. The government's priorities were clearly set out. On Rothschild's orders, having circulated this memo, Read was to consult with relevant departments and produce a full report on how the government might conserve energy by September 1973.[1466] There were now two government bodies formulating a suitable response to the forecast energy crises. The CPRS, who were supposed to bring market-based know-how, and the DTI, who as the ancestor of Harold Wilson's monolithic MINTECH, represented the old-style centralised approach to policy-making.

The CPRS would complete their report in May 1973, just as the DTI published their rival report *An Energy Policy for Britain*[1467]. There were some serious divergences between the two, most significantly in relation to forecasted oil price. The CPRS presented three scenarios, from the current price ($2.20 a barrel): EASY ($3.75), SCARCE, ($6) and CRISIS ($9). Though they suggested the $6 per barrel scenario was most probable, though $9 was

[1464] Blackett & Plowden, 1988.

[1465] CAB 184/113 Why Conserve Energy?

[1466] CAB 184/113 Heath to Rothschild, February 28 1973.

[1467] CAB 184/114 CPRS, An Energy Policy For Britain; POWE 63/1034, An Energy Policy for Britain.

entirely possible. Heath took the CPRS forecast seriously, suggesting the DTI explain their lower estimates, which was nearly a dollar lower ($0.90). The effect of such a minor difference would have been considerable in terms of Britain's balance of payments, as Rothschild had argued back in 1971.

Accordingly, Heath arranged a private briefing at No. 10 for Ministers to hear the CPRS's warning in full. Rothschild announced the CPRS's findings as a foray into 'the world of futurology', a future in which oil would cost $9 a barrel. This price, he suggested was not a joke, but the assumption of a major oil company[1468]. Rothschild's presentation caused some ministers to accuse him of scaremongering[1469]. Four months later, following the announcement of the oil embargo, his presentation would seem extremely prescient.

The CPRS had made use of a 'scenario planning' method, a novel qualitative forecasting technique that had been developed at Shell. The oil price scenarios were based on the consideration of a number of uncertainties that conventional econometric and technological forecasting could not account for, such as the likelihood of accessing North Sea Oil or the successes of environmentalist lobbying[1470]. Whilst still at Shell, Rothschild had suggested applying the method to the problem of Middle Eastern oil supply. The results suggested the company was likely to lose control in the region, though many senior executives refused to believe it[1471]. So it appears that the dire forecast David Barran had shared with Heath in 1971

[1468] Hughes, 2012.

[1469] Blackett & Plowden, 1988.

[1470] POWE 63/1034 CPRS, An Energy Policy For Britain

[1471] Kleiner, A. (2006) The Age of Heretics: A History of the Radical Thinkers who reinvented corporate management. John Wiley, Ltd.

had been initiated by Rothschild[1472]. As was the organisation's intended function, the CPRS had transmitted this finding from the private to the public sector.

The CPRS also proposed a much more controversial political response to price rises to that of the DTI. Despite ongoing disagreements with the NUM, Rothschild proposed a far greater role for British coal; advocating exploratory drilling to increase output and calling for power stations to be 'dual-fired' to run on either coal or oil, a proposal which Burke Trend amended with the warning 'with all that this implies for economic and social policy'[1473]. To revive the coal industry Heath would have to revise his anti-inflationary policy of price controls and reconsider his relations with unionised labour, in effect he would have to renege on his 'U-turn' and agree to increase NUM's wages.

The miners had achieved a seven percent increase in basic pay, and various other benefits following negotiations in October, but they soon realised the oil embargo had increased the worth of their labour considerably. If the five percent cut of the embargo was realised, Britain would need between 5 and 6 million tonnes of extra coal to generate the required amount of electricity. But a month after the embargo, the NUM began an 'overtime ban' to ensure their bargaining power remained strong and to ensure a surplus of coal could not be built up under the aegis of crisis. Rather than cede to further demands, Heath called his fifth national emergency[1474].

[1472] Jefferson, M., Voudouris, V. (2011) 'Oil scenarios for long-term business planning Royal Dutch Shell and Generative explanation, 1960-2010', CIBS Working Papers Series, No. 18. Pp. 1-40. Suggests a 'planning document' was produced in January 1971, which by October 'Barran [… was] communicating […] to senior members of the OECD and the European Union'.

[1473] PREM 15/1847 Trend Memo May 14 1973

[1474] Hughes, 2012, p. 175.

But perhaps more controversial was the CPRS's proposal that the price of electricity 'be increased to a level which reflects costs' in order to discourage excessive use. Emboldened by the miners' strike the Electrical Power Engineers' Association (EPEA) also began an overtime ban, creating a third prong to the energy crisis. Each time the CEGB failed to provide sufficient electricity to meet load demand, a state of emergency was declared in order to impose shorter working weeks, to reduce electricity use[1475]. Since nationalisation in 1957 the Central Electricity Generating Board (CEGB) had offered subsidised electricity in order to encourage economic growth, and price controlled electricity was considered a vital means of inflation control in the post-war period[1476]. In accordance with this view, the DTI had not suggested raising electricity prices to reduce electricity demand, fearing it would worsen inflation, and worse, it would contravene Heath's recent price and incomes freeze. The CPRS' call for liberalised energy prices was therefore a notable deviation from the post-war consensus regarding fixed fuel pricing.

Despite Rothschild's enthusiasm for energy conservation, and the hope it might allow energy demand to be reduced without effecting the economy, the CPRS' survey of conservation measures was stalling. The idea seemed to sow disagreement and confusion in government. Treasury economist George Corti, for example, wrote to Ian Read, the CPRS's lead author, to suggest price-driven conservation would interfere with the 'test discount rate'[1477], the forecasted interest rate the Exchequer used to cost public sector borrowing. Corti complained that if electricity were suddenly priced at the market rate, this would cause rapid inflation and the Exchequer would have to revise its entire budget[1478]. By July, his warnings having gone

[1475] Hughes, 2012, p. 174.

[1476] Shepherd, W. (1965) Economic Performance under public ownership: British Fuel and Power. New Haven, Yale.

[1477] CAB 184/113 Corti to Read, May 9 1973

[1478] Tivey, L. (1973) The Nationalised Industries since 1960: a book of readings. London, Unwin.

unheeded, Corti began expressing 'heretical thoughts' to the CPRS, and he argued that price signals were an ineffective means of accounting for future scarcities[1479].

Clearly American economists' notion of conservation (Chapter 8), in which forecasted scarcity was considered a mechanism for saving resources in the present, had yet to reach the treasury[1480]. Faced with such disagreement, Rothschild circulated a memorandum clarifying the very purpose of energy conservation policy, which he suggested, was primarily a response to possible interruptions in supply, such as that caused by the embargo and miners' strike, it was not, he clarified, a move toward market pricing[1481].

A further complication was that initial energy conservation research undertaken on behalf of the CPRS remained firmly of the post-war 'fuel-efficiency' kind (Chapter 3). Imperial College professor of thermal engineering Walter Murgatroyd (1921--) was commissioned to estimate the potential for energy conservation in industry. He proposed a number of engineering improvements, but re-iterated fairly conventional post-war fuel efficiency policies of the kind outlined in Chapter 3, such as subsidies for the purchase of more efficient plant. Ian Read of the CPRS, in reviewing Murgatroyd's work, disagreed. In his annotations he exclaimed 'No! The incentive should be part of pricing policy of the nationalised energy industries'[1482]. The older policies of fuel efficiency had been based on government subsidies and advisory services, whereas the newer notion of ERC was based on the imposition of a revised pricing structure which was closer, at least in theory, to market pricing. An

[1479] CAB 184/113 Corti to Read, July 23 1973
[1480] Mitchell, 2011: 196.
[1481] CAB 184/113 Rothschild memo, July 25 1973
[1482] CAB 184/115 Energy Conservation in Industrial Motive Power, September 12 1973

ideological conflict between the older policies of fuel efficiency and the newer notion of ERC was becoming apparent.

The DTI's own work on conservation had left them 'confused as to whether there was anything special in energy conservation which made it a more desirable […] than the conservation of, say, food, steel, or building materials'[1483]. And, just as news of the embargo broke, Alan Urwick of the CPRS admitted to Rothschild that 'input from the Ministries concerned had been of varying quality, but in many cases disappointing'[1484]. The accompanying draft CPRS report suggested conservation provided 'no solution to the immediate crisis'; as rapid savings were only possible 'by imposing very severe restraints on the public's freedom of choice'[1485]. Contrary to Rothschild's confidence, the investigation into energy conservation was disappointing. Government departments seemed confused by the motivation for, and mechanism by which, energy could be conserved.

MARKET FORCES WORKING GROUP

The CPRS took another knock at the end of September. A week before the outbreak of the Arab-Israeli war, Rothschild gave a speech to mark the opening of an Agricultural Research Council laboratory in Wiltshire. Earlier that year he had met Herman Kahn of the Hudson Institute, who was in Britain to assist in the promotion of their study of British decline[1486]. Kahn's promotional tour, touting Hudson's gloomy prognosis for Britain, had seemingly influenced Rothschild. In line with the Hudson report, he suggested that Britain's productivity would be half that of Germany or France by 1985. Unfortunately, Heath,

[1483] CAB 184/115 Davies, November 7 1973

[1484] CAB 184/115 Urwick to Rothschild, November 8 1973

[1485] CAB 184/115 CPRS draft, November 8 1973

[1486] Blackett & Plowden, 1988.

simultaneously, though in Essex, was giving a more laudatory speech, suggesting Britain was entering a period of general prosperity. The press noted the divergence between the two, and suggested it was a sign of a government in crisis. The press furore meant Rothschild, and the CPRS more generally, somewhat fell from Heath's favour[1487]. Notably, a week later, the OAPEC embargo was announced and a true crisis hit government.

Two weeks earlier, Peter Rogers, a CPRS member who also sat on the World Future Trends Committee (WFTC) contacted Ian Read, lead author of the CPRS conservation report. Rogers suggested he had completed a 'first shot' at a paper on the economics of energy conservation which he hoped might 'throw some light on the underlying issue'. Acknowledging the term 'conservation' was opaque, Rogers suggested it implied the current rate of oil-consumption was excessive, and that the price mechanism was not able to signal the coming exhaustion of fuels, as prices were kept below the market rate. He suggested that this need not be the case, and that drawing on economic 'models of general price equilibrium', it could be shown that 'a properly functioning price mechanism would handle the needs of conservation'. He argued that price rises would encourage substitution, and this would reduce the rate of resource consumption. Reduction in consumption, he suggested, 'seems to be what people have in mind when they speak of oil conservation'. Here was the economists' notion of conservation that was outlined in Chapter 8. But in Britain, where nationalised industry prevailed, such an idea was somewhat unorthodox.

Rogers went on to suggest the price mechanism could even conserve energy 'based on the anticipation of high prices in the future': as prices rose, oil owner's 'rate of time preference', their valuation of oil today compared to the future, would encourage a reduction in their rate

[1487] Hennessy, 1985; Davis, 2009, p. 155.

of supply. Hence Rogers argued 'expectations about the future are reflected in today's market prices'[1488]. Here was the anticipatory conservation economics Koopmans, Solow and Nordhaus had outlined in America, but now articulated at the heart of British Government (Chapter 8). But in contrast to this optimistic view of the conservative potential of the price mechanism, only a week later, to counter inflation, Heath announced a statutory 90-day wage and price freeze.

Where had Rogers got this idea? Cabinet papers suggest his ideas had been derived from the work of Canadian economist Harry Johnson (1923-1977), based at the London School of Economics (LSE). Rogers had written to Johnson's secretary to request a paper Johnson had written 'criticising excessive concern over the problem of conserving limited fuel supplies'[1489]. LSE was a growing centre of neo-liberal economics, having moved both theoretically and politically far from the department's Fabian socialist roots[1490]. Johnson contributed to this, having trained at Chicago and worked with Robert Solow, he was also an advisor to the Institute for Economic Affairs (IEA)[1491]. Just as Solow and others had done (Chapter 8), Johnson's paper argued the price mechanism offered the best means of conserving oil, as price rises would encourage substitution and would mean 'oil reserves will be held for future profit'[1492]. Notably, Johnson berated the authors of *Limits,* and similar studies, for ignoring that the 'factual information' they based their forecasts on was 'generated by the economic processes of competition and growth, and hence represents no

[1488] CAB 185/115 'Energy Conservation', Rogers to Read, September 27 1973

[1489] CAB 184/115, letter from Rogers to Miss Rogers, LSE, August 8 1973

[1490] Tribe, K. (2009) 'Liberalism and Neoliberalism in Britain, 1930-1980', in Mirowski, P., Plehwe, D. (2009) The Road From Mont Pelerin: The Making of the Neoliberal Thought Collective. Harvard University Press.

[1491] Moggridge, D. (2008) Harry Johnson: A Life in Economics. Cambridge University Press.

[1492] CAB 184/115, Miss Rogers to Rogers, LSE, [undated] 1973 []

inevitability in the relationship between man and his environment'[1493]. As a career civil servant, Rogers' promotion of Johnson's ideas six years before Thatcher's rule implies such ideas were far from unusual before her political administration began.

But at the time, such ideas were joined by more unusual approaches to conservation. A persistent criticism within the WFTC was that *Limits* failed to account for 'market forces', the stabilising effect of price increases in moderating demand: in September, before their fifth meeting, David Ovens, of the Department of the Environment, circulated a paper which argued *Limits* had not paid sufficient attention such forces as mechanism which could avert the predicted catastrophe'[1494]. He suggested resource prices should reflect 'the costs of replacing, in a future period, resources consumed today', which he termed 'replenishment cost'. To do so would require the development of a sophisticated forecasting system, which could formulate a suitable discount rate for the opportunity cost of using a given amount of resource at a given point in time, whilst also accounting for resource substitutions and externalities. He suggested Harwell's Programmes Analysis Unit (PAU), Wilson's futurology department, could provide suitable estimates of replenishment cost[1495]. But at the time the PAU was being run-down, it was seen as incompatible with a new 'customer-contractor' principle in government funded science[1496]. In effect, Ovens was suggesting central government could, given sufficient expertise, use forecasting to establish a better, more conservative resource price than that of the market. This ran at odds to the economists' notion of the market as the primary means of energy conservation, and by suggesting the PAU should become a centre for calculating the correct cost of energy resources, Ovens' idea was

[1493] Johnson, H. (1973) Man and His Environment, British North American Committee, Canada., p. 26.

[1494] CAB 134/3703 WFTC Meeting 5, September 4 1973

[1495] CAB 134/3704, WFTC Note 20, July 23 1973

[1496] A move also introduced by the CPRS. See Smith, M. (1982) "The Experience of the UK Programmes Analysis Unit', Impact Assessment, Vol. 1, Iss. 3, pp. 40-53.

diametrically opposed to the market-led principles espoused by the CPRS. In fact, in many ways Ovens had resurrected the old debates of the 'Socialist Calculation debate' outlined in Chapter 4. Their appeared to be a determinative role for metrology in the realisation of energy as a resource. Could the market or government better attend to the metrological work of calculating the efficient allocation of energy resources?

Ovens claim that the PAU could calculate 'replenishment cost' was sufficiently credible for Cottrell to suggest a working group investigate the idea. The 'Working Group on Market Forces, Resource Use and Technological Change' reported in December 1973. Two weeks earlier the National Union of Mineworkers had announced an overtime ban, Environment Secretary Peter Walker had announced a ten percent cut in fuel supplies owing to the oil embargo and Heath, in response, had announced a state of emergency[1497]. Against these events, civil servant Donald Braben, the Market Forces group's chair, announced that Ovens' idea of replenishment pricing was 'too inflexible'. The group concluded that 'a normally operating market would lead to an efficient allocation of resources'. Government needed to do nothing other than liberalising energy prices in order to reduce energy demand. An argument, as Braben suggested, as set out in the 'exposition of the economic theory of optimal resource allocation in a competitive economy'[1498].

Given that Britain was not a competitive economy at the time, the group fudged how this might occur. Where government intervention was unavoidable, the group suggested a 'benchmark price' could be established, which could be in some way 'associated with optimal allocation', though they noted the 'intractable problems of quantitative estimation'

[1497] Ball, S., Seldon, A. (1996) The Heath Government, 1970-1974: a reappraisal. Longman. New York and London.

[1498] CAB 134/3704 MFWC 'A Critique of Market Forces and the Case for Intervention', December 4 1973.

and the likelihood this would involve 'a large measure of subjective judgement'. This sounded unappealing and unworkable, and Braben concluded that, though his group did not 'advocate complete laissez-faire', the government should only act as a 'watchdog', intervening in cases of 'market failure', by which they meant barriers to economic competition. If there was any ambiguity about the group's view on contemporary developments, they suggested an example of such failure included 'restraints on price competition imposed by government wage and price controls'[1499]. At this point, Heath's government had just begun Stage 3 of its price freeze policy[1500].

The title of Braben's report 'A Critique of Market Forces and the Case for Intervention' was ironic, if not intentionally deceptive, as it in fact suggested a reduction in government intervention on the basis of conserving energy. This was not without its own irony, considering the report was produced by Civil Servants originally convened as a result of the fear of resource limits. Far from implying the need for unparalleled government intervention, as *Limits* had warned, the Market Forces working group recommended liberalisation was the best means of averting limits. In doing so, they arguably wrote the earliest and most complete articulation, within British policymaking, of a set of ideas normally associated with theories of neoliberalism[1501]. Distinct from conventional liberalism, neoliberalism has been increasingly recognised as a technocratic political philosophy, an exercise in the science of decontrol, in which 'marketisation' transformed individuals into calculative devices, and their adherence to the philosophy was enacted via their use of mundane energy-using technologies[1502]. As energy analyst Walter Patterson noted in 1978, as fuel policies had

[1499] Ibid.

[1500] Holmes, M. (1987) The Failure of the Heath Government. Macmillan

[1501] Jackson, B. (2012) 'The Think Tank Archipelago: Thatcherism and Neo-Liberalism', in Making Thatcher's Britain. Cambridge University Press, 2012. pp. 43-61, B. Jackson and R. Saunders, eds.

[1502] Davies, 2014.

become subsumed under a more systemic 'energy policy', a field which could include even theories of political economy, the notion of energy conservation had been transformed. Whereas once it had meant 'doing without', now, it was 'in no sense a noble sacrifice. It is on the contrary a highly-structured pursuit of self-interest'[1503]

THE CONSERVATION REPORT

The Market Forces Working group completed their study just as power-cuts began across Britain. By January 1974, a three-day week had been instated and the Prime Minister had finally agreed to negotiate with the miners. However, by February 1974 these talks failed and the miners began a strike. Faced with a political deadlock, Heath called an election, which he lost, with Wilson returned to power. The programme of political liberalisation Heath had set out to achieve had been ended by miners' restricting access to coal and the panic over the supply of oil that the OAPEC embargo caused. The imagined role of ERC, as both a means of reducing dependencies on coal and oil, and as means to move toward market liberalisation, had failed to materialise. Under the new Labour government the CPRS persisted and their attempt to produce a comprehensive report on energy conservation policy continued[1504].

At the end of April 1974, the MP Eric Varley announced the establishment of the Labour Government's Department of Energy, which he would lead. He also leaked a finding from the CPRS report, which suggested that a 10 percent reduction in fuel-use could save a forecasted £600 million a year, without a drop in living standards, and that this reduction could be achieved painlessly and with minimal political intervention. He suggested the full details would be published in the CPRS' final report, which would be made publicly

[1503] Patterson, 1978, p. 6.

[1504] Blackett & Plowden, 1988.

available, a first for the CPRS, in July[1505]. That month Varley announced the report's findings to Parliament, and suggested that on its basis, his intention to move toward 'realistic energy pricing', which in effect meant a 15 percent rise in electricity prices for households and 5 percent rise for industry. The government would save £200 million in annual subsidies, now paid by the consumer, alongside the associated 'conservation' savings that would come from deriving utility without expenditure on energy[1506]. Just as the policies of ERC had for the American governments of Nixon and President Carter, this new idea allowed the incoming Labour government to make claims as to the quantity of energy resources that could be saved, based only in reference to a hypothetical, profligate, but avoided, future. In doing so, ERC became the principal conduit for arguments in favour of market liberalisation, according to a rationale which transcended party affiliation.

The CPRS' final report on energy conservation was clearly influenced by the work of the Market Forces Working Committee. It began by stating that 'In theory the price mechanism should provide consumers with an adequate incentive to undertake all the appropriate cost-saving energy conservation measures', though it was admitted that in practice this would not always be the case, and that 'regulation, subsidies and taxes' could encourage conservation in situations of 'market failure'[1507]. The CPRS' document shows that the notion of 'market failure', and with it, the idea of self-regulating markets, found one of its earliest articulations in British politics in relation to ERC. Other authors have wrongly claimed the term 'market failure' was first used in a UK policy document in 1989[1508]. The very term market failure suggested there was a transcendental thing called 'the market', which without barriers, would

[1505] Kenward, M. (1974) 'The Art of Conservation', New Scientist, July 4.

[1506] Kenward, M. (1974a) 'The Government of Energy', New Scientist, April 11.

[1507] HMSO (1975).

[1508] Rigby, J. (2005) 'Policy, Theory, and Pragmatism: Implementing the UK's Energy Efficiency Best Practice Programme', Vol. 33, No. 2, pp. 277-296.

act in a seamless way to allocate resources via calculative processes of informational feedback. The government's role was reduced to simply ensuring the market's untrammelled operation[1509]. In resource ontological terms, the CPRS' report established the idea that conserved energy was equivalent to material energy resources. In September 1975, the Parliamentary Select Committee on Science and Technology suggested that, on the basis of their findings, 'Henceforth the government should consider the extent to which increases in energy demand should be met by investment in additional supply capacity, or avoided by investment in energy conservation measures'[1510].

The CPRS' energy policy proposals were primarily oriented around the idea of a self-regulating market which would ensure that energy demand was reduced as prices increased. Aside from a number of engineered efficiency increases in the transport and electricity generation sectors, such as improving diesel engines, or exploring the potential use of wave power, the majority of the CRPS' polices were directed at the domestic and industrial sector. There, informational feedback, via price information, was the primary means by which it was suggested energy could be conserved. The principle goal would be to 'Encourage Information Flow': and this could be achieved by pricing energy at its true cost, and ensuring that the energy demand information was accurately calibrated by ensuring buildings were well insulated, and electrical appliances met minimum efficiency standards[1511]. In a view redolent of older fuel efficiency approaches, it was also suggested that a hydraulic system for using heat more efficiently in homes and industry should be promoted, curiously, as an informational solution.

[1509] Mirowski, 2002, p. 283.

[1510] Patterson, W. (1978) 'Energy Conservation: 'not doing without but doing more', Bulletin of the Atomic Scientists, Vol. 34, No. 10, pp. 66-7.

[1511] HMSO (1975).

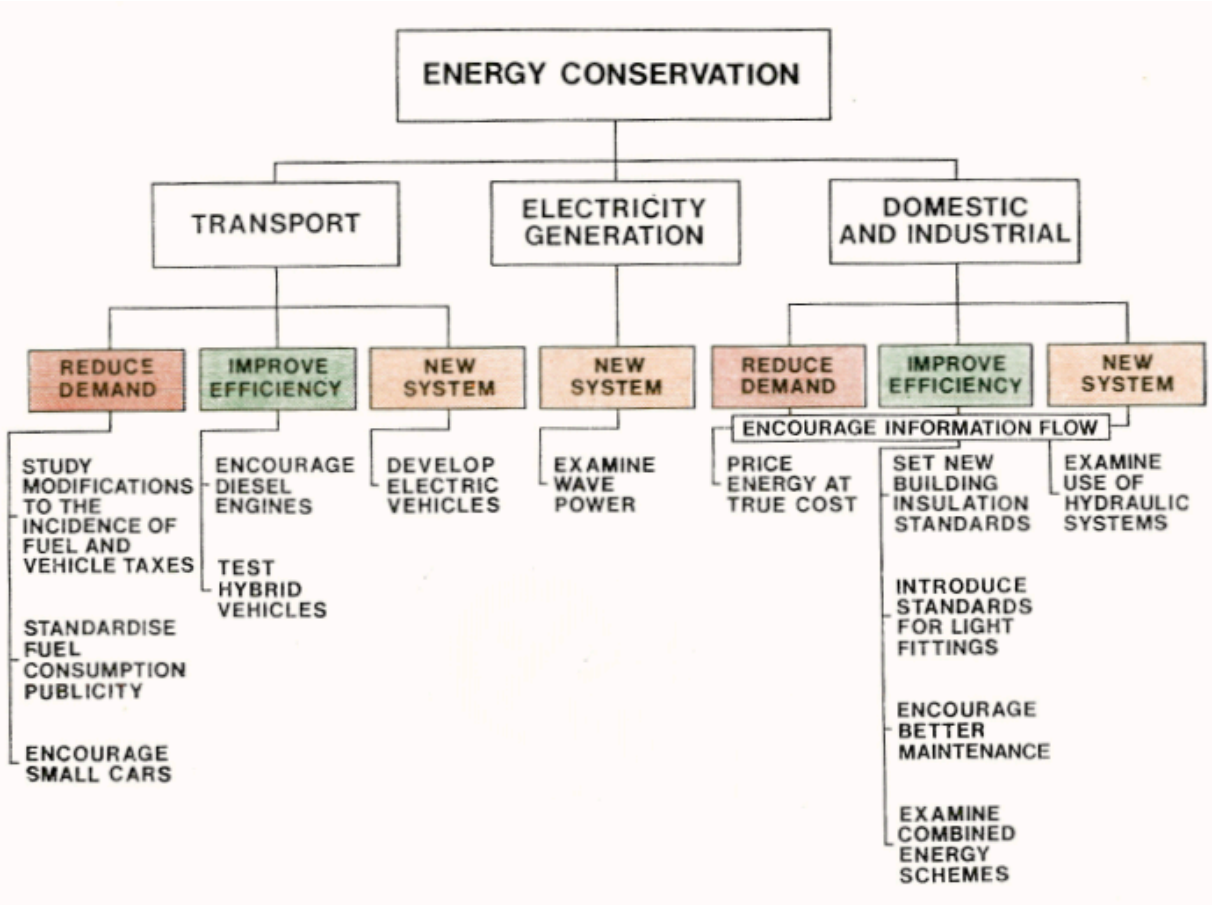

Figure 10.4. Insert from Energy Conservation: a study by the Central Policy Review Staff
HMSO (1974: 44)

There were however some concessions to intervention, though these might be considered as means of helping consumers act in their own best interests, not at odds with the idea of the market[1512]. Eric Varley announced that publicly funded research into energy efficiency and alternative energy supplies would be carried out a new facility in Harwell, the site of the AEA, at the newly created Energy Technology Support Unit ('ETSU'), where new forms of 'alternative' energy supply, such as wave-derived energy and synthetic fuels, were supposed to be developed[1513]. Varley also led a government-backed publicity campaign called 'Save

[1512] Davies, W. (2012) 'The Emerging Neocommunitarianism', The Political Quarterly, Vol. 83, Iss. 4, pp. 767-776.
[1513] Wilson, 2012.

It!' to inform consumers on how they could 'help themselves and the nation by using energy more carefully and efficiently'[1514]. Significant steps were also taken in promoting energy saving technologies via ETSU, such as combined heat and power and district heating technology, which utilised waste heat from power generation to heat homes. And in pursuit of further efficiencies, ETSU developed a number of 'public-private' enterprises, such as the National Heat Board, which were reminiscent of NIFES in their attempts to promote 'best practice' to industry. But in 1979, with the arrival of Thatcher's government, the majority of these schemes were abolished[1515]. Instead she promoted conservation measures via private industry, via the Association for the Conservation of Energy (ACE), established in 1981 to promote energy-efficiency in industry. Most significantly, in 1982, Nigel Lawson gave a speech at the British Institute of Energy Economics, announcing his intention to privatise the energy sector. In future, the government's role would be 'to set a framework which will ensure the market operates with a minimum of distortion and energy is produced and consumed efficiently'[1516].

CONCLUSION

This Chapter began with the suggestion that in Britain, the government's response to the energy crises had profound implications for the political economy of energy: prompting a move from policies of 'fuel' or 'power', the crisis marked a shift toward a more all-encompassing 'energy' policy. This rather abstract term could include not only interventions to improve the efficiency of certain types of fuel use, as it had for much of the postwar

[1514] Phillips, N., Nelson, E. (1977) 'Social Marketing: the 'Save It' Campaign', Advertising Quarterly, No. 51, Spring 1977.

[1515] Russell, S. (1993) Writing Energy History: Explaining the Neglect of CHP and DH in Britain', The British Journal for the History of Science, Vol. 26, Iss. 1. Pp. 33-54.

[1516] Pearson, P., Watson, J. (2010) 'UK Energy Policy, 1980-2010: A history and lessons to be learnt', IET & Parliamentary Group for Energy Studies.

period, but it extended political concern to the entire infrastructure of energy as a whole, and the theories of political economy by which it was managed. In effect, the establishment of a science of ERC, and the claim that energy could be conserved from use, made the idea that Britain's nationalized energy industries should be liberalized increasingly credible. On the basis of conserving energy, it was suggested that price controls should be removed, and fuel industries should be buffeted by the competitive forces of the market. Then, and only then, could the ontological resource of conserved energy be summoned in optimal quantities.

Here was a clear example of Mitchell's notion of carbon democracy. In a nation subject to the energo-political demands of mineworkers, seeking greater economic intervention, oil producing countries seeking greater revenues, and less impositions from Western geopolitical hegemony, and oil companies themselves, seeking a combination of oil consuming government's support to ensure that the governments of producer states did not interfere in their continued exploitation of oil resources. But Mitchell did not consider the role that energy conservation might have in imposing its own forms of political relations. By suggesting that Britain might use less energy, various government departments, most notably the CPRS and WFTC, suggested that not only could the political demands of mineworkers and oil producers be partially deleveraged, but the entire British polity could be remodeled so that it could, collectively, act as a mechanism for conserving energy resources, at no cost to economic growth.

In tracing the argument for market liberalization in Britain back to the nation's reception of the principles of ERC, this Chapter offers a new history of the emergence of neo-liberal thought in Britain. In contrast to contemporary narratives which point to the work of new right think-tanks, such as the IEA, the argument made here is that the *science* of conserving

energy at a national level expressed ideas that were similar to those advocated by the conventional voices of liberalism, but did so in a way which was explicitly technocratic, and see at the time as non-partisan. This reveals that conserved energy, as a resource, imposed its own form of political relations, just as coal and oil had done in previous decades. Whereas coal was associate with the rise of organized labour and the realization of the demands of the working classes, and oil was associated with the rise of the transnational corporation, and the rise of a political class whose role was to stabilize these relations, conserved energy suggested that political control needed to be ceded to the market.

CHAPTER 11. CONCLUSION: ACCOUNTING FOR CONSERVATION

At the outset of this thesis it was suggested that the idea that we can 'save' energy by using it more efficiently has become a commonplace homily, though one that has assumed eschatological significance owing to its perceived role in limiting the worst effects of climate change. Under the UNFCC Paris agreement, current international climate change mitigation policy is grounded upon the idea that increased efficiency of energy use can decouple the consumption of energy from the pursuit of economic growth, meaning that cumulative greenhouse gas emissions occur at a lower rate than would otherwise have been the case. In response to this orthodoxy, I argued that, if this idea was addressed from the perspective of the long twentieth century, such a claim seems unwarranted. Despite all this effort, just as Jevons predicted in 1865, in this period, more energy efficient nations tend to consume more energy[1517]. And so, one of my principle claims is that idea that society can conserve energy by using it more efficiently has proven far from self-evident, and that the principles of ERC have a longer, and more polyvalent history that was, at times, more concerned with state-craft, geopolitical strategy, and a radical, decentralised, approach to political sovereignty. This thesis has revealed a series of contradictions and disagreements, and radical shifts in thought, rather than a linear narrative of scientific progress and an emerging political consensus with regard to the conservation of energy. In this short concluding Chapter, I return to the main reasons why the history of ERC is of significance to our historical understanding of the long twentieth century, our current climate predicament, and our shared future.

[1517] York, R., McGee, J. (2016) 'Understanding the Jevons paradox', Environmental Sociology, Volume 2, Iss. 1, pp. 77-87.

THE SCIENCE AND POLICY OF ENERGY RESOURCE CONSERVATION

This thesis has attempted to show that the problem of energy resource conservation has had a demonstrable impact on policymaking in Britain and America. In Chapter 2 it was shown how, following the discovery of the laws of thermodynamics, evidence of the wasteful use of energy abounded. This prompted William Armstrong, head of the British Association for the Advancement of Science (BAAS) at the time, to question the duration of Britain's coal supplies, and to call upon British scientists and engineers to develop more efficient ways of using fuel and substitute means of achieving motive power. Economist William Stanley Jevons responded to the same question, but in doing so critiqued the basis of Armstrong's argument. Jevons argued that the increased efficiency of energy use would do nothing to increase the duration of Britain's coal use. Efficiency increases, he argued, would in fact cause coal to be used at a greater rate and scale, due to the effect that lower operating costs would have on price (reduced) and demand (increased). This argument ran counter to popular contemporary claims made by engineers and political economists who argued that coal scarcity would encourage human ingenuity, which would compensate for coals' diminution. What explained this divergence? Jevons' paradoxical argument was grounded in the principle that humans are utility maximisers, who in all instances will seek to increase the usefulness that they can derive from scarce resources. As coal possessed an extraordinary utility, demand could not be satiated and society would favour coal-use over other forms of motive power. In 1866 this prompted the first Royal Commission on Britain's coal supplies, the first time that the efficient fuel use proposed as a problem of government. Nonetheless, both Jevons and the more moderate Royal Commission defended the idea that the responsibility to use fuel efficiently fell to those in manufacturing and industry, and was best administered by a liberal market, which would assure the optimal derivation of utility from scarce coal.

Whatever the outcome, it was clear that the efficiency of fuel use had become a political problem.

In Chapter 3 we saw how the principles of scientific management, the control of productive processes according to empirical scientific research, was applied to fuel efficiency efforts. By tracing the literal genealogy of ideas around the efficiency of coal use, the work of William Jevons' son Herbert was used to describe how the principles of scientific management were fused with a vision for a utopian British socialism which, Herbert hoped, would radically increase the productive capacities of Britain's coal industry. Like his father, Herbert did not argue that coal could be conserved via its efficient use, instead he suggested government intervention, extending to even include the nationalisation of mines, could increase the efficiency of the transformation of coal into 'National Capital'. Used efficiently, Britain's coal, he suggested, could create a surfeit of capital which could be used for collective good. Herbert's view anticipated developments in British policy, as after the Second World War, Britain's coal mines were nationalised, followed by its gas and electricity infrastructure. Alongside the nationalisation of energy industries, government also promoted best practices in fuel-use for industries and homes, and carried out authoritative measurements with regard to optimising efficient fuel use at the Fuel Research Board's laboratory. Incremental improvements in the efficiency of pyrolysis, combustion, heating and smelting had become a government concern.

In this same period, the American government had developed a swathe of policies to conserve the productive capacities of fuel resources. As Chapter 4 recounted, during the Progressive era, policymakers were enthused by an idea of 'conservation', by which they meant the application of scientific management to wisely use resources (initially riverine) in

order to preserve their productive capacity for future generations. Owing to a glut of petroleum in the 1930s, which served to exacerbate the ongoing economic depression, this approach soon found itself applied to the productive capacities of the nation's oil wells. Industry, Federal, and State government agreed to constrain wells' rate of output through a complex of state-level production rationing ('pro-rationing') licenses and federal oversight of the rate of oil imports. These two policies, limiting production and controlling the rate of import, effectively gave government control over oil and gas prices, which could be helpfully kept low in order to try to control inflation. Accordingly, in America, the practice of fuel conservation for much of the twentieth century meant the regulation of the rate of petroleum production and import in order to preserve the potential productivity of petroleum in the ground. This position was supported by the principles of institutionalist economics, which paid close attention to the geological, technological, and political determinants of fuel supply. This form of thought reflected a more widespread loss of faith in nineteenth-century liberalism. But in the post-war period, an insurgent counter-argument arose which proposed a radically different form of 'petroknowledge'. In the 1950s, the application of econometric methods of optimal allocation to resource economics and agronomy had planted the idea that government intervention such arena always led to a suboptimal allocation of resources, and impeded efficient consumption.

Before the rise of this new form of thought, for the German-American institutional economist Erich Zimmermann, the suggestion that government should intervene in the consumer's sovereign right to consume fuel as they saw fit had seemed unthinkable. Even though he saw the irony of increasing the productive capacity of petroleum wells whilst allowing fuel to be used with unchecked profligacy. However, as documented in Chapter 5, it was precisely this

consumer-led, end-use approach to conservation that was adopted by Federal government in response to manifold crises in energy supply in the 1970s.

Part of the reason that this end-use approach to energy conservation emerged was that the crises in supply occurred alongside a crisis in the legitimacy and funding arrangements of American science. As a result, a move toward 'applied' rather than 'basic' research was deemed necessary by federal government, which re-orientated agency toward the market and the consumer rather than the state. Under the Research Applied to National Needs (RANN) programme, America's energy consumers were recast as a mechanism for societal energy conservation. There was a semantic shift too, the objective was now to manage the supply and use of 'energy' as a collective noun, rather than specific types of fuel. The resultant 'energy policy' would widen the scope for government intervention in society's use of fuel. This shift in regulatory focus, from producer to consumer, and the idea that fuel scarcities required a systemic approach to conserving a collective notion of 'energy', would, as later chapters attest to, hold important implications for political economy more widely.

Under the RANN program, scientists and engineers developed an increasingly techno-scientific approach toward the conservation of energy. The conservation of energy became an applied science, achieved via the use of technologies rather than, as in the era of pro-rationing, via policy. The logic of using of energy-conserving technologies, as Chapters 6, 7, and 8 show, were grounded in underlying conceptual shifts with regard to the way in which the relation between society and energy was understood. Amongst other things, they involved recasting the entire infrastructure of energy use as a *system* of informational feedbacks, in which the quantity of energy was just one source of feedback information amongst many. This *systematisation* of the energy economy in the nineteen-seventies helped redefine the

notion of efficiency. Rather than leaving resources in the ground, conservation now meant increasing the efficiency of energy in use.

In this same period, employing similar notions of the economy as an abstract system, econometricians, most notably Tjalling Koopmans, in contrast to engineers and physicists, made claims about the aggregate energy savings that could be achieved at the societal scale: t was argued that in a liberalised market decisions regarding the allocation of energy could be made at the lowest possible level. This would ensure that a vast amount of informational feedback could be collated, and used to drive iterative reductions in energy consumption. With reductions in energy use occurring at no cost to economic growth, as different forms of capital – including information – could act as a substitute for energy resources. In contrast to the centralised decision-making that had been characteristic of pro-rationing, this decentralised approach would, its advocates claimed, mean energy resources were consumed with optimal efficiency. Particularly so, if government ensured an energy resource futures market existed which would provide an kind of anticipatory source of information with regard to future scarcities of energy resources. This meant the goal of conserving energy lent credibility to a wider political programme calling for the end of government intervention in the markets, which has subsequently become known as ‘neoliberal’.

The growing credibility of the idea that market liberalisation was the primary means by which an economy could conserve energy had clear political implications in both America and Britain. Both Carter and Reagan recommended that a free-market approach was the best way in which society could conserve energy. As the latter President had quipped, the problem was not a shortage of energy but an excess of government. In contrast to Nixon’s proposed ‘Project Independence’, a vision of an energy autarkic America, President Carter’s National

Energy Act of 1977 outlined a liberalised, market-led approach to energy resource conservation. This was, in many ways, very similar to President Reagan's, aside from its' ambitious modelling efforts (CONAES) and advocacy for minor, market-regulating policies like product efficiency standards. However, as this thesis argues, Carter's micro-level interventions were different to the kinds of post-war, Keynesian interventions that had been characteristic of the pro-rationing age. Rather than seeking to *correct* the energy market, they sought to *correct* reality in order to make it conform more closely with the abstract principles of econometric modelling.

The political transformation of the concept of energy conservation as policy was complete; government was now seen as a barrier rather than facilitator of ERC. Any government intervention was intended to emulate and refine the market rather than to control its excesses. Added to which this transformation seemed to have harnessed the ongoing cultural revolution in America. As documented in Chapter 9, a fusion of anti-statist countercultural thought and new liberal thinking combined in their advocacy for energy resource conservation. In this chapter, it was suggested that the two schools of thought found common cause in the new science of energy resource conservation, and that this enthusiasm embodied a new spirit of capitalism that emphasised personal autonomy, decentralisation, and non-hierarchical control systems. This chapter sought to argue that the counterculture's support for this new science had political consequences in so far as it engaged an important oppositional culture in the project of market liberalisation.

In the thesis' final Chapter, 10, we saw how the idea that energy resource conservation was best achieved via market liberalisation was accommodated in Britain. A country that was arguably one of the more interventionist states in the West at the time. Faced with a two-fold

crisis in the supply of oil and coal, energy conservation was seen as a means of maintaining the buoyancy of the British economy during a period of national emergency. However, it soon became apparent that for energy conservation to occur, as the American 's portrayed it, both Britain's post-war nationalised industries and the Keynesian system of economic government via wage and price controls would have to be scrapped. Energy resource conservation therefore implied a programme of liberal reforms that went far beyond that envisioned by Prime Minister Heath in 1970. As it was, Heath's government subsequently succumbed to the crisis, but the idea that an unrestrained energy market was the best means of conserving energy gained a foothold in British policy making, which would help to legitimise the Conservative party's decision to liberalise the market in 1981. Through tracing the transformative effect of the adoption of the science of ERC, this Chapter, and the thesis more widely, demonstrated how the problem of societal energy resource conservation was of central importance to the political trajectory of the long twentieth century.

HISTORICAL ONTOLOGY OF ENERGY RESOURCE CONSERVATION

The next aim was to document how the efficient use of energy came to be considered as a means of energy supply. This reconceptualization was termed an act of 'resource ontology', in recognition of the fact that various practices and forms of knowledge helped contribute to the idea that the non- or efficient use of energy was in some way equivalent to the use of energy resources like coal or petroleum. A central argument that emerge from this ontological perspective was that conserved energy is an idiosyncratic resource, one that is not obviously material, but consists in the physical or temporal conservation of potential causal relations. This idiosyncratic resource's *coming into being* is based on demonstration, legislation, measurement, and the reconceptualization of energy – according to principles

drawn from control engineering, cybernetics, and systems theory - as in some way equivalent to information.

However, this causal relation between energy and information had a long history. It was based on precedent analogies. For example, in the nineteenth century, thermodynamic theory suggested that energy, when it took the form of a motive power derived from the combustion of fuel was equivalent to the mechanical force of a worker. As such, obdurate minerals like coal were reconceived of as material embodiments of labour. As such, suitable minerals were increasingly prized as resources, whose value was enshrined as steam engines and smelting, amongst other combustive industrial processes, became more efficient (or, in Jevons' phrase, increasingly 'under perfect control') over course of the long twentieth century.

As William Jevons argued, thermodynamics demonstrated that energy resources were a wasting asset, whose inefficient use was everywhere observable, and was irrecoverably radiating potential usefulness and value out into space. In light of this knowledge, Jevons suggested other political economists and engineers were acting without a full understanding of the implications of this entropic constraint, and they wrongly argued that an increase in the technical efficiency of energy use and extraction could help to preserve, or even increase the supply of scarce mineral fuels. No less a figure than David Ricardo, for example, had asserted that the 'fertility' of mines could be increased by human ingenuity. Jevons, by contrast, argued an increase in the efficiency of coal use would do nothing to preserve Britain's coal. Efficient coal use was in no way comparable to an increase in material supply, and an increase in the efficiency of use, he had argued, would only cause more to be consumed. Jevons' son Herbert argued increased efficiency of coal use could not conserve coal, but it could help convert this matter into something he termed 'national capital', a

reservoir of capital that could be re-spent on improving the welfare provision of the nation for the permanent benefit of all[1518]. Clearly, at this stage in the history of ERC, there was no way in which efficiency was considered as if it were a source of fuel supply.

In Britain and America in the first two decades of the Twentieth Century, intervention in fuel production, either directly or in an advisory capacity, as detailed in Chapter 3 and 4, was considered the best means of increasing the duration of fuel supplies and the efficiency of its combustion; this was increasingly termed 'fuel conservation', borrowing the term first used in America to describe the maintenance of the productive capacities of rivers. Fuel efficiency was understood as something to be pursued for economic ends rather than according to preservationist thinking. Pro-rationing, however, physically *conserved* fuel reserves. However, increased efficiency was not discussed as if it were a resource, in ontological terms; the emphasis was on production, where the target of the intervention was already considered a reserve, which was in turn, undeniably, a resource. However, in Chapter 4 we saw how the work of the economist Harold Hotelling had begun to shift the semantics of conservation toward something more closely aligned to the principle of economics. Hotelling began a process whereby the economists' notion of efficient allocation appropriated the term 'conservation' to describe the efficient use of fuel over time. This marked a significant semantic shift, as conservation, in this sense, meant the consumption of energy in a manner deemed efficient rather than the restriction of energy production (as it had under the pro-rationing scheme). This was a critical step in the ontologisation of conserved energy, as energy use could now be sensibly described as resource conservative.

[1518] Jevons, H. (1915) The British Coal Trade. London: Kegan Paul, Trench, Trübner., p. 766.

In Chapters 5 and 6 it was argued that the systematisation of energy policy outlined was central to the 'ontologisation' of conserved energy. In part, this was a product of the re-orientation of problem. The RANN programme, in particular, marked an unprecedented research effort into the determinants of energy *demand*. Whereas previous research efforts, and governmental focus, had been directed toward increasing energy *supply*. Facing constrained supply during the energy crises, researchers reasoned that a decrease in demand for energy could be considered equivalent to a increase in the rate of fuel supply. As the *Resources for the Future* economist Hans Landsberg remarked in 1974, whereas conservation had once meant 'keeping primary sources in the ground or managing their extraction in ways to maximise their flow over time' it now denoted 'efficiency in utilisation' and 'avoidance of waste in application'[1519]. For example, as described in Chapter 6, in California the growing demand for energy was forecasted to reach a unsustainable level, in terms of space and cost. Accordingly, conservation was increasingly conceptualised of in terms of the number of kilowatts that would not be needed or even power plants that would not need to be built, were suitable conservation initiatives undertaken.

But it was the work of America's physicists, who, unsurprisingly given their precedent authority, lent greatest credibility to the idea that efficient energy use was equivalent to an increase in the supply of energy. In Chapter 7 we saw how, in response to the energy crises, a number of the nations' leading physicists came to reconsider the notion of efficiency in terms of the conservation of 'available work' in a given system, rather than increasing the ratio of energy inputted to work outputted (so-called 'second law' efficiency, rather than 'first law'). The effect, as Berkeley physicist Arthur Rosenfeld saw it, was that every energy using

[1519] Landsberg, H., Schanz, J., Schurr, S., Thompson, G. (1974: 140) 'Conservation in Energy Use', in Energy and the social sciences: an examination of the research needs. Resources for the Future, Inc. Washington. Funded by the National Science Foundation.

appliance, from refrigerators to cars, could be reconceived of as a potential reservoir of available energy, were less available energy consumed in that system than was previously the case. In this way, making an ontological assertion, he suggested increasingly efficient appliances could be considered as a source of energy supply. As he stated, 'the reserves of energy created through conservation do not lie in the ground; rather they lie in the end uses of energy'[1520].

On this basis, simple extrapolations were made, grounded in engineer's estimates of the savings possible from a specific technology's increased efficiency, as to the potential savings possible at the scale of nation's economy. The mistaken assumption being, as one later critic put it, that estimates of efficiency savings 'could be extended from the laboratory to society'[1521]. However, as historian of economics Philip Mirowski suggested, it was somewhat disingenuous to cast increments of available energy, causal relations between the components of energy using systems, as 'resources'. To do so was to suggest they were available for human use or fungible in some way. When in fact, large parts of this supposedly available energy could only conceivably remain an artefact of measurement and accounting rather than a resource that could be subject to human control[1522].

Despite the ontological claims these physicists made for conserved energy, they had been reticent about making any authoritative claims about the aggregate effects of energy efficiency increases. As such, it fell to Amory Lovins, a renegade physicist turned environmentalist, to assert that individual acts of energy efficient could translate into

[1520] Meier, A., Wright, J., Rosenfeld, A. (1983) Supplying Energy Through Greater Efficiency. The Potential for Conservation. University of California Press., p. viii.

[1521] Khazzoom, D. (1980) 'Economic implications of mandated efficiency in standards for household appliances', The Energy Journal, Vol. 1, No. 4, pp. 21-40.

[1522] Chapter 7, p. 20.

dramatic energy savings for America as a whole. In doing so, he combined the work of physicists with that of econometricians, scaling up the careful estimates of specific interventions and aggregating them to make the dramatic claim that America could double the efficiency with which it used energy ('end use efficiency') by the year 2000.

As we saw in Chapter 8, building on Hotelling's work, Tjalling Koopmans', and the agronomist Siegfried Ciriacy-Wantrup had come to argue that energy resources could be optimally allocated over time, even accounting for scarcity, if the price mechanism were allowed to freely operate, and information about the future availability of resources was developed by a market in energy futures. Central to this claim was the idea that demand for energy was 'elastic', that an increase in the price of energy would encourage a reduction in demand. Contrary to earlier beliefs, the response to the energy crisis of 1973 seemed to attest to this, and on this basis economists confidently asserted that energy scarcity would lead to increases in energy price, which owing to the principle of elasticity, would encourage reductions in energy use as substitutes for energy use were found or people went without. And according to the principles of linear programming, partly developed by Koopmans, this reduction could occur at minimal cost to economic growth, as alternative forms of capital could be substituted for energy resources. The various inputs to the economy would just be re-calibrated to ensure that a reduction in energy use did not impede economic progress.

As such, economists came to describe the economics of elasticity and substitution as if they were equivalent to material energy supply. Forecasts of profligate, sub-optimal scenarios were contrasted with optimally efficient scenarios, and the estimated difference between these hypothetical futures treated as though the differential was a resource. Here was the most

hubristic act of resource ontology, as using simulations to carry out forecasts, one could claim energy resources has been saved only in reference to an unrealised profligate future.

A METROLOGICAL RESOURCE

My third argument, developed by tracing the historical ontology of ERC, the emergence as a concept fashioned by practices, was that conserved energy is specific kind of resource, as rather than being mined or refined, it comes into being primarily through acts of measurement. As such, I have suggested ERC might be considered a *metrological resource*. I do not mean this in terms of a resource for measurement, but instead as a resource that *becomes*, to borrow Zimmermann's term, as a function of measurement. Andrew Barry has argued that certain geographical areas can be categorised as 'metrological zones', owing to consistent standards and practices of measurement over a give space, and the establishment of 'zones of qualification' in which the qualities of objects are measured and agreed upon can be seen as a political and scientific endeavour [1523]. If the demarcation of space can be achieved via acts of measurement, why not consider conserved energy resources, whose properties are shaped by practices of measurement as metrological achievements? Conserved energy is not, as this thesis has demonstrated, a conventionally material resource like other fuels.

Throughout this thesis, it has been argued that calculation and calculative technologies, able to measure and compute, were central to the realisation of ERC. In William Jevons' work, outlined in Chapter 2, it was the individual utility optimiser which provided the fundamental computational unit. Their subjective evaluations of utility led to the calculation of a price, information which, when aggregated in a market, provided a quantitative indicator of value.

[1523] Barry, A. (2006) 'Technological Zones', European Journal of Social Theory, Vol. 9, Iss. 2, pp. 239-253.

This individualised calculation of the value of physiological energy expenditure would not remain the sole means of metrology. For example, in the post-war period, with the growing application of the principles of scientific management to fuel use, Harold Hartley, the director of the British Fuel Research Board (FRB), suggested engineers could use fuel with increasing efficiency if 'control engineering' technologies, which made use of 'informational feedback' were deployed across industry, involving mechanisms for translating physical values into numerical information. Control engineering could also involve the use of computers to automate aspects of measurement. As detailed in Chapter 3, the FRB's Calorimeter, an analogue computer automated and accurately calibrated the measurement of the fuel efficiency of various appliances. On the basis of the Calorimeter's calculation, estimates were made as to the aggregate savings that could be achieved across Britain. In contrast to Jevons' time, the calculative work of efficient fuel use had become an increasingly technologized.

During the American years of pro-rationing fuel policy, with growing government control over the calculative work of estimating the production and import for petroleum, the calculative work of energy resource conservation was increasingly removed from individual control, as it had been in William Jevons' time. In the 1930s, lawyers, geologists, petrologists, institutional economists, and the petroleum industry, increasingly assumed the mantle of calculating how fuel might be used efficiently. Collaboration between these bodies lead to the development of agreed rates of petroleum extraction and levels of foreign oil import: with the aim being for a requisite portion of fuel to be conserved by leaving it in the ground.

However, as we saw in Chapter 4, econometricians, from the nascent subfield of resource economics, were becoming increasingly critical of government intervention in the fuel

economy. New econometric techniques suggested that the rate of production was not the correct component of the energy economy to focus upon, and that – in fact – leaving resources in the ground could even be considered wasteful, in so far as it could lead to sub-optimal allocations of energy resources throughout the economy. As agronomist Siegfried Ciriacy-Wantrup demonstrated in the 1950s, the optimised efficiencies demonstrated by linear and resource programming techniques were not considered possible in a system in which the price and supply of energy was effectively government controlled and, in practice, constrained. Price controls, Ciriacy-Wantrup argued, obscured the 'commensurate indicators of value attached to all physical inputs and outputs of resource use'[1524]. Without such indicators, the kind of calculative processes that took place in a perfectly competitive market, and which could – in mathematical terms – demonstrate the optimal allocation of energy in a given system over time, was not considered possible.

The informational constraint that government intervention of the supply of fuel imposed would not remain for long. The first factor in this governmental shift was prompted by the rise of systems analysis in the nineteen-seventies. In RAND's work on energy demand, the entire infrastructure of energy use was recast as if it were a control mechanism. As sociologist Talcott Parsons suggested, this described a 'network of interconnection' in which the state or activity of one component influenced the behaviour of other components. In effect, a system was a complex of control mechanisms[1525]. A progenitor of systems analysis, cybernetics, as mathematician Roberts showed, suggested energy could be governed by a network of feedback loops, able to relay both information and energy. Reconceived of in this way, it was as if the infrastructure of energy-use, the shifting network of resources, plant,

[1524] Ciriacy-Wantrup, S. (1961) 'Conservation and Resource Programming', Land Economics, Vol. 37, No. 2, pp. 105-111.

[1525] Mason, A. (2006) 'Images of the Energy Future', Environmental Research Letters, Vol. 1, Iss. 1, pp. 20-25.

appliances, fuel conveyance, and human intentionality, could collectively operate as a device for calculating the optimal allocation of energy across the system as a whole. The second factor was the adoption of a similarly de-centred logic of control by econometricians. In Chapter 8 we saw how this idea of decentralised control was reiterated in the work of econometricians, who presented mathematical arguments in favour of market liberalisation, in order that the full calculational capacities of the market could be unleashed, and with it, unparalleled efficiencies in resource allocation. This view was echoed in the popular advocacy of Amory Lovins, who lent on popular countercultural tropes to make the case for conservation via liberalisation. Decentralised networks of individuals, rather than centralised government, were recast as the sovereigns who could best calculate the optimal rate of use and allocation for superior levels of ERC.

Finally, in Chapter 10 we saw how in Britain, a system of broadly nationalised energy supply was shaken during the miners' strike and OAPEC oil embargo. Drawing on American research into the science of ERC, the price of energy came to be considered central to energy conservation. The idea of market liberalisation as a means of energy resource conservation chimed with wider debates ongoing in Heath's government, and British political thought more widely, about the correct way to govern industry and the market more generally. Whether industries should be fashioned by the competitive forces of the market or centrally controlled was a point of consternation for the Conservative government. In the Civil Servant David Ovens' work, on behalf of Heath's futurology department, it was proposed that energy should be priced according to its 'replenishment cost', and that this should be calculated by the government's Programmes Analysis Unit, a futurological research group established by Harold Wilson's Labour government. However, allowing a government-led research organisation to calculate the correct price for fuel was antithetical to the American theory that

a perfectly competitive market was the best way to achieve optimal levels of conservation. As the Chapter went on to describe, thanks to the work of the Central Policy Review Staff and World Future Trends Committee the calculative capacities of the market were ultimately favoured over those of a government-run institution.

Many of the metrological advances required to demonstrate energy resources could be conserved were dependent on computing technology. Computers, as Donna Haraway has suggested, obscure materiality, owing to their emphasis on the manipulation of information and producing simulation[1526]. But clearly, despite this obscurity, computation is a process that demands both material and energetic resources[1527]. But the relation between the material and metrological realisation of conserved energy is more obvious than this materialist retort: a growing concern over the scarcity of fuel resources over the long twentieth century encouraged a number of academic disciplines to re-orient their research focus toward reducing the demand for energy at the level of individual appliances, and at the societal level. In effect, the material circumstances which drove the search for a systemic, structural and collective means of conserving energy led to the science and policies of ERC. But it was not without some irony, that this new form of knowledge would suggest, counter to spectre of scarcity, that new forms of calculation could help in 'maintaining nature as an infinite resource'[1528]. Evidence of material scarcity resulted in a system of thought that claimed to transcend the material constraints of energy supply[1529]. The production and consumption of energy resources was liberalised, and this was cast as means of conservation.

[1526] Haraway, D. (1991) Simians, Cyborgs and Women: The Reinvention of Nature. New York; Routledge., p. 154.
[1527] Bennet, C. (1981) 'Thermodynamics of Computation', International Journal of Computational Physics, Vol. 21, Iss. 12, pp. 905-940.
[1528] Mitchell, T. (2011)., p 249.
[1529] See Koselleck's point about the implicit tension between concepts and matter. Ft. 24.

Measurement has long been a way of informationally enriching our understanding of materials, and a point of intersection between the physical and conceptual[1530]. Metrology must be seen as the central determinant of ERC, the mediation between 'resourcefulness' and a commensurate quantity of inert nature. But, with regard to the eschatological problem put forward at the start of this thesis, the question is left open as to whether this process does, as organisations like the UNFCCC claim, lead to a reduction in emissions. Can the informational component of ERC, the multiplication of a resource's 'forms of existence'[1531], be traced back to a physical quantity of fuel that remains unburnt? We will return to this question in concluding.

POLITICS OF ENERGY RESOURCE CONSERVATION

The fourth argument of this thesis was to develop Timothy Mitchell's observation that different forms of political life can be assembled according to transformations in the materiality and infrastructure of energy supply. But the intention was to expand his argument to accommodate the so far unaccounted for politics of energy resource conservation. In his book *Carbon Democracy,* Mitchell stated that particular forms of democratic life were created by enabling or restricting the supply of energy, and that owing to the material conditions of energy supply, the politics of these material flows or their blockage assumed distinct forms. Obdurate coal, where the miner is the critical link between the geo- and the social, Mitchell argues, helped to realise increasingly egalitarian forms of politics, as miners could restrict the physical basis of economic growth in return for increased political representation. This point was well illustrated by Herbert Jevons' account of miner's lives and political organisation in Chapter 2. By contrast, oil, often extracted and conveyed under

[1530] Barry, A. (2005) 'Pharmaceutical Matters: The Invention of Informed Materials', Theory, Culture & Society, Vol. 22, Iss. 1, pp. 51-69.

[1531] Barry, A. (2014) Material Politics: Disputes Along the Pipeline p. 141.

and through its own pressure and liquidity, was used to circumvent the re-distributive demands of egalitarian politics. Despite the salience of these observations, Mitchell's book failed to consider the political implications of ERC, the science and policies of reducing energy demand, the collective term for all fuels and their various motive, chemical, and thermal functions.

Contrary to Mitchell's broad categorisation of coal as egalitarian and oil as a means of constraining egalitarianism, this thesis has shown that there is no clear way to categorise the politics of energy resource conservation. Still, Rancière's critical definition of democracy, which Mitchell appropriates, is a suitable analytic for capturing the heterogeneous politics of ERC. In some instances, the pursuit of reduced energy use was motivated by genuine egalitarian impulses, however, at other points, it was considered a means of constraining such impulses[1532].

For example, in the nineteenth century, the highpoint of Victorian economic liberalism, reductions in energy use were believed to be ruinous to the British imperial project. Both Jevons and earlier Classical economists agreed on this point and advocated market liberalism. However, in Herbert Jevons' time, liberalism's lustre had faded, competition was increasingly seen as inherently wasteful. In this context, he and many others called for intervention and the centralised control of coal industry. Herbert applauded Miners' trade unions as a means of realising socialism, anticipating Mitchell's description of miners as 'machines for democracy'[1533]. However, rather than constraining their provision of coal, Herbert suggested miners could best serve a truly egalitarian future by increasing the

[1532] Rancière J (2006) Hatred of democracy. Verso, New York, London

[1533] Mitchell, T. (2011) Carbon Democracy: Political Power in the Age of Oil. Verso. New York and London., p. 13.

efficiency of coal production, in order that a greater quantity of 'national capital' could be accumulated, which could then be used to pursue an egalitarian form of government.

In the Progressive era, conservation was seen as a means of constraining the wasteful practices of industry and breaking oligopolistic business practices for collective good. Natural resources were to be conserved for the benefit of all with the aid of the state. But as President Taft remarked, conservationism was an ambiguous term, and the term could be applied to the free licence of business as much as government regulation[1534]. In the 1930s, following a glut of oil, petroleum conservation policy developed into a federally overseen system of state level pro-rationing controls. The pursuit of conservation clearly acknowledge the sovereignty of the state in moderating the excesses of competition, in line with the government's 'New Deal' vision of a technocratic government acting in favour of the collective good, if not redistributive egalitarian ends[1535].

However, in the 1970s, with the redefinition of energy conservation that occurred partly as a result of RANN funded research, the politics of energy resource conservation shifted considerably, and were pluralised. There were multiple political consequences.

As we saw in Chapter 7, for radicals and environmentalists reducing energy use was seen as a means of demonstrating ones' opposition to nuclear energy, environmental destruction, and the technocratic, high growth, authoritarian Cold War State. In Chapter 9 we saw the emergence of 'low-energy subcultures', attempts at communal life independent from the conventional infrastructure of energy supply. But not all radicals supported energy

[1534] Anon. (1910) 'National Conservation', Outlook, May 14m Vol. 95, Iss. 2, pp. 57-59.

[1535] Hughes, T. (2004) American Genesis: A Century of Invention and Technological enthusiasm, 1870-1970. University of Chicago Press.

conservation. The 'Energy Left' considered calls for personal asceticism as a ploy to ensure workers would sacrifice their labour and comfort to perpetuate the exploitative capacity of capitalism[1536]. However, in the work of Lovins, we saw a utopian hybridisation of countercultural politics and a new form of liberal economic theory which, he suggested, would lead to a rebirth in spiritual values. This scenario required that there were no barriers to the free operation of the price mechanism[1537]. The democratic impulse would be directed toward the realisation of personal autonomy rather than collective action[1538].

In geopolitical terms, it was argued that energy conservation must be seen as a product of détente Cold War diplomacy, as well as a response the Arab oil embargo of 1973, which can be seen as warfare by other means. Former Cold War strategist James Schlesinger viewed energy conservation as a strategic response to Soviet-affiliated Arab States' use of the 'oil weapon'. As Chapter 6 and 7 documented, America's leading research organisations, many of whom had helped develop nuclear weaponry, became increasingly committed to the less obviously strategic development of energy conservation measures. Even Carter described prosaic acts of energy efficiency in explicitly martial terms[1539]. By decade's end, Cold War hawk and physicist Edward Teller described conservation as far 'powerful defence weapon' to help maintain the American way of life. At the same time, Arab states had described their embargo as an act of conservation, in the older pro-rationing sense, as aside from its role in diplomatic bargaining in relation the Israel-Palestine conflict, their aim was to keep their petroleum in the ground until a fair price was reached for the product. Thus, conservation in

[1536] Jhirad, D. (1974) 'Energy', Science for the People, 1974, Vol. 6, No. 1, p. 7.

[1537] Lovins, A. (1977) Soft Energy Paths: Towards a Durable Peace. San Francisco: Friends of the Earth. International/Ballinger.

[1538] Boltanksi, L., Chiapello, E. (2006). New Spirit of Capitalism. London, Verso.

[1539] Chapter 7.

this context could be enrolled into a more general anti-imperialist movement[1540]. It was clear that an idea as diffuse as ERC could clearly be accommodated within a number of distinct political programs.

Part of the reason for this mobility was a persistent sense, built on Cold War thinking, that the principles of ERC transcended political reasoning. The science of optimal resource allocation, as Koopmans argued, transcended the ideologies at the heart of the Cold War. But the politics of this claim would become readily apparent, when the political credibility that the science of ERC lent to the project of economic re-liberalisation in American and Britain, and the effect of this epochal shift in political economy upon genuine egalitarian impulses would become fully realised only in later years.

And what of the future? The history recounted here has re-emerged into the present in recent claims that energy can be saved by artificial intelligence, 'smart' meters, homes, and grids, and the 'energy internet', all of which are informed, on the basis of this thesis' findings, by the idea that energy conservation is a metrological resource[1541]. These information-led energy saving approaches are increasingly cast as means of controlling the 'technosphere', a hybrid of technological and natural systems by which society's energy and material flows are managed[1542]. Within such discussions, the history of ERC can also be seen as the prehistory

[1540] Mitchell, 2011, Ch. 8. 'McJihad'.

[1541] Losch. A., Schneider, C. (2016) Transforming Power/Knowledge apparatuses: the smart grid in the German Energy Transition', Innovation: The European Journal of Social Science Research, Vol. 29, No. 3, pp. 262-284; Deepmind Website (2016) 'AI Reduces Google Data Centre Cooling Bill by 40%', Available at: https://deepmind.com/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-40/: Mitchell, T. (2013) 'Afterword to the Paperback Edition', Carbon Democracy: Political Power in the Age of Oil, 2nd Edition. Verso Books.

[1542] Zalasiewicz, J., Williams, M, Waters, C., Barnosky, A., Palmesino, J., Rönnskog, A, Edgeworth, M., Neal, C., Cearreta, A., Ellis, E., Grinevald., Haff, P., Ivar do Sul, J., Jeandal, C., Leinfelder, R., McNeill, J., Odada, E., Orekes, N., Price, J, Revkin, A., Steffen, A., Summerhayes, C., Vidas, D., Wing, S., Wolfe, P. (2016) 'Scale and Diversity of the physical technosphere', The Anthropocene Review, Online First, November 2016.

of current optimistic fantasies about the 'Anthropocene', in which Earth is believed, at least by some, to have become a site for experiments in human control over natural processes[1543].

However, we would do well to remember Isabelle Stengers' point that thermodynamics teaches us that '*the tendency to escape from domination manifests the intrinsic activity of nature*'[1544]. If the history of ERC teaches us anything it is that energy both conforms to and resists human will. And the political future? In a period in which it has become evident that the effects of anthropogenic climate change will have the most deleterious effects on the world's poorest, the suggestion that technological efficiency is a fundamental means of mitigating these effects, may only promote policies that further reinforcing global inequalities[1545]. A limitation of this study has been its focus upon the developed rather than developing world, this focus is defended as this is where the appearance of ERC was achieved. Further study should investigate the geographic alterity of this claim in the developing world.

On that note, though I promised not to address the question in a quantitative way, to not even look in that direction is foolish. Though obviously not possible to do so here in full. Irrespective, in quantitative terms, we might ask, after all this effort, has energy be conserved? Despite the development of a science of ERC, global energy use has roughly tripled since 1971, growing from 224 exajoules to 597 in 2015[1546]; alongside this, carbon dioxide emissions have increased from 20.1 billion tonnes (CO2e) in 1971 to 32.7 billion in

[1543] Stilgoe, J. (2015) Experiment Earth: Responsible Innovation in Geoengineering. Earthscan.

[1544] Stengers, I. (1997) Power and Invention: Situating Science, University of Minnesota Press., p. 36.

[1545] Davies, J. (2016) The Birth of the Anthropocene. University of California Press.

[1546] Energy Information Administration (2016) International Energy Outlook 2016. DOE/EIA-0484.

2010[1547]. In some sense, this can be seen as a success. Energy use has become more efficient, allowing economies to grow, incomes to increase, and widening access to energy rich lifestyles[1548]. However, clearly the reductions in emissions that the UNFCC are hoping will occur in coming decades as a result of increased efficiency in energy use, have not, in the past century, been realised.

In one sense, Jevons' paradox does not need to be seen as a problem. Increased energy efficiency has increased the productivity of technology, and beneficially enlarged 'the field of its operation'[1549]. But, energy efficiency increases in the developed world have occurred alongside increased energy use in the developing world; like emissions, energy use has been 'outsourced', often to less energy-efficient countries[1550].The United States' Energy Information Administration (EIA) has recently estimated that energy consumption will increase by 48 per cent between 2012 and 2050, with the largest portions of this growth coming from China and India[1551]. The problem, which future researchers need to establish, is whether the pursuit of energy efficiency has *accelerated* the rate and scale of energy consumption, as Jevons foresaw, or reduced it, as advocates of ERC would suggest? An empirical, quantitative, and geographically grounded answer to this question, like providing evidence of the rate and effects of climate change, would require a vast, global metrological apparatus to account for conserved energy in a consistent way[1552].

[1547] Ibid.

[1548] Fouquet, R. (2014) 'The Role of Energy Technologies in Long Run Economic Growth: a Historical Perspective', International Association for Energy Economics, IEAEE, New York, June.

[1549] Jevons, W. (1865) The Coal Question, p. 78.

[1550] Davis, S., Caldeira, K. (2010) 'Consumption-based accounting of CO2 emissions', PNAS, Vol. 107, No. 12, pp. 5687-5692; Herrmann, I., Hauschild, M. (2009) 'Effects of Globalisation on Carbon Footprints of Products', CIRP Annals, Vol. 58., Iss. 1, pp. 13-16.

[1551] EIA (2016).

[1552] Edwards, P. (2017) 'Knowledge infrastructures for the Anthropocene', The Anthropocene Review, Online First. Available at: http://journals.sagepub.com/doi/pdf/10.1177/2053019616679854; See also, Edwards, P. (2010) A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming. MIT Press.

As Andrew Barry has suggested, there is an 'intrinsic relationship' between energy and measurement[1553]. Acts of measurement are the means by which physicists and engineers provide quantitative evidence of the conservation and dissipation of energy in a given process or system. However, for advocates of ERC, such as the UNFCC, to claim that measurements of conserved energy have a direct effect in reducing the quantity of greenhouse gas emissions emitted by the global industrial economy, some kind of burden of proof must be offered. At the moment, there is no causal relation between measurements of energy conservation and a requisite reduction in the combustion of hydrocarbon fuels. As such, for ERC to achieve emissions reduction, it would be necessary for some kind of extrinsic relation to be imposed that assures fuel is withheld from combustion.

Though speculative, the history of ERC gives some indication as to how this might be achieved. Research from University College London's Institute for Sustainable Resources has called attention to the fact that, if, as the UNFCC's agreement dictates, signatories are committed to limiting global warming to below 2°C, then the combustion of existing fossil fuel reserves far exceeds the future's total emissions budget. They estimate that between sixty and eighty percent of fossil fuel reserves are classed as 'unburnable', if the emissions reduction targets agreed in Paris are to be met[1554]. This theoretically unusable fuel has been termed a 'stranded asset', as its prospective value as a resource has been damaged due to its potential contribution to the risk of catastrophic climate change[1555].

[1553] Barry, A. (2015a).
[1554] McGlade, C., Ekins, P. (2015) 'The Geographical Distribution of Fossil Fuels Unused when Limiting Global Warming to 2°C', Nature, Vol. 517, pp. 187-190.
[1555] Jakob, M., Hilaire, J. (2015) 'Unburnable Fossil Fuel Reserves', Nature, Vol. 517, pp. 150-151.

In post-war America, when a glut of oil devalued petroleum reserves, production was constrained via a complex system of production rationing licenses ('pro-rationing'). By limiting the production rate of petroleum, significant quantities of fuel were conserved underground[1556]. At the time, there was little effort to conserve energy at the point of use, and yet in subsequent decades, as this thesis has shown, significant advances were made in increasing the efficiency of energy using technologies[1557]. It is not unreasonable to suggest that some combination of these two regulatory systems, the control of fuel production and efficient use of energy, could in some way be connected, to translate savings achieved at the end use into an equivalent reduction in the combustion of fossil fuel.

This thesis has described how America's system of pro-rationing was abandoned because its interventionist execution, in which Federal government controlled the rate of petroleum production, came into conflict with a growing belief in the conservative capacities of the market. Government intervention in the supply, and for that matter, the pricing of fuel, was seen as something which distorted the calculative capacities of the market, which suitably liberalised, it was argued, could ensure the efficient allocation of resources (Chapter 7). In effect, advocates of ERC came to argue that government intervention blocked the free flow of information which could regulate supply and demand for energy. However, as historian Paul Edwards speculates, in our current data-rich age, we have an abundance of consumer information regarding the use of energy and materials, data which is not currently used as part of any energy or resource conservative system. Conceivably this information exceeds the informational capacities of a liberalised market. And, as Edwards points out, the work of the UNFCC attests to the fact that global-scale metrological exercises can result in political

[1556] Chapter 3.
[1557] Chapters 6, 7, 8.

action based upon widely accepted informational infrastructures[1558]. Perhaps it is time for a new approach to ERC, focused on the causes rather than effects of climate change, in which attempts are made to effectively integrate the wealth of data on energy use that is now available with estimates as to the quantities of carbon that must remain unburnt. Quite how such a regulatory system might be achieved is open to debate, as is the political likelihood of its acceptance. But given the apparent failure of efforts to conserve energy resources thus far, however unlikely, such a plan bears consideration.

[1558] Edwards, P. (2017) 'Knowledge infrastructures for the Anthropocene', The Anthropocene Review, Vol. 4, Iss. 1, pp. 1-10.

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