THE POLITICAL ECONOMY OF TECHNOLOGICAL CHANGE, ENERGY AND CLIMATE CHANGE

Nicholas A. A. Howarth

Candidate number: 52856
Christ Church

A thesis submitted towards the fulfilment of a
D.Phil. in Geography

Supervisors: Professor Gordon Clark and Dr Dariusz Wojcik

(93,304 words)

Trinity Term, 2012

Year of registration for D.Phil. 2007

ABSTRACT

This thesis sets out to explore some of the key dimensions in the process of socio-technological change inherent in the shift to a low carbon economy. This is done in two parts, the first focusing on theory, the second, empirical case studies. Out of the diversity of interactions between actors, technologies, and policies surrounding this process, one key question emerges: *can societies really shift the structure of their economies so fundamentally to achieve a low carbon future within a reasonable timeframe?* Chapter One develops an integrated approach to economic and political change to interrogate this question. This synthesizes a review of literature (Part One) examining the role of technology within some of the main theories of economic change in the social sciences. Two broad paradigms are distinguished. First, a paradigm based around the notion of equilibrium, notably the standard welfare approach of neoclassical economics; and secondly, an evolutionary paradigm, which views the economy as a complex adaptive system – such as exemplified by theories of path dependency. This theoretical background provides a broad narrative to frame and inform Part Two of the thesis. First in Chapter Four, socio-technical change is investigated in the context of the diffusion of energy efficient lighting in Germany. This study investigates the relationships between human behaviour and attitudes, lamp technology and the evolving nature of institutions, to provide a framework with which to consider the contentious issue of individual freedom versus government control in the politics of change to lower-carbon emissions. In Chapter Five, the case for the creation of a market for CO_2 pollution permits is developed. In making this case, the strengths and weaknesses of emissions trading are compared and contrasted with other policy instruments and the broader political economy of the various policy options discussed. Chapter 6 builds on this to examine the political economy of implementing an emissions trading scheme in Australia and the impact the Kyoto Protocol has had on domestic politics and GHG mitigation. Chapter Seven continues with the theme of building 'a political ecology of the state' by investigating the politics and economics of greenhouse gas mitigation in Russia. Finally, Chapter Eight recapitulates the aims, nature and conclusions of this research and draws out its implications for policy as well as mapping out some areas for further research. In particular, the need to bring a greater sense of politics back into the study of the economy is highlighted as a vital part of building a renewed, more sustainable economic paradigm in the wake of the financial crisis and, as a way of strengthening the connection between social values and market outcomes.

Acknowledgements

I would first like to thank Professor Gordon Clark and Dr Dariusz Wójcik for supervising me as a doctoral student. Their advice and support over the four years of this and other research has been both a personally and intellectually enriching experience. In addition, I have also been fortunate to have benefited from various collaborations over the course of my D.Phil. In addition to my supervisors, I am very grateful to have had as colleagues Mr Arnaud Brohé, Dr Nick Eyre and Dr Andrew Foxall. Working with them has been a pleasure and I look forward to future collaborations. I would also like to acknowledge the advice and support of Dr Eric Knight, Dr Cameron Hepburn, Professor Dieter Helm and Lord Nicholas Stern, whose collegial advice and encouragement on early drafts of book chapters and papers helped me realise the potential of my work. I would also like to thank Mr Peter Carter of the European Investment Bank who supported my research on low carbon investment while at the Bank and Ms Caroline Duvier who helped facilitate a research sabbatical for me at the Institute of Psychology, Department of Personality and Social Psychology, University of Otto-Von-Guericke, Magdeburg. I would also particularly like to thank the British Council and Christ Church, who provided valuable financial support over the course of my time at Oxford in the form of the Sir Arthur Zelman Chevening, and Hugh Pilkington Scholarships respectively. Finally, I would like to thank my friends and family, especially my parents Peter and Beatrice, who have been a constant source of support and inspiration, and without whom, this work would not be possible.

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Chapter 1 Introduction

1.1 The aims and motivation for this research

This thesis sets out to explore some of the key dimensions in the process of socio-technological change inherent in the shift to a lower carbon economy. This agenda is not exclusively tied to the need to control the risks associated with dangerous climate change from greenhouse gas emissions. Rather, it is also driven by concerns of energy security, resource geopolitics as well as competition, industry and employment imperatives. Indeed, as will be shown, some of the forces which can most profoundly drive carbon emissions may have no connection at all with climate change priorities and policies, but are the outcomes of broader changes in political organisation and economic structure and performance.

Out of the diversity of interactions between actors, technologies and policies surrounding these processes, one key question emerges: *can societies really shift the structure of their economies so fundamentally as to achieve a low carbon future within a reasonable timeframe?*

In this thesis an integrated approach of economic and political change is developed to interrogate this question. This work is positioned within the field of economic and political geography. This critiques and extends the general theory of equilibrium and price-based analysis favoured by neoclassical economics, to assess, more broadly, how the evolving structure of the economy, its politics, laws and public opinion shape the nature of socio-technological outcomes across time and in different locations in a way that gives rise to the diversity of social and economic outcomes we observe in the world around us.

The motivation to move from an analytical approach based on equilibrium, to one based on evolution, is grounded in the now widely acknowledged problems with the neoclassical paradigm as a basis for understanding and predicting certain economic phenomena and the 'solutions' that an evolutionary approach offers. It also reflects the author's own intellectual development from an undergraduate economist via the roles of an economist in the Australian government, then as an applied economist in industry; to a doctoral student at Oxford. This also explains the somewhat anachronistic review of the theoretical literature in Part One, starting with the neoclassical treatment of the nature and direction of technological change before moving onto the evolutionary theories, despite the later having their grounding in earlier work of political economy. Having been 'brought up' in the neoclassical school in the early 1990s, the author's early economic training fell into what Paul Krugman (2009) has called 'The Dark Age' of macroeconomics:

> Remember, what defined the Dark Ages wasn't the fact that they were primitive – the Bronze Age was primitive too. What made the Dark Ages dark was the fact that so much knowledge had been lost, that so much that had been known to the ancient Greeks and Romans had been forgotten by the barbarian kingdom that followed.

The integrated approach of economic and political change presented in this thesis is thus an attempt to bring the 'political' back into the study of the economy, while learning from recent developments in neoclassical and alternative theories. It is argued that to be relevant for decision makers in government or industry, such an integrated approach should be considered fundamental to the reliable explanation and prediction of observed economic phenomena. Indeed, methodologically at least, this type of detailed case study description as a foundation for analysis is what many applied economists are likely to be doing already. The key point is: in order to more robustly and reliably support decision-makers in industry and the policy process in government; the context specific institutional setting in which neoclassical analysis is conducted must be understood and taken into account. Such is the experience of the author, and as such, this thesis is also an attempt to place a coherent theoretical and methodological framework around this type of applied research.

However, this work is not an outright rejection of neoclassical theory. It will be suggested that the equilibrium-based paradigm of welfare economics offers a useful framework to understand and explain shorter-run phenomena along what are called "stable states" or pathways in the economy. Evolutionary logic, on the other hand, emphasises the absence of a stable state, a world of constant change which, following Schumpeter and others, this thesis argues is driven forward by the incessant nature of technological innovation inspired by the power of our creative intelligence, curiosity and ingenuity.

Geographers and others have long expressed concern over the emphasis placed by the neoclassical approach on equilibrium and parsimony and the resultant loss of institutional realism (e.g. Clark, Feldman and Gertler, 2000; Martin, 2010; Deitz, Michie and Oughton, 2011; Dosi et al., 1988; Freeman and Louca, 2001; Hodgson, 1988; Galbraith, 1958; Hayek, 1974; Schumpeter, 1942[1975] and others). Through its restrictive and unrealistic assumptions, the neoclassical approach sets out to create a world where interesting issues can be explored and key relationships examined without the confounding factors found in the actual world. For example, just as physicists describe motion on a frictionless plain or gravity in a world without air resistance, economists describe changes in relative prices and quantities of goods or services in a world without politics, transaction costs, or (crucially, for the subject of this thesis) significant shifts in technology. It is not that theorists believe that the world is without air, or that the economy is static in time and institutionally consistent across different countries, their approach reflects that it is simply just too hard to study everything at once.

While this approach may be as legitimate a method in economics at it is in physics, a problem has arisen because regulatory structure in the 'real world' has been put in place based on neoclassical axioms. For example, under the idealised conditions of the model, the government is usually viewed as an inherently inefficient agent and social objectives are seen to be best satisfied through private market exchange. One manifestation of this logic was the deregulation of financial markets based on the efficient markets hypothesis. This has now been attributed to have significantly contributed to the financial crisis of 2008 and the subsequent recession (Colander, et al., 2009; Kay, 2011). What has occurred is that economists educated in quite often abstract theoretical (and often mathematical) models have built institutional frameworks around those idealised models with little comprehension of what actors in the real world might make of them. In light of the instabilities and perverse incentives created from this, what seems to be lacking in this approach is that basic respect for observed facts, which is so important to the modern scientific method and fundamental in geography.

Furthermore, the ‘market-based’ approach of the neo-classical school has an inherent values neutral logic - in that ethical questions are generally put to one side and are only valued insofar as they are expressed in market transactions - the ‘laws of demand-and-supply’ rule. In reality, there are likely to be other goals such as social equity, personal liberty or environmental protection which are valued and may or may not be consistent with efficient economic growth and the unrestrained laws of demand and supply. The point is that by treating preferences as exogenously given, the neoclassical approach suppresses the analysis of the normative process of their formation. Understanding this process is crucial, as it contributes through the political and commercial process to define the institutions which provide the context for market action. This plays a significant role in explaining the heterogeneity of social and economic outcomes we observe in the world, and, in the context of the shift to a low carbon economy, is central - as such a shift involves active *choice* or political agency to be exercised, as will be explained and argued in the body of this research.

The neoclassical vision of the world probably found its high tide at the turn of the 1990s with the liberalisation agenda of the Reagan-Thatcher administrations and the political downfall of collectivism and central-planning in Russia and Eastern Europe (Michie, 2001:1233). However, as the decade progressed, a number of events worked against the universal validity of this viewpoint, including: the collapse of economic activity and chronic institutional instability in the newly independent former Soviet Republics and the manifest failure of the Washington Consensus to sustain a successful programme based on market reform and deregulation of state functions in the developing world. However, the strongest perceived failure of the neoclassical paradigm, drawing critics ranging from Queen Elizabeth II downwards, has been its failure to explain and predict the series of crises in monetary markets, culminating in 2008 in the second largest collapse in economic output since the Great Depression. One important gauge of this change in theoretical sentiment is to be found in the *Economist* by the institution of the column *Schumpeter*, and in the March 2008 article 'Order in the Jungle':

> Economists became fascinated by the rule of law after the crumbling of the "Washington consensus". This consensus, which was economic orthodoxy in the 1980s, held that the best way for countries to grow was to "get the policies right"... But the Asian crisis of 1997-98 shook economists' confidence that they knew which policies were, in fact, right. This drove them to re-examine what had gone wrong. The answer, they concluded, was the institutional setting of policymaking...

While in the same article Francis Fukuyama (albeit "from the perspective of a political scientist") was given space to opine: "I believe that the institutionalists have won this argument hands down," the intellectual heritage of "getting the policies right" still looms large over mainstream economics - as manifested in the climate change sphere by the ongoing policy choice chestnut "to tax or to trade" (e.g. Nordhaus, 2007).

In the heat of the recent crisis, many of the most important policy decisions for economic management have become highly pragmatic, based very little on economic theory, neo-classical or otherwise, such as the multitrillion dollar nationalisations of banks. While these dramas play out, climate change policy has been left somewhat in the doldrums, bereft of strong direction – some prominent examples being the drifting of negotiations to extend the Kyoto Protocol and the vacillating politics of 'to tax or trade' in the United States and Australia. If there is one, the unifying logic that seems to have replaced the "market-driven" approaches of the 1980s and 1990s is now more of a pragmatic "what works" or at best an "evidence-based policy" approach (which, as Diane Coyle (2007:253) dryly notes, makes you wonder what came beforehand). On this basis there seems to be a new agenda for political economy that needs to be articulated with some urgency. This point was recently made in *The Routledge studies in contemporary political economy*, especially Deitz, et al., (2011) in the context of the environment and climate change.

Economic geographers have responded by highlighting that the biggest economic problems, such as climate change, require a more comprehensive analysis to support decision making. It has been argued that the solutions to such issues need to recognise the observed reality of the systematic departures from the 'rational actor' model of human decision making and also position actors within a process of geographically contexualised institutional evolution (Clark, 2011; Gertler, 2010; Martin, 2010). For instance, Clark argues that neoclassical partial equilibrium analysis has reinforced incrementalism in the economy by putting Pareto optimality, a condition, he argues, is unlikely to ever exist, at its analytical heart. This is an important point, and one that will be explored in greater detail in Parts One and Two through the classification of technological change in the economy into three classes: reproduction (movement along a production function), transformation (movement of the production function) and transition (movement to a completely new production function).

It is relevant to note that this thesis addresses a dialectic between neoclassical equilibrium-based theory and a historically rich evolutionary economic paradigm which has been taking place for over a century. For example, at the end of the nineteenth century, the English economic historian T. E. Cliffe Leslie (1875) wrote: ‘two different conceptions of political economy now divide economists’. He goes on to define an ‘English approach’ as one that treats political economy as a body of universal truths or natural laws, or at least as a science whose fundamental principles are all fully ascertainable and indisputable. This was a movement for rigorous dispassionate mathematical reasoning (e.g. Cournot 1838, Senior 1836, Edgeworth, 1881, Marshall, 1890) which was viewed as necessary to free political economy from subjectivist influences. To this Cliffe contrasted the ‘German School’ which drew on the ‘Older Historical School’ and which followed Hegelian principles of realism – that human nature with its seeming contradictions between the rational mind and the impulsive body, should be seen as part of an integrated and united whole. This body of work was led by Wilhelm Roscher (1843), who argued that any attempt to create rules for economic behaviour would be contingent upon their historical, social and institutional contexts and that this would require a multidisciplinary form of empiricism in scholarship.

Thus we see that political economy was the precursor to economics – i.e. political economy was economics – the former term being replaced by the latter towards the end of the nineteenth century, due to the increasingly scientistic connotations of 'economics' (Groenewegen, 2008). As Clark (2011) notes, today there are many definitions of political economy, some rooted in these historical traditions, some set against them, some highly normative, and others very shallow. Indeed, in many cases 'political economy' has taken on simply a symbolic meaning, used to emphasise methodological differences from the mainstream neoclassical school. The term has become increasingly loose, associated with an eclectic set of methodologies, or simply denoting analysis that introduces 'non-economic' factors, especially political factors. For example, some economists use the term to describe issues that relate to public policy within their work such as the implementation process of emissions trading schemes, usually as an aside in explanation to why outcomes differ in practice from what neoclassical theory suggests (e.g. the rent seeking behaviour which explains why emissions trading tends to be preferred as a regulatory instrument by industry over taxation (Fankhauser and Hepburn, 2010:4385), a 'political economy' observation that has prompted Deiter Helm (2005) to call emissions trading not a polluter pays approach, but a pollutee-pays approach. For others, political economy represents the body of work, building on the Virginia and Chicago Schools, which analyses the functioning of democratic political institutions using economic tools, based around notions of rational choice (Besley, 2006). For still others, political economy also means the study of how political institutions interact with the economy, but in this case, there is a stronger emphasis on an interdisciplinary approach, admitting a wider range of questions and methods (Dietz, et al. 2011:2).

For Clark (2011), political economy seeks to:

> understand the relationship between human behaviour and social institutions, emphasising the constructive nature of institutional design for realising human aspirations.

Such aspirations may include economic development, social equity, individual liberty as well as what Clark describes as humanity's "common commitment to environmental sustainability". However, Clark goes on to note that "if institutions are understood as setting the rules whereby people collaborate, then it is not just a question of environmental regulation, it is also a question of what counts as legitimate use of the environment". This qualification distinguishes the geographer's approach to political economy from one that might focus more on a universal conception of value (such as basic human rights). Considering that the 'environment' is actually quite particular to time and place, Clark suggests that perhaps the most subtle theory of political economy is one that can realise a rapprochement at the local level with global objections such as the stabilisation of global CO_2 at levels that control the worst of climatic risks. This reinforces Paul Robbins (2003) call for "an *everyday political ecology of the state*".

Within geography and the climate change context this agenda has been pursued most significantly by Compston and Bailey (2008) and Compston and Bailey (2012). This research has highlighted the practical difficulties in overcoming entrenched organisational and institutional rigidities as well as identifying pathways for flexibility in institutional realignment to achieve carbon mitigation. It has also sought to empirically progress beyond the notion that *institutions matter* to interrogate *what institutions matter in which circumstances for what purpose*. This detail is crucial for policy choice, but is one which is often overlooked by not just by the neoclassical framework's universalist logic, but even some econometric studies of institutions based on broad measures such as 'rule of law' or 'political stability' (Gertler, 2010:12).

Within geography, this is the agenda which the author's own research programme seeks to contribute to. This has involved: a book chapter (Howarth and Foxall, 2012) in Compston and Bailey (2012) involving the development of a case study on the economics and politics of energy and climate change in Russia (Chapter 7); a paper published in *Political Geography* on the economics and politics of greenhouse gas mitigation in Australia (Howarth and Foxall, 2010) (Chapter 6); the publication of a co-authored book *Carbon markets: an international business guide* (Brohé, *et al.*, 2009) examining the economics and politics of climate change and emissions trading focusing on the European Union; the United States, Australia, New Zealand and Japan (an extract from which comprises Chapter 5); and the economics and politics of energy efficiency in Germany through a case study of CFL diffusion which has been submitted to *Environment and Planning A* (Chapter 4). In addition, the integrated approach to political and economic change presented in the next section of this Chapter was also published in *European Panning Studies* (Howarth, 2012). Perhaps most significantly, over the course of this D.Phil., the author's co-authored book was recognised as one of the top 25 academic titles in the economics category by the journal *Choice*, a publication of the American Libraries Association – and is used as a basis for teaching in many universities around the world – including at workshops and lectures at Oxford run by the author. Thus, while the body of work presented in this thesis represents a cohesive collection of work on the theme of the shift to a low carbon economy, it is part of a much wider research and teaching project of the author which, for example, has also involved field work on nuclear risk in Chernobyl, and the supervision of master's theses on topics including electric car and bike diffusion in Australia and China and the evolution of emissions trading in China and Turkey and consideration of cooperation and competition in the co-evolution of the wind energy sector in China and Denmark. Throughout this work, the geographical situatedness of institutions is a central theme, so that while the case studies are quite diverse, this theme binds the work together.

Just as the political dimensions of the economy have been gradually excluded by what Hayek called an increasingly 'scientistic' approach to the study of economic phenomena – so too has 'the government' become seen as a mutually exclusive way of organising the economy when compared to 'the market'. Increasingly, this dichotomy is being reconsidered as false – and not only false, but also damaging in its policy ramifications (Coyle, 2010:218):

> … both [the market and government] are types of economic institution, designed to organise our life in large social groups. None of these institutions could exist and function outside a basic political framework, usually the national state which provides – with varying degrees of success – a legal framework, including the law of contract and employment laws, protection of property, policing and enforcement, security, standards of weights and measures, a monetary standard, and also sets the macroeconomic context. Indeed, the very concept of property, without which no economic activity from barter onward would occur, is shaped by the state.

It is the realignment of these institutions that set the context for social and economic action that Coyle argues should be the focus of the policy challenge:

> [debt, climate change, social inequality] … all these reflect the failure of political and social institutions to keep pace with the ways the economy and technology have developed in the past generation. The natural world is the most urgent and potentially catastrophic manifestation of the inadequacy of institutions we have for co-ordinating the lives and decisions of seven billion people. But these crises of sustainability are related. They are all, including the environmental challenges – the symptoms of a failure of the institutions that shape our economies and societies, the forms through which we reach collective decisions. The term institutions encompasses both markets on the one hand and political and governance structures on the other.

Such contributions exemplify the resurgence of interest in political economy. This has come in a number of guises. Clark (2011) identifies two broad theoretical currents: renewed interest in the nature and scope of decision-making, using empirical studies to show that it is subject to systematic biases and anomalies, rather than simple minded ‘rationality’ as assumed in neoclassical models (Chapter 3); and secondly in the growing influence of institutional economics and the re-introduction of the notion of ‘value’ lost in the ambivalence of the neo-classical approach with respects to the ‘good’ society (Chapters 4-7).

So far, a high-level overview of the aims and motivation of this research has been articulated. To recapitulate, these are:

- To articulate a theoretical approach to the study of economy that provides a synthesis between ‘economic’ equilibrium-based neoclassical theory and ‘political’ institutionally rich evolutionary theories; and
- To demonstrate how such analysis might be put to work to examine the shift to a low carbon economy.

Having made this broad case for political economy as the vehicle for understanding the study of the shift to a low carbon economy; the next section presents the author’s specific conception of what such an integrated approach might look like. This theory is not intended as an ontological description of reality, but rather, as a set of analytical and heuristic tools with which empirical observations may be understood and patterns identified on which predictions of the future can be made.

1.2 An Integrated approach to economic and political change

Following the research project set out by authors such as Joseph Schumpeter (1911, 1942, 1954), Nathan Rosenberg (1976, 1982), Nelson and Winter (1982), Chris Freeman (1987), Freeman and Louca (2001) and Frank Geels (2002, 2004) the integrated approach to be presented in this section places particular emphasis on the role of technology in driving economic change. Such an approach is considered particularly relevant for the study of greenhouse gas mitigation because emissions are largely a function of various technologies that are employed, for the most part, in the generation of energy. It is an integrated approach, insofar as it endeavours to provide a synthesis between evolutionary theory and equilibrium-based theory by arguing that the neoclassical framework - with extensions - is most relevant for understanding relatively short-term incremental change in the economy, while evolutionary theories are more relevant for interrogating the underlying structure and long-term competitiveness of an economy. Furthermore, it is argued that to answer applied questions of government policy or firm strategy, such analysis must be positioned within an institutional context. This should provide an appropriate historical and geographical setting to the analysis with due regard for research on the realities of human behaviour (e.g. Kahneman and Tversky, 1979; Granovetter, 1985). This approach aims to place the focus of enquiry on understanding change in the actual world, rather than some hypothetical world constructed for the sake of parsimony or abstract theoretical conjecture. This focus on the close observation of the empirical world and the resultant embracing of diversity across social and economic outcomes also firmly positions this thesis's epistemic cornerstone within the fields of economic and political geography.

Many applied economists may already be following a course of analysis similar to the treatment of neoclassical theory within this integrated approach. However, what is most likely missing from their theoretical background is a broader appreciation for the evolutionary processes which shape economic change. Such an appreciation may go a long way to help inject a sense of longer term value into the analytical framework of mainstream economics. This sense helps explain why economic outcomes can differ so drastically across countries and firms. Following Schumpeter, it asks the analyst to look strategically beyond short-term 'market-returns' which exist within relatively 'stable states' to potentially radically different technological pathways characterised by increasing returns over time and competition for the installation of new technologies of path creation and dependence.

By placing the nature and direction of technological change at the centre of the analysis, this framework also seeks to explicitly draw out subtle, yet profound differences in the conception of 'the economy' implicit in each type of analysis.

As somewhat dryly noted by Clarence Ayres, economics is, by definition, the study of the economy – but what is this 'economy'? On one thing, at least, Ayres suggests all economists seem to agree (Ayres, 1962:xii):

> It is a system of interrelated activities to do with the ordinary business of living.

Alfred Marshall assumed that as a matter of course the agency by which all these activities takes place is through the market – the buying and selling mechanism, supply and demand. In an observation which has even more currency today perhaps, John Kenneth Galbraith (1958:6-18) referred to this as the “conventional wisdom” of our society - to question it is to be almost unintelligible.

In the traditional economic analysis of climate change this conventional wisdom has manifested itself through the application of standard welfare economics (Edgeworth, 1881; Dalton, 1920; Pigou, 1932; Hicks,1939) which adopts a utilitarian logic to establish the costs and benefits of a level of pollution and the optimal or most cost effective way to achieve it through regulation of prices, quantities, or both. To do this, two broad alternative approaches are usually considered: the Pigouvian tax, where polluters pay for the externality they impose on others; and the Coasian approach, which allocates property rights for use of the environment and argues that these be made transferrable (Coase, 1960). To balance each approach’s various disadvantages and advantages hybrid schemes have also been suggested by incorporating price floors or ceilings into emissions trading design. For a selection of work in this area see: Baumol and Oates, 1988; Cropper and Oates, 1992; Pizer, 2002; Jacobi and Ellerman, 2004; Philibert, 2009 Hepburn, 2006; Nordhaus, 2007; and Fankhauser and Hepburn, 2010a, 2010b.

The logic of the standard approach suggests that having ‘internalised the externality of pollution’ by setting a price on carbon, the problem of energy policy can be reduced to ensuring that energy prices reflect the full social costs of energy production and utilization. This is on the basis that the world is far too complex for politicians to “pick winners” with direct subsidies and, aside from providing some informational support or changing relative prices to correct for any externalities, it is best to leave people "free to choose" and let "the market decide" as much as possible.

Market driven interventions, such as carbon price-based policy, fit comfortably within the rubric of neoclassical equilibrium analysis, where well-informed consumers purchase products and energy services in a way that maximises their own welfare, and by extension, best promotes the interests of society at large. In this vision of the world, investment decisions by supply companies are driven by consumer demand for what is seen as a relatively homogeneous good – energy. Furthermore, issues of path dependency are put to one side and firms are most often assumed to be able to smoothly bring online and offline different supply technologies to reflect changing preferences and prices – the theoretical sliding up and down on demand (marginal revenue) and supply (marginal cost) curves.

It was Hayek, a student of Schumpeter, who in the 1930s vigorously championed this market model over that of more planned regulatory approaches which he observed emerging in the Union of Soviet Socialist Republics and other nations. He argued that in the market system actors can be coordinated through a single signal – prices – whereas, in a planned system, to efficiently allocate resources across the economy regulators would need to know all the utility and product functions of all the actors – an impossibly vast amount of information. Hayek argued that this uncertainty would create "government failure" where, through acting on incomplete information, or becoming beholden to the special interests of a powerful minority, the interests of society at large (efficiency) would be compromised. Taking inspiration from Arrow (1951), this notion was further supported by extensions of the standard welfare economics approach which directly applied this logic to the political process through public choice theory, providing yet another warning of the imperfections of centrally-planned regulations (Buchanan and Tullock, 1962; Olson, 1965).

Within the economic and policy mainstream, this helped support a culture which held that while market failures were bad, intervention to correct them was to be approached very cautiously. These concerns were further heightened given that the actual economy was ridden so profoundly with market failures and policy distortions that even if policy makers managed to put in place an efficient policy with respect to say, a carbon tax, because of its interaction with other market failures or previous interventions in other parts of the economy, it could actually lead to a fall in aggregate welfare (see Corden, 1997). These bodies of theory helped create a culture of aversion to government intervention in the economy among economists.

It would be wrong, however, to characterize the economic mainstream as seeing low carbon technological change as something to be completely determined through the broad interaction of price signals in the market for a homogeneous good - energy. For example, Nicholas Stern (2007:111) argues in his *Review on the Economics of Climate Change*:

> Many commentators are sceptical about technology policy, saying it is wrong for bureaucrats to 'pick winners'. There is something in this, but it is also naïve or dogmatic in its underlying assumption that markets work perfectly unless distorted by government. In this case, markets do not work well unless assisted by government.

The theory of induced innovation, for example, is a hypothesis that seeks to explain the nature and direction of the technological change underpinning invention in the traditional model through the impact of factor prices (Ahmad, 1966; Kamien et al., 1968; Binswanger, 1974). Within this body of work, *technological externalities* have been identified providing a rationale for government intervention in a specific technology market (Acemoglu et al., 2009). For example, technological externalities in research and development are likely to exist because many technologies are non-rival (one person's use of the technology need not exclude another's); and because they are non-excludable, meaning property rights with respects to the technology are difficult to enforce. Because firms are assumed to be profit maximisers, they will only invest in research and development if they can capture sufficient economic rents from the effort; as this investment is likely to have broader applicability, which would benefit the rest of the economy, positive spillovers are also likely to exist. Isaac Newton's "standing on the shoulders of giants" is an apt metaphor here. The conclusions from this body of research for energy the environment and innovation are usefully surmised by Grubb and Ulph, (2002:104):

> …while environmental policies [such as carbon pricing] may induce innovation that will lead to cleaner technologies, the theoretical and empirical evidence we have does not give us a great deal of confidence that environmental policies alone will be sufficient to bring about major environmental innovation. It seems, that to have a significant impact, it will be necessary to pursue both environmental and technology policies. Given that we are dealing with two

distinct areas of externality [the GHG externality and the technology externality], this conclusion is hardly surprising.

The assumptions which underlie the fundamental theorems of welfare economics state that: in a perfectly competitive market, an equilibrium reached by trading between buyers and sellers at market prices will be economically efficient; and that, *ceteris paribus*, such an equilibrium can always be reached from any given starting allocation of resources (Arrow and Debreu, 1954). This logic means that government interventions are framed in terms of trying to recreate a theoretical model of perfect competition – where the goal is achieving the single equilibrium that allocates resources efficiently across the economy (Foxton, 2011a:136). At this point, there is no further impetus for change emerging from within the model. If change does occur, it is through exogenous factors determined outside the model, such as a change in technology or in consumer preferences – and then firms adapt to the new set of circumstances and reach a new equilibrium. While it is acknowledged that these exogenous forces can be profound, and things are almost certainly never *ceteris paribus* because of the great diversity of social and economic systems and outcomes across time and in different locations, the model's logic requires these assumptions to be made.

One of the great advantages of the traditional neoclassical economic analysis is its parsimony. However, as is often the way, in its greatest strength lies its greatest weakness. Because the problem of climate change and GHG reduction is modelled in a demand and supply framework, the tools at the analyst's disposal are those within the model's analytical logic. As such, focus is given to the properties of price and quantity, their elasticities with respect to demand and supply and marginal change is explored through the application of differential calculus. However, in this framework non-price regulation is analytically problematic, so in many cases it is simply ignored, or dismissed as an inferior tool on the basis of its informational requirements to achieve efficiency. What is missing in the traditional model is a set of tools which enable a more comprehensive understanding of the forces that influence the mechanics of economic change. For many short-term, or sector specific circumstances, the assumptions of the standard approach may not be problematic, but for analyzing long-term, non-marginal phenomena, such as what underpins low carbon technological transition, it represents a significant theoretical weakness. This is especially the case in long-term planning decisions, especially in industries characterized by increasing returns and where investments have large sunk costs, which can lead to path dependence, such as in energy supply and distribution. It is here that this thesis argues an evolutionary perspective of climate policy is particularly important.

The difference between an evolutionary perspective versus the traditional approach can be most easily understood through an interrogation of the core metaphors from which each paradigm draws its analytical logic: evolution versus equilibrium. The former emphasizes change, movement, progression, unpredictability, crisis and metamorphosis; whereas the later, emphasizes stability or stasis, a state of rest or balance due to the equal action of opposing forces. As one might expect, the implications of their epistemological differences in economics and public policy are profound.

Joseph Schumpeter challenged the conventional wisdom set out by Alfred Marshall by emphasising the role of technology as the engine of economic development and by focusing on how fundamental scientific discoveries and their application were able to destroy old markets and create new ones through product and process innovation. Rather than seeing firms competing on the basis of prices – he saw firms competing on the basis of technology - whoever had the technological edge, would win the day (Schumpeter, 1911:64):

> Add as many mail coaches as you please, you will never get a railway by doing so.

A key text in this approach is Nelson and Winter's (1982) *Evolutionary Theory of Economic Change*. This builds on the work Joseph Schumpeter (1942) and Herbert Simon (1957, 1991) to place technology at the centre of study in the economic model, where economic agents display 'bounded rationality' - that is, they are limited by their ability to access and process information, and hence look for satisfactory 'satisficing' solutions. Economic change in this model can come in a variety of forms, at "critical junctures" or in "gales of creative destruction" which can be far from marginal – however, the key point is that change is *incessant* (Schumpeter, 1942:82-3):

> Capitalism, then, is by nature a form or method of economic change and not only never is, but never can be stationary. And this evolutionary character of the capitalist process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change alters the data of economic action; this fact is important and these changes (wars, revolutions, and so on) often condition industrial change, but they are not its

> prime movers. Nor is this evolutionary character due to a quasi-autocratic increase in population and capital or to the vagaries of monetary systems of which exactly the same thing holds true. The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organisation that capitalist enterprise creates.

From this Nelson and Winter (1982) introduced the fundamental notion of the 'routine' which could be any technical, procedural, organizational or strategic process used by a firm as part of its normal business activities; for example, its R&D strategy or a particular production profile. They argued that firms compete by searching for better techniques or processes that satisfy their chosen criteria – whether that be for profit, market share, or some other objective – and which evolve out of a historically embedded adaptive process. From this, stable routines may emerge (technological pathways), formed by a dominant set of actors. However, this outcome was also observed to be highly contingent on the starting point of the system, so outcomes may be quite heterogeneous according to initial conditions.

Unlike most of his neoclassical colleagues, Schumpeter argued that the decision to invest in new technologies should be considered endogenous to the economic process since it originates from firms' attempts to claim a monopolistic position by technological advancement. However, over time this monopolistic power would be limited by the ability of competitors to copy the innovating firm's product and process innovations. This process is neatly described in Dosi et al. (1988):

> When a new engineering or economic possibility comes along usually there are several ways to carry it through. In the 1890s the motor carriage could powered by steam, or by gasoline, or by electric batteries…. They may 'compete' unconsciously and passively like species compete biologically, if adoptions of one technology displace or preclude adoption of its rivals; or they may compete consciously and strategically, if they are products that can be priced and manipulated…. What makes competition between technologies interesting is the more they are adopted, the more useful and attractive they become. Competition between technologies, becomes competition between bandwagons.

The outcome of such competition is that, if a long-term perspective on economic change is adopted, increasing returns mean that rather than one efficient equilibrium, multiple outcomes become possible. Such multiple possibilities can then find expression contingent on each region or countries' institutional context – which may favour or penalise one technology over another. Probably one of the most ubiquitous examples of this phenomenon, familiar to every international traveller, is the differing electrical sockets across many countries. The same principle applies to numerous other technologies such car engines (ethanol, electric or petroleum based); energy generation – say for instance the balance between coal, gas, nuclear, hydroelectricity or other renewables; and within energy generation, to the type of technology used, for example the numerous differing design templates for nuclear power plants, hydroelectric stations, wind turbines, solar panels and so on, each with their own national government backers, right down to the type of light bulb used in homes and offices. Firms, often in partnership with governments, struggle to have their own products and national champions achieve 'lock-in' in as many markets as possible. Once lock-in is achieved, industrial protagonists and their government sponsors have an incentive to follow policies which 'let the market decide' content in the knowledge that since increasing returns have set in around their own businesses the competition is not, in fact, a level playing field - with the dice firmly stacked in the favour of those with historical support. Indeed, this may help explain many lesser developed nations' scepticism at 'free-trade' reforms such as what underpinned the Washington Consensus project.

As Ayres (1962:xvii) points out:

> this [technological] conception of the economy is not a denial of the market aspect anymore than traditional price theory is a denial of machine technology. However the question is, which is the dog and which is the tail?

Here, the notion of path dependence, or hysteresis, has been particularly influential: how decisions taken today or in the past can influence future decisions, closing off certain options, and opening up others (David, 1993, 1985, 2005; Arthur, 1988, 1989, 1994). This body of work emphasizes increasing returns effects due to forces such as: technical interrelatedness; economies of scale; dynamic learning and coordination effects and self-reinforcing expectations. This body of work suggests that these forces, combined with the quasi-irreversibility of investments and large fixed setup costs can lead to the lock-in of - in our case, high carbon industrial infrastructure and consumer patterns (Unruch, 2000).

While path dependence theory has had a profound effect across the social sciences, it has also been criticized, in its canonical form, as placing too much emphasis on the concept of lock-in to a stable equilibrium state and neglecting de-locking phenomena (Martin, 2010). Thus the model can describe the emergence of heterogeneous economic structures across different geographies, but once an equilibrium state is 'selected', little insight is provided into how the process of change occurs *between* stable states.

The idea that the economy lurches from one stable state to another is similar to Schumpeter's "gales of creative destruction" and has been explored within the field of complex systems under the umbrella term of 'punctuated equilibrium' (Beinhocker, 2007). It is within such stable states or technological pathways (involving replication of a well established technology) that it is suggested the neoclassical model provides a useful framework for analysis, but for changes between states (the novel application of a relatively unestablished technology) that an evolutionary perspective is more relevant.

This picture of an integrated model of economic and political change is described in graphical form by Figures 1.1, 1.2 and 1.3. It is significantly informed by Strategic Niche Management (SNM) and its related Multi-Level Perspective (MLP) which arose out of the sociology of technology and were originally developed to understand transitions and regime shifts (Schot et al., 1994; Schot and Geels, 2008; Rip and Kemp, 1998; Kemp et al., 1998; Kemp et al. 2001; Geels, 2002, 2005; Kemp, 1994; Levinthal, 1998). As Geels (2002:1259) points out, the Multi-Level Perspective is not meant as an ontological description of reality, but as a set of analytical and heuristic concepts to understand the mechanics of socio-technical change. These same qualifications apply to the framework presented below.

Within this framework Geels and Kemp (2006: 234-236) highlight three different types of change according to their scope and underlying mechanisms: reproduction, transformation and transition.

Firstly, *reproduction* involves change only at the socio-technical regime level, not at a landscape or niche levels and refers to the reproduction and refinement of existing technological routines. As pointed out by Rosenberg (1976, 1982), such innovations can still lead to considerable productivity improvements over time, but there is little re-organisation of dominant actors, key technologies, or the knowledge base (High Carbon Pathway 1 in the figures below).

Secondly, t*ransformation* is defined as change at the regime and landscape level, but with little interaction from new technological niches. An example could be where a significant change in politics shifts institutional incentives away to a new 'cleaner' technological trajectory, such as through the imposition of a carbon price, but new technologies which are developing in niches outside the mature market cannot compete to replace the existing systems (High Carbon Pathway 2 in Figure 1.1).

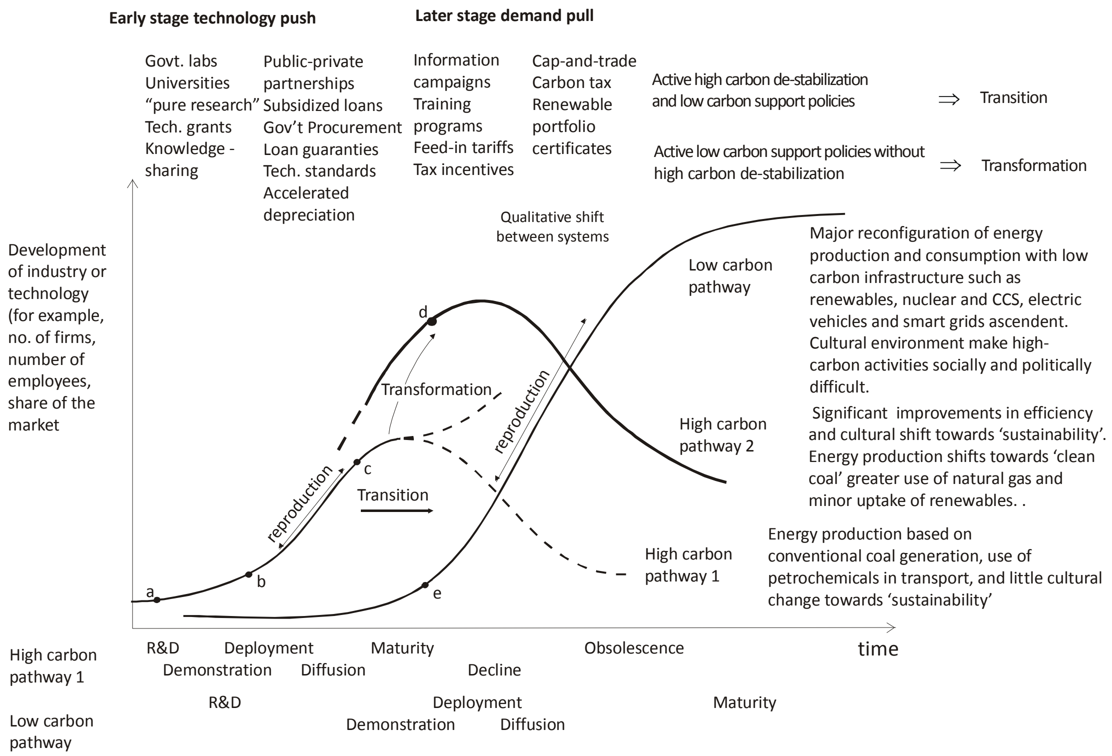
Finally, a *transition* is said to occur when interactions between niches, the dominant socio-technical regime and the economic landscape interact to bring about a major qualitative shift in the economic system, most closely resembling Schumpeter's gales of creative destruction. In transitions, incumbents are likely to attempt to suppress the new niches from emerging which may be better aligned with the social and economic landscape but are yet to achieve market maturity. This strategic behaviour may take the form of lobbying against the social and political reforms aimed at supporting the new niche –as forcefully described in the Australian coal industry context by Hamilton (2007). While formidable path dependent and behavioural barriers are likely to be present for transitions, if successful, they can bring about a significant shift in the knowledge base, introduce new technological objects, infrastructure and regulatory frameworks along with shifts in consumer preferences.

This model is usefully illuminated by Unruch's (2002) 'Escaping carbon lock-in', which helps to explain how technologies can emerge from being in niches to enter the mainstream. Innovation scholars have tended to model technological evolution as long periods of incremental innovation, punctuated by episodes of rapid change (Abernathy and Utterback, 1978; Nelson and Winter, 1993; Sahal, 1985; Dosi, 1982; Tushman and Anderson, 1986; Tushman and Murmann, 1998). In these models major technological breakthroughs are generally seen to be driven by some exogenous force so compelling that users switch to the new technology (from fixed lines to mobile phones, for example). While neoclassical theory would posit that even incremental improvements would lead to the adoption of a new technology over time; empirical studies have shown that it usually takes substantial improvements to induce a transition. One of the most frequently cited examples is David (1985) who found that time savings of 20-30% were insufficient to cause a switch from the QWERTY to the DVORAK keyboard. Other authors empirically show that improvements of a much larger magnitude are required to initiate a transition to a new technology (Grove, 1996; Drucker, 1993; Foster, 1986).

Due to increasing returns, technologies and behaviours tend to cluster around the 'winners' in the stable pathways of Figure 1.1. These are the technological routines involving consumers, producers and law-makers referred to by Nelson and Winter (1982), which correspondingly can also be thought of as the co-evolutionary self-reinforcing 'settled-habits-of-thought' of Veblen, (1919). Thus the stable state manifests around both physical objects as well as behavioural patterns. This helps explain why transitions are so difficult to effect, even for a superior new technology. Institutional change encompasses not just the politics and government policies shaping the process, but also the settled patterns of behaviour associated with different technological objects. These 'settled-patterns-of-behaviour' provide the conceptual link to the contribution of behavioural barriers to literature on path dependence (Simon, 1957, 1991; Gigerenzer, 2003), which is discussed in detail in Chapter 4.

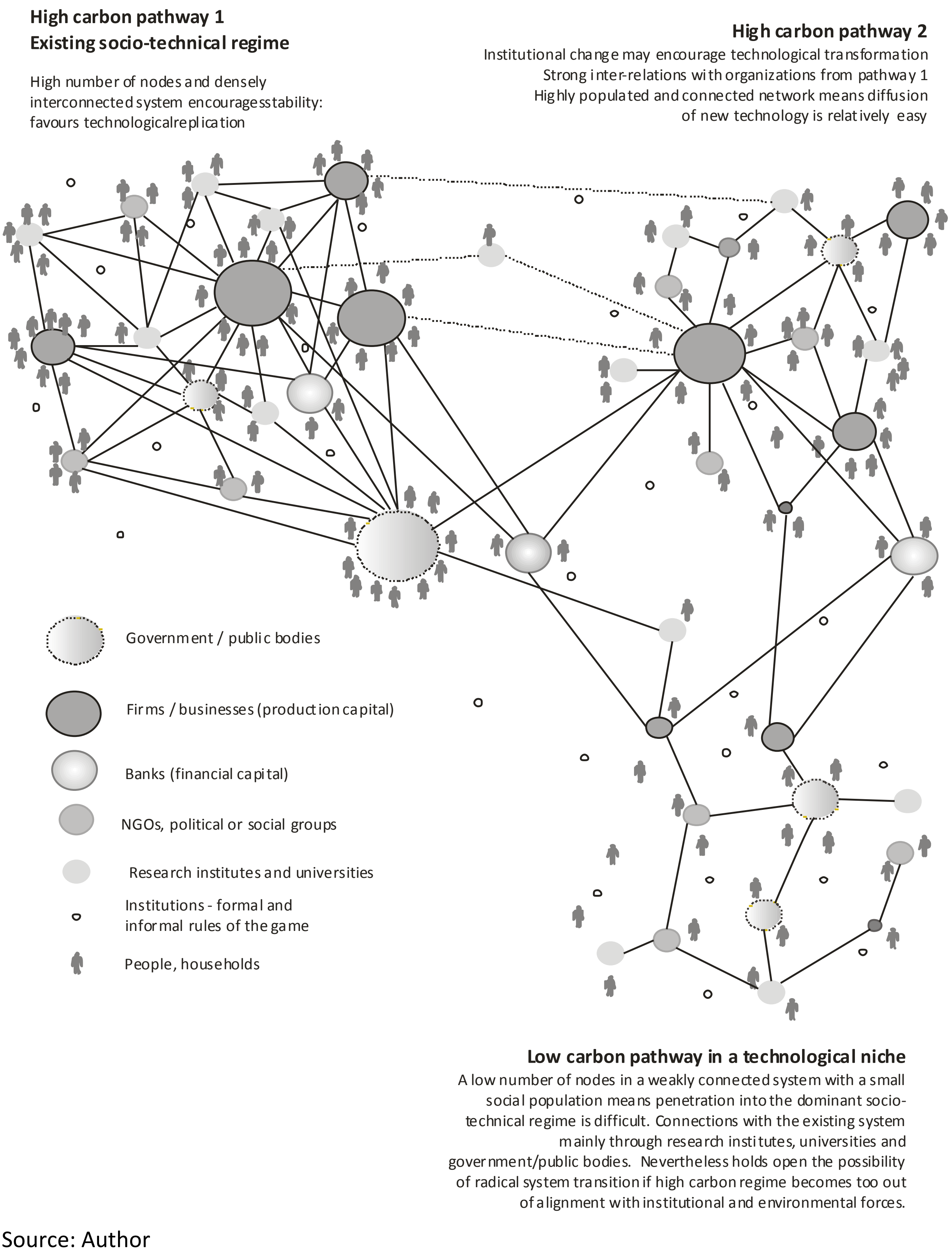
Within the innovation literature, many authors have highlighted the importance of government policy in challenging this stable state (Cowan and Hulten, 1996; Cowan and Gunby, 1996; Freeman, 1989; Perez, 1985; Hughes, 1983). Government policies can be contextualised within the broader process of institutional change, reflected in the political process. Unruch, (2002) argues that slow institutional change seems to be built into parliamentary democracies through a system of checks and balances among different branches of government which means, for the most part, institutional arrangements are characterised by long periods of stability punctuated by infrequent radical change usually accompanied by a change in Government (North, 1990). This is because it is often impossible for policy makers to undertake institutional change without a broad mandate. Thus, in a democratic society at least, broader social change is often seen as a prerequisite institutional change, which is in turn is necessary to drive technological change.

Figure 1.1 An integrated approach: climate policy and technological diffusion



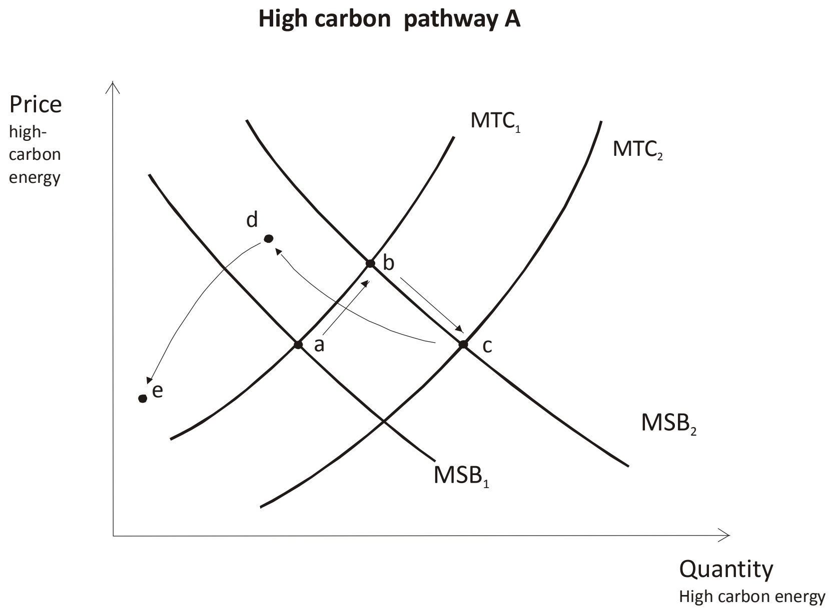
Source: Howarth, 2012

Figure 1.2 An integrated approach: organisational mapping of the economy



Source: Author

Figure 1.3 An integrated approach: stable states and out-of-equilibrium states within a partial equilibrium framework



Following a distinction made elsewhere in the literature on innovation (e.g. Schmookler, 1966; Grubb, 2004; Burer and Wustenhagen 2009) two broad types of policy are distinguished in Figure 1.1. Firstly, 'supply push' policies focus on the generation and dissemination of new knowledge with an emphasis on supporting producers and the nurturing of new products and processes through the cultivation of technological niches (e.g. education, science and industry policies). The second group of policies are 'demand pull', which focus on user demands and changes in incentives within the dominant socio-technical regime (market-based policies).

It is suggested that during the process of reproduction of a technological regime (points *b* to *c* in Figures 1.1 and 1.3) market-based policies are particularly effective. This is also consistent with the story of incremental technological improvement as producers in the economy shift up the production function (investment in a well established technology) and represented in the partial equilibrium framework of Figure 1.3 as the shift in the marginal social benefit (demand) and cost curves (MSB_1 and MSC_1) to MSB_2 and MSC_2.

In terms of organisational mapping, this can be appreciated by Figure 1.2 where the dominant actors in the densely connected High Carbon Pathway 1 are nested within a supportive and stable institutional context (the market). Over this range, a low carbon niche exists, but it is weakly connected to the market and cannot compete with the dominant actors and their associated technologies. Instead it is largely comprised of small firms potentially supported by government grants, financial institutions such as banks or existing in universities. Some groups such as NGOs and other social groups outside the dominant political interests may be lobbying for institutional change to the stable state of the existing market to encourage these niches, but their efforts at this stage have a weak effect. Niche technologies are seen to be 'immature' and thus, not 'market-ready'.

Should a low-carbon social and political movement, with its associated technologies and economic routines, begin to find traction, then a shift off High Carbon Pathway 1 beyond point *c* to either point *e* (transition) or, more likely, point *d* (transformation) is possible. It is suggested that these could be considered 'out-of-equilibrium states' where the institutional logic (the market rules) has shifted so that the previous organisational map is so significantly out of alignment with actual social and political needs that more significant structural change is brought about. At the firm level, such changes can also be viewed as shifts in the production function (transformation) or a shift to new production function (transition).

Take for example the development of the ethanol market in Brazil (Goldemburg, 2007). In the late 1970s the Brazilian Federal Government mandated the mixture of anhydrous ethanol in gasoline (blends up to 25%) and encouraged car makers to produce engines running on pure ethanol (100%). Brazilian adoption of mandatory regulations determining the amount of ethanol to be mixed with gasoline (basically a renewable Portfolio Standard for fuel) was essential to the success of the programme. The motivation was to reduce oil imports that were consuming one half of hard currency from exports. It also allowed the phasing out of lead additives and reduced sulphur, particulate matter, carbon monoxide and carbon dioxide emissions. The OECD (2012:73) now write how Brazilian subsidies for ethanol production are a thing of the past because new ethanol plants have benefited from economies of scale, learning, and the use of related modern technologies, such as high-pressure boilers, that allow the co-generation of electricity from the process. While initially not making 'market sense' to move to ethanol, today it is held up as an example of successful transition to a more sustainable energy source.

In related work regarding the emergence of another 'winner', the Danish wind turbine cluster, Karnøe and Garud, (2012) also highlight the importance of sequencing in the technological 'selection' environment. In this case sequencing refers to how *problems*, in this case, energy supply, the social desire to avoid nuclear energy, and recently climate change, come together with *solutions* (wind energy but also bioenergy and others) and *actors* who are connected in a disorderly process of interweaving and ordering of resources. Sequencing depends on the 'simultaneity' of how elements in this process 'arrive' and 'depart'. According to the authors of this case study, this process matters as much as the policy. The emergence and success of the Danish wind turbine cluster did not result from a public policy strategy that 'picked a winner', but 'nor was it shaped by pure market forces', as 'Danish regulators stepped in with subsidies and grants to nurture and shape the emerging technology'. The authors', reticence claim 'policy success' in this area stems from their observation of far less successful interventions in the markets for biogas and solar power technologies. Instead, they point to the importance of fostering 'distributed and emergent actions that allow for the interweaving of resources and the transformation of existing ones over time'. That nurturing a new path is more about fostering a fertile ground for a niche to develop rather than a linear process of birth, gestation and growth fostered by strategic policy intervention. Insights form this work have helped inform the adaptive policy learning approach argued for in Chapter 8 of this thesis, highlighted in the summary for policy makers.

The organisational map represented in Figure 1.2 is a stylised view of some of the main elements of an economic and political system which are likely to play a role in this process. This perspective draws inspiration from the systems of innovation literature, pioneered by Chris Freeman (1987, 1988) at the University of Sussex and developed further by Lundvall (1992), Nelson (1993) and, more recently, Timothy Foxton (2011) at the University of Leeds. It is also informed by Herbert Simon's (1991) organisational theory of decision-making, Gigerenzer's (2002) work on heuristics, Carlotta Perez's (2002) work on the role of financial and production capital in the process of technological change and Donald Schön's (1967, 1973) work on the 'stable state' and the importance of a flexible 'learning society'.

First, consider the famous passage from Herbert Simon's (1991:27-28) article in the *Journal of Economic Perspectives* describing how a Martian might describe social organisation if looking at the earth from outerspace:

> The firms reveal themselves, say, as solid green areas with faint interior contours marking out divisions and departments. Market transactions show as red lines connecting firms, forming a network in the spaces between them. Within firms (and perhaps even between them) the approaching visitor also sees pale blue lines, the lines of authority connecting bosses with various levels of workers. No matter whether our visitor approached the United States or the Soviet Union, urban China or the European Community, the greater part of the space below it would be within the green areas, for almost all of the inhabitants would be employees, hence inside the firm boundaries. Organisations would be the dominant feature of the landscape. A message sent back home, describing the scene, would speak of "large green areas interconnected by red lines." … When our visitor came to know the green masses were organisations and the red lines connecting them were market transactions, it might be surprised to hear the structure called a market economy. "Wouldn't 'organisational' economy' be the more appropriate term?" it might ask.

We can consider Figure 1.2 in the same way a geographical map is a stylised overlay against which the reality of the world can be viewed. On this map we can model institutions and organisations that have evolved in response to the problems of collective action that people in a given society have felt worth solving. For example, such problems may include: the provision of electricity to the home, of food and water, of communications, of protection from violence, the maintenance of social cohesion, the provision of education, and, regarding the subject of this thesis, the reduction of greenhouse gases.

These organisations provide the ability for people to deal with more information than the individual can handle on their own and can help solve coordination problems. Organisations move up from families and households, through to schools and universities, to firms, banks and various governmental bodies. In this sense, organisations provide the link between the individual and social systems. In the actual world, the evolution of these organisations is a process which depends upon the continual exercise of rigorous selectivity – a complex adaptive process. This process may be either guided or unguided, but need not necessarily be a change that anyone particularly wants - take for example the economic collapse associated with the transition to a market economy in Russia discussed in Chapter 7. The nature of change is strongly influenced by the nature of institutions that support or hinder one type of change over another.

Significantly, this logic also allows for the case where institutions and organisations might not even exist to control the elements of the system necessary to achieve a social objective – in which case they must be incubated before a social objective can be successfully achieved. It is argued that this incubation process requires a different set of policy tools than the eventual diffusion process which can be led by demand-pull forces of the market.

As observed by Schön (1970) the structure of governance in the economy is most often a series of memorials to the solutions of old problems rather than targeted structures to deal with contemporary issues. Indeed, he argues that this very success often gives existing institutional and organisational regimes problems in adapting to new sets of social desires. The suggested solution, he argues, lies in a flexible learning society, able to adapt and reconfigure its organisational map to a changing set of environmental and social pressures. However, there is always the pressure to attempt to re-impose an established order onto the world which results in an inherent conservatism or stability in the system.

We can view the actors in this network – individuals and organisations – as positioned within the institutional structure of the system – what Douglas North (1990:4-5) describes as 'players' within the rules of the game. Meric Gertler (2004:7-9) elaborates to define institutions as:

> Formal regulations, legislation, and economic systems as well as informal societal norms that regulate the behaviour of economic actors: firms, managers, investors, workers. They govern the workings of labour markets, education and training systems, industrial relations regimes, corporate governance, capital markets, the strength and nature of domestic competition, and associative behaviour... Collectively, they define the system of rules that shape the attitudes, values, and expectations of individual economic actors. Institutions are also responsible for producing and reproducing the conventions, routines, habits, and 'settled habits of thought' that, together with attitudes, values, and expectations, influence actors'

> economic decisions... Although these institutionally shaped attitudes, values, and conventions influence choices and constrain decisions regarding practices, they do not wholly determine them. There is still a major role here for individual agency to produce a variety of responses within the same sector, region, and nation-state.

Unlike the canonical form of path-dependency theory (Arthur, 1988, 1989, 1994a, 1994b, 1994c, 1994d, 1999; David, 1985, 1986, 1988, 1992, 1993a, 1993b, 2005, 2007), this view emphasises the role of individual agency to express itself within a guiding institutional framework. The continual exercise of agency is thus a crucial driver of change within this model, insofar as while economic activity may be shaped by institutions, it is not wholly determined by it. Rather, niches populated by 'mutant' actors (to borrow the biological terminology) come into being to challenge the dominant set of actors, technologies and historical institutions. In this conception of the economy, the dominant institutions of society make up 'the market', but unlike the neoclassical model, what constitutes 'the market' has taken on a historical and normative dimension, evolving over time. As North (1990:52) writes:

> The rules descend from polities to property rights to individual contracts. Contracts will reflect the incentive-disincentive structure imbedded in the property rights structure (and the enforcement characteristics); thus the opportunity set of the players, and the forms of the organisation they devise in specific contracts, will be derived from the property rights structure.

One of the important implications of this work is that the process by which each jurisdiction's institutional setting is derived – in other words, the construction of 'each jurisdiction's 'market' – can take geographically differentiated forms. These forms, especially in authoritarian or quasi- authoritarian regimes outside the values of liberal democracy, may not have as their basis the objective of the maximisation of social welfare at all - a conception of 'the market' which neoclassical economics takes for granted. For example, a market may exist, but the institutions have evolved in a way to encourage a certain allocation of resources among those with political power – an observation that might help explain the difference in income distribution across nations.

The point that Gertler and others make is that there is no such thing as "free market exchange" that exists in some sort of "natural state of capitalism" the attainment of which should be the default objective of government policy. Market interactions are shaped by institutions, which are formed through the historical process of politics, culture and the evolving nature of what Veblen called the 'settled habits of thought common to the generality of men' (Veblen, 1919:239).

'The market' is thus not merely a place of exchange but is formed by the normative actions of agents through the political process. Due to the fact that the government writes the rules, while the players play the game:

> …the government has strong incentives to behave opportunistically to maximize the rents for those with access to the government decision-making process… the government will [thus] cartelize economic activity in favour of politically influential parties (North, 1990:67).

In this area Mancur Olson's work has been influential. He observes that, in developed societies, organisations and institutions tend to evolve together where competing organisations are engaged in constant a distributional struggle for their own existence with income and wealth as the objective. In this context, organisations can grow large enough to influence the institutional environment (for example through securing a favourable legislative environment) and this can lead to widespread diffusion of their good or service and promote system stability. However this stability may result in undesirable lock-in if organisations seek to preserve their own markets over the interests of serving the consumer. For example, marketing departments will try to manipulate the marketplace by projecting certain products or ideas onto consumers, whether this is the market for software for computer components, sim cards in mobile phones, vacuum cleaners and filterbags, or shavers and their blades (David, 1985; Arthur, 1989; Larkin, 2008). Whether this vision helps address the underlying demands of society (for example, Fair Trade), or merely acts to entrench a commercial position (for example, the high-status fashion industry) is an empirical question. As Olson (1982:165) writes:

> The dense network of distributional coalitions that eventually emerges in stable societies is harmful to economic efficiency and growth, but so is instability. There is no inconsistency in this; just as special interest groups lead to misallocations of resources and divert attention from production to distributional struggle, so instability diverts resources that would have otherwise gone into productive long-term investments into forms of wealth that are more easily protected, or even into capital flights to more stable environments. On the whole stable countries are more prosperous than

> instable ones and this is no surprise. But, other things being equal, the most rapid growth will occur in societies that have lately experienced upheaval, but are expected nonetheless to be stable for the foreseeable future.

Figure 1.2 also highlights the critical role the separation of financial capital (for example agents such as banks, pension funds and venture capitalists) and production capital (companies or governments engaged directly in the production process) play in propelling this process forward (Perez, 2002). Here it is the investment strategy when brought to ground through new projects that play a vital role in challenging the status quo of the stable state. Whereas the production capital of established organisations is often focused on supporting new but similar supportive investments, financial capital is more likely to be focused on organisations and technologies which provide good and services to meet the demands of the day. This is not out of altruism, but out of the financial gain to be made from opening up a new market and the associated wave of investment opportunities.

Perez argues that financial capital may take technological gestation into a period of 'frenzied exuberance' of financial activity leading to a bubble economy. Here the 'blue sky' forward-looking world financial agents and new technologies become detached from the real economy. For example, in the case of solar photovoltaic panels, the cost of production has fallen significantly, which combined with the gradual winding down of government subsidies, has led some to argue there will be an oversupply of solar panels (Clark, 2011). Eventually, the existing socio-technical system reaches a crisis or turning point as the imagined world of the future is forced to reconcile with the realities in the production-side of the economy (the time between points *c* and *d* or *e* in Figure 1.1).

This conflict over alternative visions of the future - in our case between a high carbon and different varieties of low carbon energy systems - may lead to crisis as a 'clean-tech bubble economy' bursts in the face of pressure from the extant institutional world. Such a crisis may provide the motivation for change and can fuel an intense debate over what the future world should look like – either with reformed institutions to support the mutant agents, or a reassertion of existing institutions.

In the case of successful institutional change, pressure eventually accumulates to the point where the old institutional reality rapidly unwinds to be replaced by the new – often populated by a new set of winners and losers. The more obvious that the outcome of the institutional tension between mutant and established agents is collapse, the more convincing the focal point is for a transition (Schelling, 1960).

An important implication of this analytical logic is that *policy timing* has a significant influence on economic outcomes. This means in the early stage development of a technology, public subsidies for research and development and technology policy should be focused on supply push support. Only after a low-carbon technology has matured and becomes 'market ready', will demand pull policies be effective. Otherwise, in the absence of credible alternative technologies ready for adoption, undesirable energy price inflation may result. Related to this is the notion that it is just as important to dismantle previous regimes of support inherent in high carbon pathways. This support is often quite subtle, for example through university and government sponsorship of education and research; or more direct through sponsoring the exploration and production of fossil fuels directly. Non-price support such as streamlined planning approval processes should also be reviewed in light of this logic.

The integrated approach to economic and political change articulated in this section seeks to provide a synthesis between neoclassical and evolutionary theories. It attempts to show that not only that *institutions matter*, but also to prompt the researcher to ask *what sort of institutions work best in which environments?* The relevance of this approach to current research in the social sciences was recently highlighted in the Nobel Committee's note on the 2009 prize to Eleanor Ostrom and Oliver Williamson (Kungl Vetenskaps-Akademien, 2009):

> Institutions are sets of rules that govern human interactions… One important class of institutions is the legal rules and enforcement mechanisms that protect property rights and enable the trade of property, that is, the rules of the market. Another class of institutions supports production and exchange outside markets. For example, many transactions take place inside business firms. Likewise, governments frequently play a major role in funding pure public goods, such as national defence and maintenance of public spaces. Key questions are therefore: which mode of governance is best suited for what type of transaction, and to what extent can the modes of governance that we observe be explained by their relative efficiency?

It is to such an agenda that this thesis aims to contribute – focusing in the area of humanity's efforts to reduce and control anthropogenic greenhouse gas emissions.

1.3 Methodological approach

The fundamental objective of all science is the explanation and prediction of observed phenomena. No theory - whether it is in the social or physical sciences – is, however, perfectly correct. The usefulness and validity of a theory depends on whether it succeeds in explaining and predicting the set of phenomena that it is intended to explain and predict. Consistent with this goal, theories must be continually tested against observation. As a result of such quantitative and qualitative empirical testing, theories are often modified, refined and occasionally discarded. This thesis seeks to contribute to this process by first: articulating a theory of economic and social change which proposes a synthesis of neoclassical-equilibrium (Chapter 2) and evolutionary-institutional based (Chapter 3) theories; and secondly, by conducting several case studies (Part Two) which use this integrated *a priori* and *a posteriori* analytical logic on the shift to a low carbon economy. These studies aim to provide empirical detail of the type of institutions and actors over a range of different spatial scales and contexts that have supported stability or change in the economy with regard to reductions in greenhouse gas emissions.

As discussed in the introduction to this chapter, this thesis speaks to an agenda which seeks to inject a greater sense of 'the political' back into the study of 'the economy' – to contribute to the re-establishment of an understanding of the evolving nature of institutions as a central issue in the study of the economy. This is a multidisciplinary agenda which has been contributed to from various fields from across the social sciences, including from: sociology; political science; psychology;

anthropology; philosophy and notably from the ‘heterodox’ schools of institutional and behavioural economics as well as scholars of innovation theory and technological systems. With its emphasis on empirical contextualisation, this agenda has also naturally been a focus for economic and political geographers (Martin, 2000; Amin, 2001; Bathelt and Gertler, 2005; Boshma and Frenken, 2006) encompassing a research programme including such issues such as organisational, regional and national systems of innovation and learning (Cooke and Morgan, 1998; Maskell and Malmberg, 1999; Storper, 1999; Murphy, 2004); varieties of capitalism and economic performance (Hall and Soskice, 2001); the development and performance of financial markets (Wójcik, 2003; Clark and Wójcik, 2005); technology policy (Gertler and Vinodrai, 2005), natural resource management and climate change (Gizelis and Wooden, 2010; Robbins, 2000; Compston and Bailey, 2008; Howarth and Foxall, 2010) and the development of the internet (Storper and Leamer, 2001).

Such studies have drawn on a diverse range of methodologies from the analysis of local economic data and political trends, to census and survey data; to formal modelling and sophisticated quantitative analysis; through to more qualitative methods such as media discourse analysis and semi-structured interviews of key actors through close dialogue.

This heterogeneity in the ‘*how*’ of research is something that geographers have generally celebrated, although noting that with it has come a risk of a degree of ‘mutual misunderstanding’ driven by ‘methodological relativism’ Barnes et al. (2007:3):

> … the field of economic geography never evolved in a sequential, linear fashion, through a series of identifiable methodological phases. There is no grand narrative with a beginning, middle and end on which we can draw. And in many ways, we would not want one. But it does make telling the story challenging.

Bringing up this methodological heterogeneity is useful for contextualising this thesis's own reflexive approach. However, in reflecting on the empirical chapters of this thesis and their methodological underpinnings, several clear principles emerge that underlie a distinct 'evolutionary institutional approach' within geography which links method to synthesis and theory building. In other words, an approach consistent with the idea of scientific process as applied in the social sciences (Figure 1.4).

For example, Gertler, (2010:11-12) sets out four key principles for a 'reconstituted institutional economic geography'. Firstly, it needs to provide room for agency; as asserted by both individual economic agents (managers, workers, entrepreneurs and venture capitalists) and organisations such as firms, producer organisations, unions, regional governance groups and universities. The temptation to 'read off' individual behaviour from national (or local) institutional structures should be avoided in order to avoid neutering the agency individuals and organisations assert on a daily basis. Such agency is expressed through the processes of inter-firm competition, collaboration, politics and class struggle – the very stuff that makes up modern capitalism. Secondly, a focus should be given to individual institutions as well as with how they evolve and interact with other institutions over time.

Figure 1.4 Scientific process in the social sciences

Very little science outside mathematics is genuinely deductive: this creates the risk of empty exercises in analytical formality without an empirical dimension. The only descriptions (particularly in the social sciences) that fully meet the requirements of consistency and 'mathematical rigour' are artificial worlds.

A posteriori inductive reasoning
Based on experience and (above all) careful observation of the world. Organising logic is through quantitative and qualitative methods for description to provide 'empirical rigour' to analysis. Can capture the diversity of observed economic and social outcomes, influenced by geographically distinctive institutions, technologies and cultures. Outcomes evolve in ways that are not random, but that cannot fully, or perhaps at all, be captured by theoretical models. Recognizes that the future is radically uncertain, and the models, when employed must be context specific.

Theory building

reflexive search for an interpretive narrative

Empirical world

a priori deductive reasoning evolves the necessary consequences of a theory: draws conclusions from a group of axioms. The fewer the axioms (parsimony) the better. Advantages of this logic include: consistency; rigour of formal logic; predictive power; the ability to make general claims; to classify, organize and make sense of observations.

Disadvantage is that without theoretical framing this analysis can be ad hoc and not offer useful general lessons which most certainly exist and are necessary to inform government policy and decision making. Observation alone offers little overarching logic to assist with understanding and predicting phenomena.

Source: Howarth (2011)

One of the key questions here pertains to the locus of the motive forces driving change. What is needed here is a more developed and nuanced understanding of change, where institutions evolve in response to both endogenous political and economic dynamics as well as exogenous shocks.

Thirdly, greater attention should be given to the 'geography of institutional change'. Studies should aim to illuminate the process by which institutions are produced and reproduced at a number of spatial scales – from the local, to the national to the global, as well as promoting understanding of how these institutions shape and constrain (but not determine) economic activity.

Fourthly, while thick description of individual cases has become a dominant methodological tool in economic geography, greater methodological variety would help support greater influence of geographers outside their field (Barnes et al. 2007; Peck and Theodore, 2007). If the core projects are to understand how institutions are produced, reproduced, and change over time, how these institutions exert their influence over economic life, how these processes unfold at different geographical scales, and the difference that geography makes, then much is to be gained by adopting a comparative approach.

These principles serve as a good general background to the methodological approach inherent in this thesis. Methodologically, this involves a rather straightforwardly descriptive and empirical research programme adopting an amalgam of inductive *posteriori* analysis of geographically centred economic trends and commentary on the cut and thrust of politics placed within an historical context of socio-technical change (Barnes et al., 2007). This empirical focus is then buttressed by taking a reflexive and pluralistic approach to theoretical conversation with the data by drawing on both equilibrium and evolutionary based perspectives. It is an integrated approach insofar as it aims to reintroduce political analysis and the normative formation of institutions back into mainstream economics, which tends to take these institutions for granted and as homogeneous across nations.

This approach sees economic behaviour as being informed primarily by technologies and institutions, evolving in ways which, while not random, cannot be described fully or perhaps at all by the standard tools of neoclassical logic. As a result, deductive models and theories, when applied, should therefore be context specific.

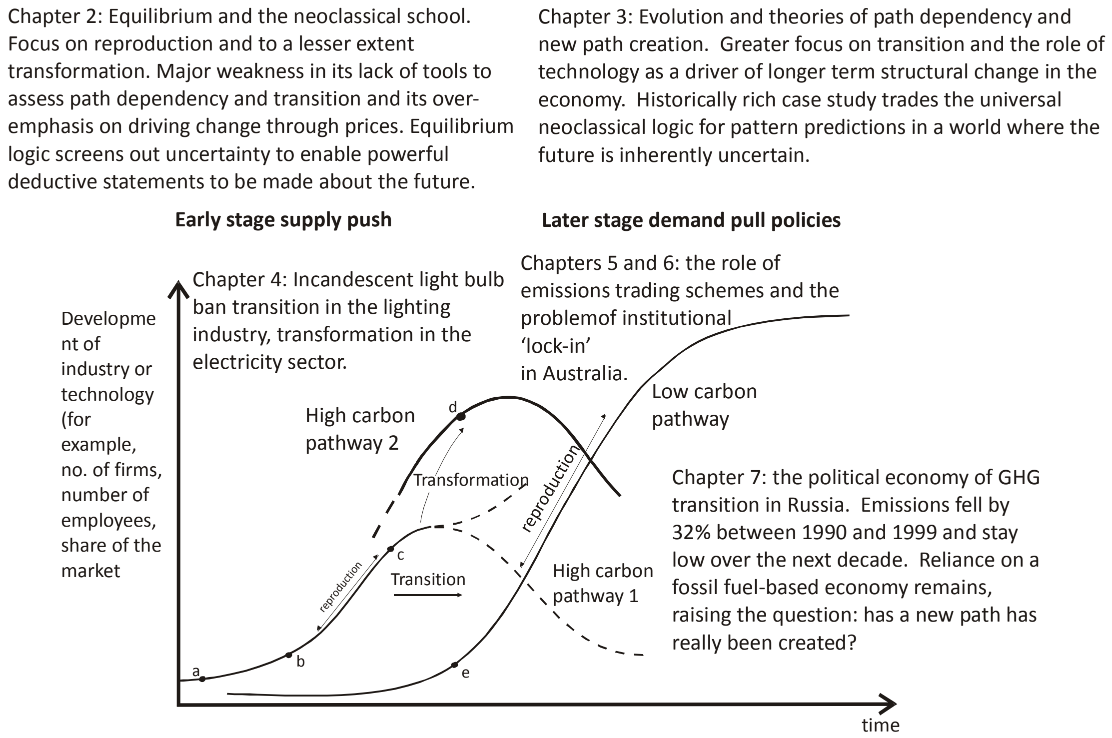
A significant part of this programme is therefore to investigate the processes of belief formation that informs the behaviour of individuals, firms and governments in the economy. For a complex issue, such as the shift to a low carbon society, the role of politics is central to this task. In most cases, societies learn about themselves through politics, and the process of public debate and discussion, is itself, central to driving change in society (Schön, 1973). Indeed, it has been argued that prices in markets can be seen as being determined as much by the clash of competing narratives of the world as by the interaction of demand and supply (Kay, 2011).

1.4 Thesis structure

This thesis was conceived to follow the 'paper-route' set out in Oxford University's examination guidelines for students wishing to submit for a D.Phil. in the School of Geography and the Environment. While the Chapters form discrete projects in themselves, the integrated approach presented in Chapter 1 is the unifying logic which provides a consistent framework for understanding this work and its contribution to evolutionary economic geography. This section has been published (in significant part) in the journal *European Planning Studies* (Howarth, 2012). This approach, presented again in Figure 1.5 below in the context of the chapters that follow, responds to a research exigency to provide a consistent framework to understand the transformation of energy sector which goes beyond 'simple' neoclassical economics (OECD, 2012:13) which tends to offer universal prescriptions overly-centred on carbon pricing. This 'consistent framework' is built from the review of equilibrium and evolutionary based theories of economic change, and recognises that while fostering 'greener growth' will require both international cooperation and putting a price on carbon, its implementation is largely a national matter and the policy mix will therefore differ across countries according to local environmental and economic conditions, institutional settings and stages of development. Thus Figure 1.5 is an organising logic with which to interrogate the empirical examples, centred on the nation state.

In Chapters Two and Three, the didactic foundations for the framework above are articulated by drawing on the literature from equilibrium and evolutionary economics. This sees economic behaviour as being informed through technologies

Figure 1.5: An integrated approach and chapter summaries



Source: Adapted from Howarth (2012)

and institutions, of which prices are but one institution. Institutions, technologies and behaviour co-evolve in a way which, while not random, cannot be fully, or perhaps at all, explained by the neoclassical school's deductive models, which are driven primarily through modelling changes in relative factor prices. This sets the stage for integrating the normative political process of belief formation which shapes institutions, for while individuals may be 'bounded rational' and subject to path dependent forces, they are also capable of learning, adapting and innovating to solve the problems of the day (Simon, 1957, 1991).

In Chapter Four, this process of collective problem solving is investigated through a case study of technological change in the market for lighting in Germany and has been submitted to the journal *Environment and Planning A*. After many years of technological lock-in around incandescent bulbs, despite the application of demand pull policies on more efficient models, significant diffusion of energy efficient lighting is underway as a result of a 'supply-push' policy: the phased ban on incandescent light-bulbs. This chapter links path-dependency and new path creation theories to the literature on behavioural biases and the empirically observed and systematic failure of people to behave in the ways predicted by the neoclassical model (Gigerenzer, 2002; Kahneman and Tversky, 1979). It is argued that in this context, it is reasonable to expect institutions to evolve over time to address this 'inaccurate' assessment of risks and payoffs. It is argued that if such interventionist regulation is seen as being part of a learning process, played out as part of the democratic process, with open and transparent collective decision-making processes to manage the plurality of (often competing) social goals, then such regulation need not be seen as a compromise to individual freedom.

In contrast to Chapter Four which explicitly focuses on non-price supply push regulation, Chapter 5 makes the case for the role of demand-pull price based policy in the case of emissions trading. This chapter draws on Chapter Two of the author's co-authored book *Carbon markets: an international business guide* (Brohé et al., 2009) and positions emissions trading within the broader suite of low carbon policies. In the context of Figure 1.5, it is argued that such price-based policy is most useful at moving low-carbon technologies up the diffusion curve once a new pathway has already been established.

Where Chapter 5 built up the theoretical case and potential for emissions trading, Chapter 6 on the political economy of greenhouse gas reduction in Australia, looks at the difficulties of implementing such policies in practice and draws out some of the forces at play which can act to entrench stability in high-carbon pathways. This chapter has been published as a paper in the journal *Political Geography* (Howarth and Foxall, 2010).

In Chapter 7, the political economy of greenhouse gas reduction in Russia is investigated. With an economic and political system which underwent a 32% decarbonisation in the energy sector, and a 51% reduction overall, Russia is a case study of transition. This chapter also employs strategic actor network theory to draw out the particular features of the national context in Russia and the political and economic strategies for further carbon reduction that have the most chance of success given the Russian context. This Chapter was published as a book chapter in Compston and Bailey's *Feeling the heat: the politics of climate change in rapidly developing countries* (2012).

Finally Chapter Eight concludes this thesis, by providing a summary of this work for policy makers, and by outlining some of the areas of future research which flow from this work.

1.5 Conclusion

This chapter has introduced the aims and motivation for this thesis, outlined its methodological approach which is grounded in evolutionary institutional economic geography, and provided a summary of its overall structure, in a way which clearly describes how each chapter relates to the integrated approach articulated in section 1.2. This integrated approach is the central organising logic behind the narrative in the thesis, that in order to properly understand the risks, both economic and climatic, it is necessary to position equilibrium-based thinking within a broader, longer-term, historically rich, evolutionary framework. It is argued that this requires a synthesis between ‘economic’ equilibrium based neoclassical theory, and more ‘political’ evolutionary theory - a reinvigorated political economy of energy and the environment.

Part One

Theory

On the nature and direction of technological change

Introduction to Part One

From the BBC Reith Lectures 2005 'the triumph of technology'…

Questions directed to Lord Broers,

Vice Chancellor of Cambridge University,

President of the Royal Society of Engineers,

from Orlaff Bayer, technology researcher at Corporate Watch

Compare: Sue Lawley.

ORLOFF BAYER: *Would you agree that one of the fundamental issues that needs to be considered when examining new technologies is who owns it, who controls it, and who stands to benefit most from it?*

LORD BROERS*: If you say who's controlling it; do you want government to control all these things? Where are governments going to control and not control? I like environments where it is the users of technology who decide how they want to use them and whether they want to use them.*

ORLOFF BAYER: *For me, speaking as an individual, as a consumer, I'd like to be seen as something more than a consumer. I would like to have a choice as to which track technology takes, which technologies are prioritised over other technologies. I'd like technologies that are developed to fulfil societal needs, rather than technologies that are developed for corporate profit.*

LORD BROERS: *And what mechanisms would you suggest for doing that? I am with you, but I don't quite know, do you think we should have some sort of national* *referendum on these issues? and then control research companies in their laboratories?*

COMPARE: *Or indeed a global referendum?*

ORLAFF BAYER: *I would say at the very least we need something of that nature.*

LORD BROERS: *Well, but yes – we've got to get a consensus haven't we? You might have your own selection, but someone else out there might have a different one.*

ORLAFF BAYER: I would argue that we have nothing approaching a consensus on most decisions taken about technology at the moment.

LORD BROERS: *My feeling overall is that technology has been and is being hugely beneficial for the human race, but like anything, there are downsides as well as upsides; we can see every corner of the earth now which we couldn't do before; we can educate in every corner of the earth; so I am still an optimist and I still think the positive side outweighs the negative side.*

The above exchange, taken from the question time of Lord Broers' final lecture during the Reith Lecture series in 2005, captures in dialogue form several of the key themes to be investigated in this thesis. The significance and resonance of this exchange is profound, not least because of the esteemed discussants.

Firstly, one notes the frustration of Orlaff Bayer's position 'as an individual and a consumer' to be able to influence the broad direction of technological events around him – a frustration mirrored in its inverse reflection by Lord Brohers' deferral to 'users of technology' deciding 'how' and 'whether' to use technologies.

This inconsistency in the perceived power of the consumer to influence the direction of technological change has long been a subject of discussion in the social sciences. On the one hand there are those, like Mr Bayer, who consider that the direction of technological change is, for the most part, outside the control of the individual or consumer to influence – indeed, that 'society' is even controlled by the technologies around it. On the other hand, there are those like Lord Broers who consider that, for the most part, individuals are 'free to choose' different technologies based on their individual preferences. According to this perspective, technological change follows the path that best reflects consumers' interests. These two views are central to a debate that will be theoretically explored and tested with examples relating to the treatment of 'technology' in the neoclassical 'free-to-choose' framework developed in Chapter Two (equilibrium) and the perspective of path dependency and complex adaptive systems theory where 'history matters' discussed in Chapter Three (evolution).

Another telling observation that can be made from the exchange is how the discussion is framed. Mr Bayers sees himself as 'an individual, as a consumer' rather than as a citizen capable of shifting the path of technological change through the political process. Lord Broers reinforces this sense of democratic inefficacy through his remark, 'do you think we should have some sort of referendum on these issues?' A question to which he answers, 'Well, but yes -we've got to get a consensus haven't we? You might have your own selection, but someone else out there might have a different one', implying that it is best to leave such decisions undisturbed by the political process – in other words, to let the market decide. Lord Broers recognises that there are 'down-sides as well as up-sides' but offers no guidance on how society might influence the nature of technological change other than through broad references to improved observation techniques (evidence) and education. Thus this exchange also seems to reflect the deep infusion of market-based logic within society's leaders of opinion.

This absence of an appreciation for the political process as a way to critically reflect on social preferences, deliberate as citizens and improve on institutions to achieve our collective goals, such as GHG reductions, can perhaps be seen as symptom of the general lack of appreciation for the 'political' in the study of the 'economy' discussed in Chapter One. The past dominance of such 'market-based' logic and the recent emergence of alternatives based on evolutionary ideas is what has motivated Part One of this thesis. Given the search for a new economic paradigm following the recent financial crisis, it seems prudent that first we must understand where we have come from to this point. As noted by John Maynard Keynes (1935:383) in his *General Theory*:

> The ideas of economists and political philosophers both when they are right, and when they are wrong, are more powerful than is commonly understood. Indeed the world is ruled by little else. Practical men who usually believe themselves to be quite exempt from any intellectual influence are usually the slaves of some defunct economist.

In addition to informing the development of the integrated approach of economic and political change presented in Chapter One, the next two chapters are aimed at highlighting how ideas from the social sciences have helped us understand and, at times, shape the nature and direction of technological change. It should be clear by this stage that such an understanding is central to solving the problem of humanity's response to climate change.

Chapter 2 Equilibrium - the basic neoclassical model and extensions

2.1 Introduction

Beginning with the industrial revolution, the observation that technology has been at the heart of economic growth, is fairly well recognised. What is more controversial, is how technological change is perceived by the different schools of thought across of the social sciences. Thus it can be argued, views on the nature and direction of technological change extend beyond single issues, such as climate change and energy, to the very core of debate about the process by which economic growth occurs and the extent to which it can, or should, be shaped by society, such as through the political process and government policy.

Chapter Two sets out to establish some of the core micro and macro-economic foundations related to the study of technological change. While primary aim of this section is to present the basic tenants of neoclassical theory as can be applied to energy and climate change, this body of work will also be useful to provide the theoretic foundation for the many critiques of this theory such as found in economic geography – for instance through a clear articulation of concepts such as *increasing returns* and *network effects*. First, drawing on Pindyck and Rubenfeld (1992) and Mas-Colell, Whinston and Green (1995), the micro-economic foundations of the neo-classical paradigm model are introduced. This begins with the basics of demand and supply and an explanation of the market mechanism and how a 'competitive equilibrium' can be reached via the 'market mechanism' leading to a 'Pareto efficient' allocation of resources. The theories of consumer and producer choice are then introduced in the context of the choice between high and low carbon consumption and production. This brings into the analysis notions such as *utility* and *profit maximization* and *elasticity* which underpin the demand and supply framework. Next, a detailed examination of the role of technology inherent in the production function of the firm is made. To put these theories to work, a short analysis of electricity production and consumption is developed. Next, the theory of 'market failure' is introduced in the context of energy supply and climate change.

At this stage, the observation is made that the standard neoclassical analysis of the problem of climate change is framed not so much as a technological problem, but as a problem relating to the costs of the environmental externality (dangerous climate change) and the appropriate price for high-carbon vis low carbon energy. The neoclassical framework emphasises a process of technological change that emerges bit by bit through many small decisions taken by agents who maximise utility or profit. For the firm or the consumer, technological progress is generally conceived as driven by the desire to get a certain good or service at the lowest possible cost. These agents are co-ordinated by the price mechanism. The emphasis for policy-makers in this framework is for government to intervene only to *price* carbon at the full cost of the environmental externality. According to theory, this then allows an efficient allocation of resources between 'high' and 'low' carbon energy production to evolve. In this analysis, the nature and direction of technological change is usually treated as a residual outcome of price changes, epitomised by the metaphorical "invisible hand" of Adam Smith - the theoretical basis of the quip that it is wrong for the government to "pick" technological "winners".

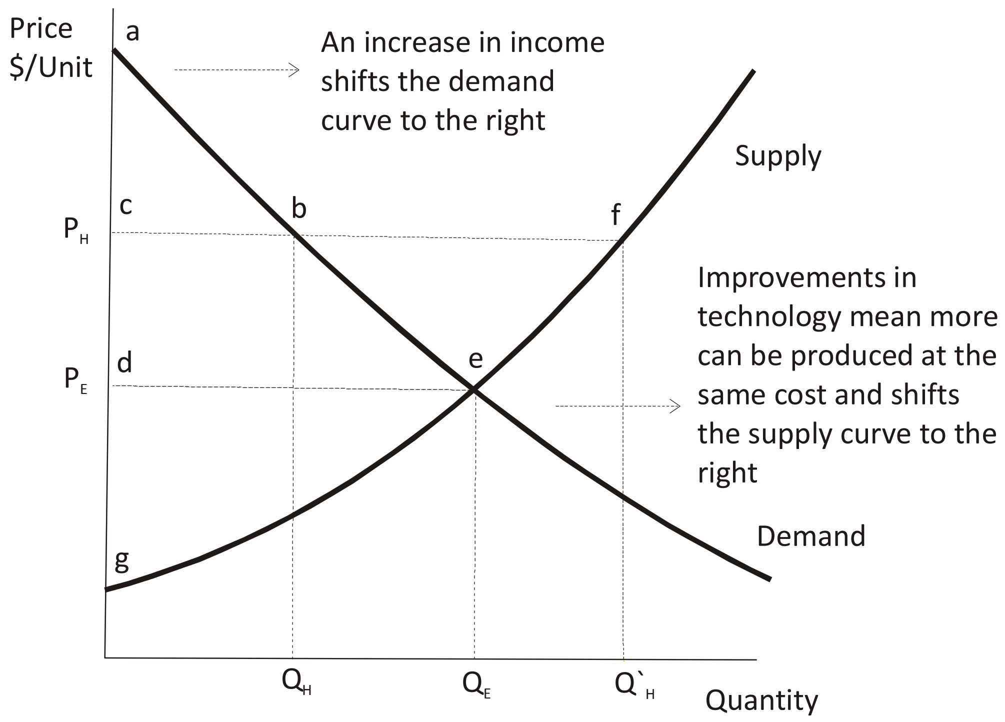
Having articulated the core concepts of the standard microeconomic model particularly relevant to technological change, the next section reviews the place of technology in the work of economists who have investigated the question: what makes economies grow? This section briefly outlines the key features of classical growth theory (Hume (1742[1987]), Smith, 1759[1790]; Ricardo (1817[1821]); neoclassical or exogenous growth theory (Solow, (1956), Swan, 1956); endogenous growth and 'new' growth theory (Romer, (1986), Lucas, (1988) and induced innovation theory (Ahmad, (1966) Kamien and Schwartz, (1968) and Binswanger (1974).

2.2 Demand, supply and the market mechanism

Perhaps the most obvious place to begin to appreciate the relevance of neo-classical analysis is with the theory of demand and supply and the market mechanism. In this model, the economy is split into two groups of agents: consumers on the demand side; and producers on the supply side. The demand curve tells us how much consumers are willing to buy for each price per unit that they must pay. It slopes downwards because consumption increases if prices are lower – consumers who already buy the product or service may buy more of it, and those who previously could not afford it, will begin buying it. *Consumer surplus* is the area under the demand curve, but above the price, and represents the difference between the marginal benefit consumers receive from the good (the demand curve) compared with what they pay for the good (the price). The supply curve tells us how much producers are willing to sell for each price that they receive in the market. It slopes upwards, because the higher the price, the more firms are generally willing and able to sell. For example, higher prices allow firms in the short run to hire more staff, or have existing staff work longer hours; and in the long run to purchase new capital or move to a larger production facility. This is because for some consumers (high up on the left of the demand curve) the value of the good exceeds the price they are likely to pay. *Producer surplus* can be represented by the area below the price and above the supply curve. For each unit, this surplus represents the difference between the price received and the *marginal cost* of production (the supply curve) and represents the profit on each unit, plus any *rents*, accruing to factors of production – labour or capital.

One of the most powerful insights of the neo-classical model is that consumer and producer surplus or *total welfare* are maximised when the price is at the point where demand equals supply. In the world of the neo-classical model prices can be set through the *market mechanism* or by government intervention.

Figure 2.1 The market mechanism



The *market mechanism* is the tendency in a *free market* for a price to change until the market clears and the quantity supplied and the quantity demanded are equal. To understand how the market mechanism works consider P_L in Figure 2.1. At this price quantity *Q′* is demanded by consumers, however, only a small amount Q_L of supply is possible due to the *increasing marginal costs of production*. Thus there is a supply shortage, or pent up excess demand of the difference between *Q′* and Q_L. Consumer and producer surplus are given by the areas *abc* and *gdc* respectively. However, at this price there are a significant number of consumers who would be willing to pay more (all those consumers along the demand curve between points *g* and *b*) to actually physically be able to buy supplies of the product. These consumers start to compete with each other for the scarce product, pushing up prices from P_L towards *P′*. However, if markets are *flexible*, prices need not go up to *P′* - as extra production is supplied the shortage lessens and there is less pressure for rising prices. Eventually the *market clearing* price P_e is attained at point *e*. At this point there is neither excess demand nor excess supply so there is no pressure for prices to change further and the market is said to be in *equilibrium*. Total welfare (consumer and producer surplus) is also maximised at this point, and is graphically represented by the areas *aef* and *feg.* This point is also called the point of *Pareto efficiency*, after the Italian economist, the point at which no person can be made better off, without making someone else worse off.

This outcome assumes that the market is at least roughly *competitive* or that both buyers and sellers have only a small ability to individually affect the market price and that they can accurately articulate and realise their values and preferences through the market. Of course, market-based interactions also require for markets to actually exist; and sometimes what we value and what we can buy and sell do not easily align. This is particularly relevant in the context of the development of new markets for environmental goods and services. In addition to this basic existential issue, a variety of *market failures also* means that too much or too little of one good may be consumed or produced and a degree of government intervention is required – either setting prices, or controlling quantities. However, the point to be made at this stage is that markets, once they are up and running, have been shown to be a very good way of organising economic activity and of promoting the diversity, quality and quantity of goods and services available to people. It is a powerful logic, which *a priori*, co-ordinates the complex actions of a multitude of agents to achieve a social optimum – maximising total welfare through a single rule – price signals.

The fundamental theorems of welfare economics (Arrow and Debreu, 1954) state that, in perfectly competitive markets, the equilibrium reached by trading between buyers and sellers at market prices will be economically efficient, and that such an efficient equilibrium can always be reached from a given starting allocation of resources. Another important point to be made at this stage, is that in this model government interventions are framed in terms of trying to recreate the theoretical point at which markets deliver economically efficient solutions (Foxton, 2011: 136)

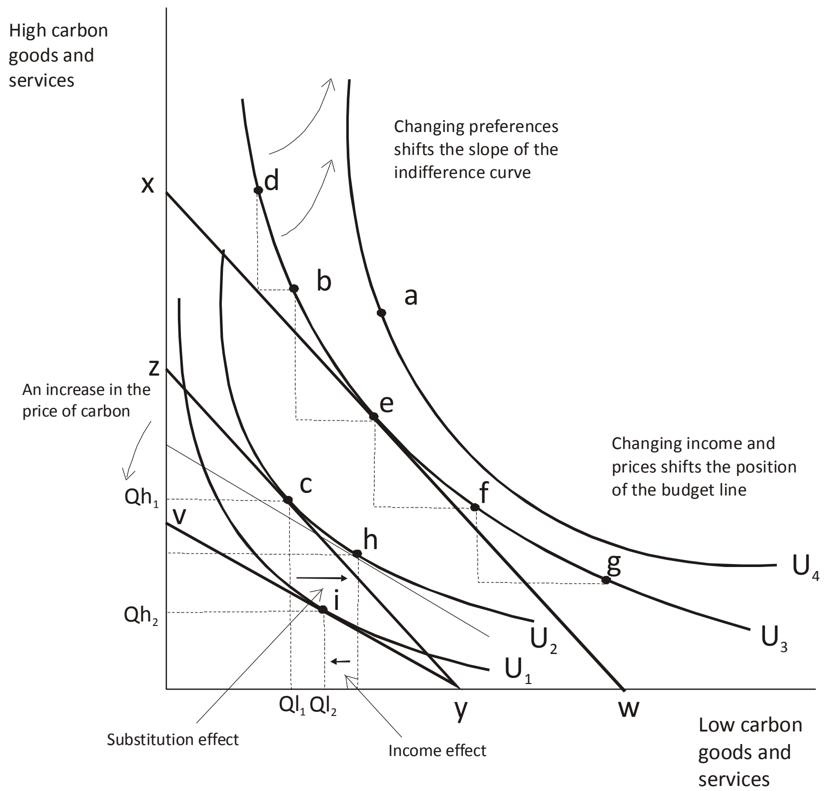
2.3 The theory of consumer choice

The market demand curve for goods and services in Figure 2.1 follows from the consumption choices of individuals. The typical way to model the consumer behaviour which underpins demand for the vast number of goods and services in the economy is through the theory of *consumer choice*. According to this theory, stemming from Alfred Marshall (1890), and surveyed most comprehensively in Deaton and Muellbauer (1980), all preferences can be thought of in terms of different *market baskets*, or combinations of one or more products such as food, clothing, entertainment, fuel, education and so on. It is firstly assumed that people are able to compare and rank all these different market baskets (that preferences are *complete*). Secondly, it is assumed that if a consumer prefers market basket A to B, and also B to C, then they also prefer A to C (that preferences are *transitive*); and finally it is assumed that goods are desirable, that they always prefer more of one good to less. For purposes of analysis, consumer preferences can be mapped graphically using *indifference curves*, which represent all combinations of market baskets that provide the same level of satisfaction to a person. Once a person is consuming on their indifference curve, they cannot be made any better off by changing their market baskets, say between D, B and E in Figure 2.2.

Another way of describing the level of satisfaction that a person gets from economic activity, is through the notion of *utility.* This concept is somewhat broader than simply the preference ranking of market baskets and related to the pursuit of things that provide pleasure and avoid pain. For analytical purposes, indifference curves are also described as *utility functions, w*ith higher curves associated with greater levels of utility.

While this analysis can help us rank market baskets in the order of most preferred to least preferred (an *ordinal* ranking), it will does not indicate by how much these different baskets are valued (a *cardinal* ranking). In Figure 2.2, two groups of products are modelled using the framework: on the one hand, a high carbon set of goods and services; and on the other hand, a low carbon set. Underpinning this analysis is the assumption that the indifference curves are *convex* to the origin (bowed inwards). Figure 2.2 describes the maximum quantity of high carbon products that a consumer is willing to forego for an extra unit of low carbon products at any point. This rate is called the *marginal rate of substitution*, and as we move down the curve, it increases (becomes less negative) or flatter. How realistic is this assumption? It implies that as more and more low carbon goods are consumed the willingness of the consumer to forego high carbon goods diminishes. This seems to make intuitive sense: as the number of products for which it is easy to substitute away from high carbon sources diminishes, consumers are reluctant to take on more low carbon alternatives in their consumption patterns. On the left hand, upper part of the curve large substitutions might take place such as energy efficiency investments or buying local produce instead of imported ones; but in the lower, right hand part of the curve it would take a lot of low carbon alternatives to compensate for foregoing, say, an important long-haul flight. Of course, this analysis also assumes that consumers differentiate between high-carbon and low carbon goods and services. In the event that a person does not care about the difference between these two classes of consumption, then the slope of the indifference curve would be constant – they would be perfect substitutes.

Figure 2.2 Consumer choice with changing income, prices and preferences



Consumer behaviour is not, however, just determined by preferences. Choices are also affected by *budget constraints* which limit people's ability to consume in light of the prices that they must pay. The *budget line*, indicates all combinations of high and low carbon goods for which total income is equal to income for a given set of prices. To determine the actual point of consumption, neoclassical theory assumes that consumers act in a *rational* way – that is, that they seek to maximise their utility or welfare (i.e. consume on their highest possible indifference curve), given the prices of goods, subject to their available budget. Graphically this means that consumption should take place on the budget line (i.e. all income is allocated between these two goods) and that the maximising basket must give the consumer the most preferred combination of goods and services (it should lie on the indifference curve). In Figure 2.2 this occurs for the budget line *zy* at point c*.*

When income goes up, then the budget line shifts parallel and to the right (from *zy* to *xw*); and when prices change it rotates around one intercept, inwards for a good that becomes more expensive outwards if a good becomes cheaper. Thus, if carbon taxation is applied and the price of carbon intensive good rises, then the budget line will shift from *yz* to to *yv*. We can also see from Figure 2.2 that the effect of price changes can be separated out into a *substitution effect* – the relative change in the consumption basket (from point *c* to *h*) holding income constant along U_2; and an *income effect* – the change in consumption resulting from having relatively less money to spend on both goods (from *h* to *i*). From these results follows the derivation of an individual's demand curve – as prices rise for a good – the consumer will desire less of it.

Another interesting observation that can be modelled within this framework, is the tendency for people on higher incomes to value lower-carbon goods and services than those on lower incomes (based on the idea of the environmental *Kuznets curve*). If we accept this relationship holds, as the consumer moves onto higher budget lines and indifference curves, the slope of the consumer's indifference curve tilts away from the y-axis and becomes steeper at any given point. Such goods are also commonly referred to as *superior goods* (demand for them increases as incomes increase); *normal goods* have a linear relationship and for *inferior goods* one's demand for them falls as incomes increase (for example, public transport).

An important concept which is used to systematise these effects is the concept of *elasticity*. An elasticity is the sensitivity of one variable to changes in another. Specifically, it is a number that tells us the percentage change that will occur in one variable in response to a percentage change in another. Three important examples are:

The *price elasticity of demand*: gives the percentage change in the quantity demanded of a good in response to a percentage change in its price. For example, when deciding to buy a domestic light bulb consumers look at the shelf price of the products of offer. The percentage change in the number of bulbs purchased in response to, say a 50% reduction in their price, is the price elasticity of demand for that product.

$$\varepsilon_p = \frac{Q_1 - Q_0 / Q_0}{P_1 - P_0 / P_0} = \frac{P_0}{Q_0} \cdot \frac{Q_1 - Q_0}{P_1 - P_0} \qquad (2.1)$$

The *cross-price elasticity of demand*: gives the change in the quantity demanded of a good in response to a change in price of another good. For example, the quantity of compact fluorescent light bulbs demanded may be sensitive to price changes of incandescent bulbs. As they are substitute products, as one becomes relatively more expensive demand for the other would be expected to rise. The cross price elasticity of demand is a way of quantifying this relationship.

$$\varepsilon_p = \frac{Q^a{}_1 - Q^a{}_0 / Q^a{}_0}{P^b{}_1 - P^b{}_0 / P^b{}_0} = \frac{P^b{}_0}{Q^a{}_0} \cdot \frac{Q^a{}_1 - Q^a{}_0}{P^b{}_1 - P^b{}_0} \qquad (2.2)$$

The *income elasticity of demand*: gives the change in the quantity of a good demanded in response to a change in income. For example, the percentage change in the quantity of CFLs demanded may change with changes in income. In this case, people on lower incomes are potentially more likely to be put off by the higher upfront costs of CFLs than those on higher incomes.

$$\varepsilon_p = \frac{Q_1 - Q_0 / Q_0}{I_1 - I_0 / I_0} = \frac{I_0}{Q_0} \cdot \frac{Q_1 - Q_0}{I_1 - I_0} \qquad (2.3)$$

This brief introduction into demand and the optimising behaviour behaviour of consumers has strong similarities to the optimising behaviour of producers and the supply side of the market. Next, the standard neoclassical theory of how firms organise their production is set out, highlighting the important role of technology in driving the model forward.

2.4 The theory of production, cost and the firm

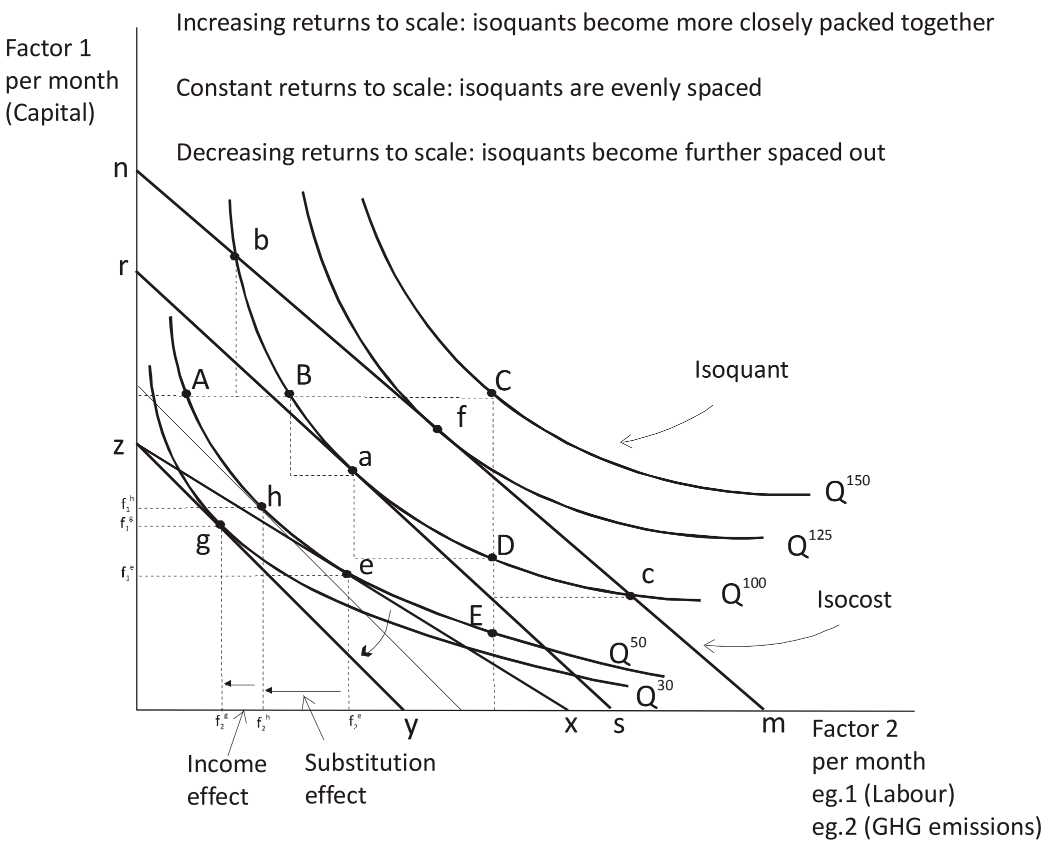
In the production process, firms turn *inputs* (or factors of production) into *outputs* (or products) via a process of transformation using the available technology. Inputs can be divided into three broad categories: labour (*L*), capital (*K*) and materials (*M*); and can further divided into subcategories such as: skilled and unskilled labour, fixed and flexible capital and so on. For example, a wind turbine manufacturer uses inputs which include the labour of its assembly workers, engineers and the entrepreneurial efforts of its managers; capital, such as its buildings, equipment, inventories and materials such as steel and fibreglass; and other running costs such as electricity and water. It is worthwhile highlighting that in addition to commodities such as steel, petroleum, cement and so on, raw materials can be thought to include environmental inputs such as waste water and the atmosphere, especially as firms are being faced with paying for access to the environment as a pollution sink. This relationship between inputs and outputs can be described by a *production function* – which relates the output *Q* for every specified combination of inputs:

$$Q = F(K,L,M) \qquad (2.4)$$

Just as the theory of consumer choice describes the consumption decisions of the individual through the interaction of indifference curves and the budget line, the theory of production describes the behaviour of the firm by the interaction of the *isoquant* and *isocost* curves respectively (Figure 2.3). For graphical simplicity, the following discussion will limit the number of inputs to two. Two examples will be developed using the framework in Figure 2.3, one modelling the relationship between capital and labour, and a second modelling the relationship between capital and GHG emissions, exemplifying how 'the environment' may be considered a factor of production.

An isoquant is a downward sloping convex (to the origin) curve which shows all the possible combinations of inputs (in our first case, labour and capital) that can yield the same output (*Q*). An important difference to the theory of consumer choice is that while indifference curves can only give ordinal rankings of preferred market baskets, isoquant curves have a quantitative measure associated with them – thus also give a cardinal ranking. A set of isoquants, or *isoquant map*, describes the firm's *production function*. In Figure 2.3 Q^{50} gives all the combinations of labour and capital that yield 50 units of output a year. Q^{100} lies above and to the right of Q^{50} because it takes more of either labour or capital or both to obtain a higher level of output.

Figure 2.3 The theory of production



Note that labour and capital are *flows,* meaning a firm uses a certain amount of each factor over a period of time. Isoquants highlight the flexibility that firms have when making production decisions – for example, a shortage of cheap, low, skill labour may result in increased automation of the production process using capital, or the import of labour intensive components from low-wage countries. Thus isoquants are another way of describing the substitutability between factors of production. The slope of the isoquant at any point measures the *marginal rate of technical substitution* (MRTS) – the ability of the firm to substitute one factor of production for another while maintaining constant output. This tells us that the productivity that any one input can have is limited. As a lot of labour is added in place of capital (say, as the firm moves from point *b* to point *c* in Figure 2.3) the marginal productivity of labour falls and the MRTS decreases.

$$\text{MRTS} = -\frac{\text{Change in Capital input}}{\text{Change in Labor Input}} \qquad (2.5)$$

The relative slopes between isoquants can also be used to demonstrate the *law of diminishing returns*. For example, in the short run, capital is often difficult to expand. In Figure 2.3, as the firm moves from *A* to *B* to *C* it applies only more labour to achieve greater output. At each point the slope of the isoquant can be seen to flatten out, showing there are diminishing returns to labour. Conversely, if the firm were to expand output using only capital, moving from *E* to *D* to *C*, and as the MRTS increases the productivity of capital falls and that of labour rises, showing that there are diminishing returns to capital. Because adding one factor while holding the other constant eventually leads to lower and lower increments to output, the isoquant must become steeper, as more capital is added in place of labour, and flatter when labour is added in place of capital.

The relative slopes of different isoquants also reflects the nature of the technology embodied in the production process. For example, a relatively flat isoquant reflects a production process where the marginal productivity of capital is very high – to keep producing the same amount one less unit of capital requires a large amount of labour to replace it. For example, this might be the case in an industry using DNA sequencing technology, which requires large computers to process vast quantities of information with relatively little labour input. Conversely, a steeply sloping isoquant suggests a high marginal product of labour and a large investment in capital to replace relatively small amounts of labour to maintain production. This would be common in labour intensive industries such as some textiles or fruit and vegetable harvesting.

In the last example, one factor of production was held constant while the other was increased to demonstrate the law of diminishing returns. What if more than one input was allowed to vary? The measure of increased output associated with increases in some or all inputs is fundamental to understanding nature of the production process. There are three main cases:

- *Increasing returns to scale* are said to exist when a proportional doubling of inputs leads to more than a proportional doubling of outputs. For example, this could arise because the increased size of the firm allows greater specialisation of workers which boosts productivity and enables the use of larger, more sophisticated machinery. In these cases it is economically advantageous to have a small number of large firms supplying the market at a relatively low cost, than many small firms, at relatively high costs. These are typical characteristics of the electricity supply sector.
- *Constant returns to scale* are said to exist when an increase in inputs leads to the same increase in outputs. In this case, the size of a firm's output does not affect the productivity of its factors. With constant returns to scale, one plant using a particular production process can be easily replicated, so that two plants produce twice as much output. For example, a large company which supplies sandwiches might provide the same service per customer as a

small company and use the same ratio of capital (store space) and labour (kitchen and service staff).

- *Decreasing returns to scale* exists when an increase in inputs leads to a less than proportional increase in outputs. Decreasing returns arise in large scale operations when the difficulties of increased complexity associated with the management of a large operation begin to introduce inefficiencies leading to reductions in the productivity of both labour and capital.

Just as consumption behaviour is not determined only by consumer preferences, but also be the budget line; production is not just determined by the isoquant line. Firms face costs when using factors of production, these are represented by the isocost line. This shows all possible combinations of labour and capital that can be purchased for a given total cost (*C*).

$$C = wL + rK \tag{2.6}$$

$$K = \frac{c}{r} - \frac{w}{r}L \tag{2.7}$$

The formula for the isocost line is given by equation (6) and is determined solely by the relative price of labour (w) and capital (r). It describes the combinations of labour and capital which can be combined at the same cost. For example, if the wage rate was £10 per unit and interest rate £5 per unit, then a firm could replace one unit of labour with two units of capital with no change in total cost. It is the interaction between the isocost and isoquant curves which provides us with a description of the firm's optimal production level and mix of inputs.

In Figure 2.2, suppose a firm has decided it wishes to produce at Q^{100}. Isocost line *nm* gives the total cost of the factors of production to yield this amount and intersects the isoquant at points *b* and *c*, each with their respective combinations of labour and capital. However, the same amount of output can be produced at a lower cost along isocost line *rs* at point *a*. If we can assume the rational behaviour of the firm is to minimise costs for any given level of output in order to maximise profits, it follows that the firm will use the combination of inputs where the slopes of isoquant and isocost curves are just equal. At this point, the production of an additional unit of output costs the same, regardless of which input is used.

It is worthwhile to briefly question how realistic is the assumption of profit maximisation? For small firms, which are managed by their owners, profit is likely to be a major objective, however other ojectives such as provision of a particular non-profit service or lifestyle for the proprietor maybe also important. In larger firms, where managers have little contact with the owners (such as stockholders) there is likely to be even greater deviations from profit maximisation. For example, managers may be more concerned with revenue maximisation in order to expand growth, firm size and prestige; they may also seek to maximise dividend payouts to shareholders or short-run profit (perhaps to earn a large bonus or to take a larger proportion of revenues in salary) at the expense of longer-term profit which seeks to maximise the value of the stream of profits over time. Thus the profit maximisation assumption has several potential serious weaknesses – and as noted by Alan Greenspan following the 2008 collapse of the banking system: “those of us who have looked to the self-interest of lending institutions are in a state of shocked disbelief". The weakness of this central assumption – what Greenspan terms a "pillar of competitive markets" means that care must be taken when assessing what *exactly* markets are maximising and regulations put in place to support market abuse. In theory, firms or managers that do not place profit maximisation at the heart of their business are unlikely to survive and will become either take-over targets, or sacked by their boards respectively. However, in practice because markets are characterised by the diffuse nature of share ownership and weak corporate governance, problems regarding the goals and management of the company can go undetected creating systemic problems for the stability of markets (Kay, 2012).

This model can now be used to predict the effect of relative price changes among the factors of production on output. Changes in factor prices can occur for many reasons, be it movements in commodity prices, such as for oil; changes in interest rates; collective union agreements pushing wages up; or improved technologies which bring down the cost of inputs, such as in computing. For our example, instead of using labour as factor 2 we will use the atmosphere's properties to absorb GHG pollution as a factor of production. This assumes that property rights to the environment can be adequately defined. In this case an energy production firm is required to face the costs it imposes on others through its pollution. This is the case in example 2 of Figure 2.3, where the imposition of a price on GHG emissions is shown by the inwards rotation of the isocost curve from *zx* to *zy*. When the carbon price is increased for every tonne of GHG emissions the firm must pay the government an environmental charge. It is no long possible to produce Q^{50} at the same cost and the isocost line rotates inwards to reflect the higher price for factor 2. The shift in the point of profit maximisation from point *e* to *g* can be separated out into an income effect and a substitution effect. The substitution effect, shown diagrammatically as the shift from point *e to h* and gives the decline in the quantity of emissions (from f_2^e to f_2^h), and the increase in the capital (from f_1^e to f_1^h - a cleaner production technology, such as carbon capture and storage, for example), required to maintain output at the same level. The income effect (from point *h* to *g*) reflects that the firm now has less money to spend on inputs as it has to pay the government the carbon fee, and represents the fall in use of the environment (from f_2^h to f_2^g) and fall in the use of capital (from f_1^h to f_1^g) associated with having less money available to it. There are a couple of insights we can draw from this – the first is that the more the factors of production are substitutable, the easier the firm can deal with its GHG pollution without using the atmosphere as a waste sink and the more effective the fee will be in reducing pollution. Second, the greater the degree of substitution, the more easily the firm can avoid the effluent fee.

2.5 Technology and the production function

To model more clearly the role of technology on the production process we can set out a *production function*. The production function describes the optimal combination of inputs and outputs for *any given technology*, across all levels of output (i.e. points *e* and *a*, and so on, for each feasible isocost and isoquant curve). Technology in this context is understood to be a given state of knowledge about how to transform inputs into outputs. In Figure 2.4, a standard production function is shown where the increased use of inputs begins with increasing returns to scale (over the range *a* to *b*), transitions into constant returns (around point *b*), then into decreasing returns (from *b* to *d*) and then finally the situation of negative returns to scale is shown for output beyond point *d*.

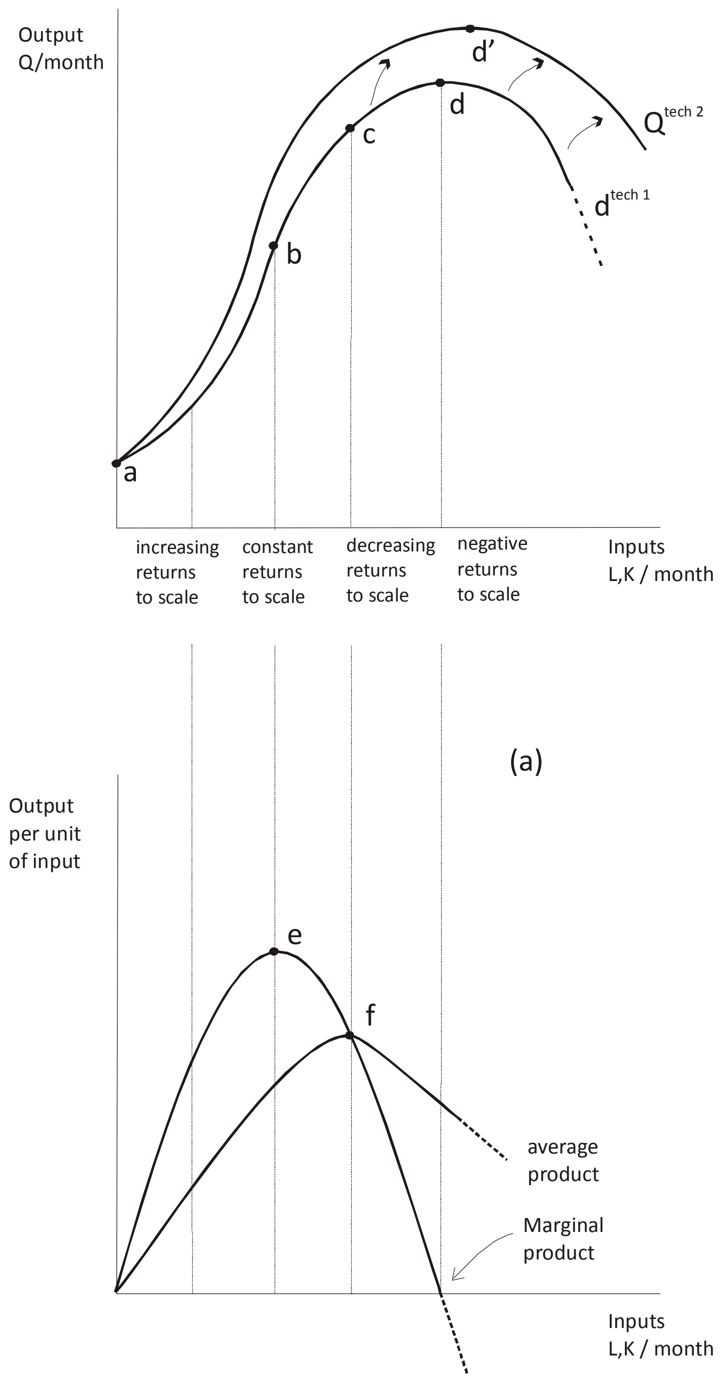
As technology becomes more advanced and is absorbed by the firm, the form of the production function changes as the firm can obtain more output for any given set of inputs. For example, improvements in nanotechnology may allow a producer of photovoltaic cells to supply a greater number of solar arrays each month for any given combination of labour, capital and raw materials. This is shown in Figure 2.3 as the shift from Q^{tech1} to Q^{tech2}. In Figure 2.4 (a) the shape of the average and marginal product curves are shown, which are closely related. When the marginal product is greater than the average product, the average product is increasing, and when it is less than the average product, they both are falling. When the marginal product crosses the axis, output is maximised at point *d* and *d'* respectively. This happens because an additional unit of input adds so much to the complexity of management, that it actually slows down the production process. Note that even though the law of diminishing returns to scale still applies as we move along Q^{tech2}, it sets in at a higher rate of output and input. This is an important insight, which explains why, although there are diminishing returns to both labour and capital, output has been able to expand preventing the economy from falling into the so-called *Malthusian trap*.

2.6 The cost of production

The theory of production presented above showed how a firm may select inputs to produce a given output at minimum cost. In this section we will now refine this understanding of cost by clarifying what economic costs are, and their constituent components. This can help understand the short and long term dimensions of production decisions, the effects of learning and more clearly see how different industries' cost structures can profoundly influence production decisions with different returns to scale. This is particularly relevant for understanding the nature of technological change within the neoclassical model - as technology is conceived as operating by lowering costs.

Underpinning the neoclassical analysis of the firm is that operational managers should take a forward looking view of costs and calculate how they can rearrange resources in the future to lower costs and improve profitability. In contrast to a retrospective view of simply the explicit costs of operations, such as wages, rent

Figure 2.4 The production function



and the cost of materials, an 'economic' perspective endeavours to focus attention on opportunity costs; or the costs foregone by not putting a firm's resources to the highest value use (Pindyck and Rubinfeld, 1992:198). Explicit costs are still important as well, because they involve opportunity costs – for example, wages are the opportunity cost of labour inputs purchased in a competitive market. However, opportunity costs can also differ from such explicit costs. For example, consider a manager who runs her own business, but does not pay herself a salary. Although no monetary cost transaction has transpired, the firm nevertheless incurs an opportunity cost because the owner could have earned a competitive salary by working elsewhere.

This notion is also essential for investment banks – the so-called brains of the capitalist system – in how they allocate resources between different projects such as renewable energy versus fossil fuel projects. It is not so important that a project is able to earn a positive return for a given level of risk over and above what the bank can earn by borrowing at low rates from the central bank. Bankers, if they do their job properly, will scour the economy looking for projects which maximise this rate of return, seeking out the best projects, thereby allocating resources in the most effective way across the economy. A tension of course has arisen recently in the context of the financial crisis in how well bankers do this job – or whether in fact they are more focused on choosing the projects that maximise their own remuneration which many argue has become disconnected from them achieving their social function in allocating capital (Kay, 2012).

Just as opportunity costs might not embody financial transfers but should be taken into account in economic decision making, sunk costs embody financial costs, but should not be taken into account. A *sunk cost* is an expenditure which has already been made but cannot be recovered. For example, if a piece of specialised plant or equipment has no alternative use, then its opportunity cost is zero and it should not be included in the firms' current or future costs. While in general, capital costs include not just the upfront purchase and running the machinery but also the wear and tear to that asset which occurs over time – in theory, the sunk cost component of the investment should not affect current investment decisions. In practice, however, they often exert a strong influence over decisions and can contribute to *path dependency* – the tendency of some decisions once taken to make other similar decisions more likely. This has given rise to the concept of *stranded assets* and has especially been the focus of research related to decisions to extend the operating life of a nuclear power plants (De Bont and Makhija, 1987).

This is another area where the common assumptions underpinning decision-making under the standard approach have been called into question. For instance, while it may be useful pedagogical tool to separate 'explicit' and 'opportunity' costs in textbooks, in practice, some economic practitioners may be just as backwards looking, especially as most economic forecasts are constructed on past performance. This has given rise to the counter movement of *behavioural finance*, in order to re-inject a sense of realism back into financial and economic management.

With this more detailed understanding of what is meant by 'cost' – we can now move onto describe its constituent components. The costs of the firm are typically separated out into short and long term elements. While the analysis in Figure 2.3 assumed perfect flexibility between factors of production, in practice, it is often impossible to vary some inputs and these costs must be paid irrespective of the level of production. These costs are called *fixed costs* (*FC*) and include items such as plant and expensive specialised equipment which can only be varied in the long run.

Short-run costs can also be described as *variable costs* (*VC*) in that they vary with the level of output produced; for example, wages and materials such as water, electricity or components used in production. There are two types of variable cost. Firstly, *marginal cost* (*MC*) is the increase in cost that results from producing one extra unit of output. As it does not include fixed costs, it only represents the increase in variable costs that results from an extra unit of output. Because marginal cost tells us how much it costs to expand the firm's output by one unit – it is also often considered analogous to the firm's supply curve. The second category of variable cost is *average total cost* (*AC* or *ATC*) and *average variable cost* (*AVC*). Average total costs are the costs per unit of output including fixed costs, while average variable cost excludes these fixed costs. Figure 2.5 sets out these relationships graphically.

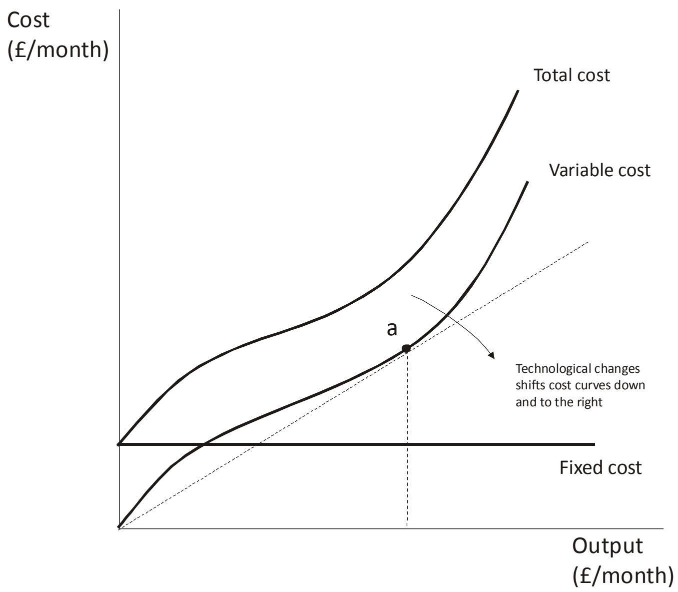
Increasing returns means that for the early units of production (up to Q_e), there is a high marginal product for variable cost inputs (such as labour). Up until this point, for every extra unit of production, average costs are falling. The slope of the variable cost curve at any point gives the marginal cost. Average variable costs are minimised when the ray from the origin in panel (a) touches the variable cost curve. This occurs at point *a* in panel (b) and the short-run variable costs exhibit constant returns (similarly for total costs at point *e*). When the marginal cost is below the average cost curves, average costs are falling, and when it is above the AVC and ATC curves, diminishing returns have set in with average costs are rising. Because fixed costs are constant, average fixed costs fall with increasing output.

By comparing average total cost to the price of the product, or *marginal revenue,* it is possible to determine the economic profitability of the firm. In a *perfectly* *competitive* market it is assumed that firms are *price takers* – this means that any one firm does not have the ability to influence the market price for their output so the market price is also the firm's *marginal revenue* curve (MR). Furthermore, at the point of *equilibrium* in perfect competition, all firms are required to be producing at zero economic profit.

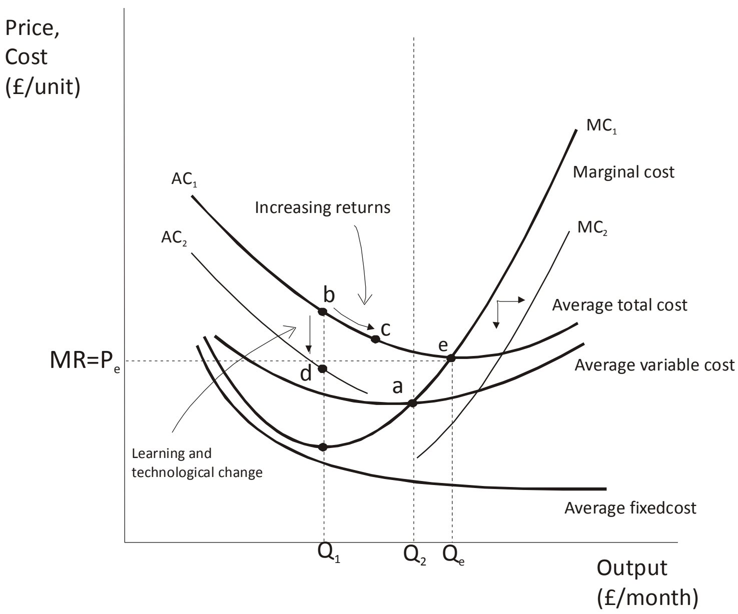
This requires equilibrium to occur at point *e* in Figure 2.5, where marginal revenue is P_e and equal to marginal cost at the minimum point of the ATC curve. Note that at this point an *accounting profit* is still possible, a return is being made on capital invested and salaries are being paid – it is just that resources cannot be allocated in a better way by this firm. If P_e is above this point then the firm would be operating at positive economic profit and if it was below it would be making a loss and eventually have to stop production. If a technological innovation occurs which enables the firm to lower the cost of production for any given level of output then the MC curve shifts downwards and to the right taking the average cost curves with it. If market prices remain constant at P_e this enables the firm to earn greater profit. It is this process that provides the engine for continual improvements in technology and management processes for if a firm can stay ahead of 'the market' norm of technology excess profits will be able to be earned – above normal market rates.

Figure 2.5 The components of cost: short run

(a)

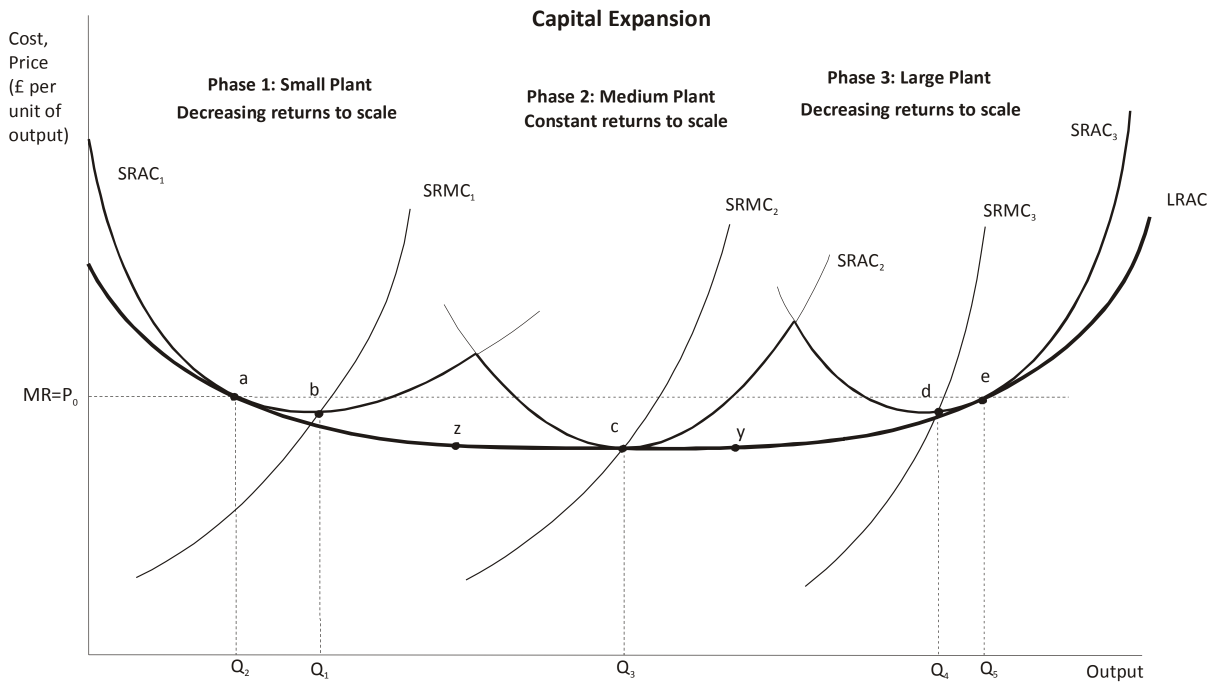


(b)



In the long-run, fixed costs are flexible (as in the model presented in Figure 2.3) and firms can alter the scale of production, for example, by adding new production facilities.

Figure2.6 The components of cost: long-run



In this case, the short-run average total cost curves for the firm can be described by $SRAC_1$, $SRAC_2$ and $SRAC_3$ in Figure 2.6. In Phase 1 the firm is initially producing at Q_1 but understands that by increasing its fixed costs and expanding its plant size, it could produce at a lower average cost. Provided the price (marginal revenue) supports such a move, the firm will move to Phase 2 capital expansion. At this stage the firm still uses Plant 1 but at the reduced level of Q_2 units with plant one and produces Q_3 units with the medium sized Plant 2. Over the range *z* to *y*, the technologies which govern the expansion of output exhibit constant returns to scale.

Any plant size (capital) along this output range will produce the product at the same average cost. However, after point *y*, decreasing returns to scale set in, and while a move to Phase 3 of capital expansion with a large plant size may still be profitable if average costs for the largest plant are below the market price at P_0.

With this industrial structure, the long run average cost curve is given by the emboldened sections of the short-run average cost curves, because this shows the minimum cost of production for any output level. Note that a small plant running at minimum cost is not as efficient as a large plant which can take advantage of increasing returns to scale to produce at a higher output level. The LRAC curve which envelopes this is the curve which traces the minimum SRAC curves if plants of any size could be built.

A more formalised way to describe these economies of scale is through the *elasticity of cost with respect to output*. Recall that elasticity measures the change in one variable in response to a change in another variable. Hence we can define the elasticity of supply:

$$\varepsilon_s = \frac{AC_1 - AC_0 / AC_0}{Q_1 - Q_0 / Q_0} = \frac{Q_0}{AC_0} \cdot \frac{AC_1 - AC_0}{Q_1 - Q_0} \qquad (2.8)$$

When ε_s is equal to one, costs increase proportionately with output (constant returns to scale); when ε_s is greater than one, costs increase more rapidly than output (decreasing returns to scale); and when it is less than one costs increase at a slower rate than output (increasing returns to scale).

While increasing returns to scale mean that costs will fall up to a point: as described by the movement along the long-run AC curve (from point *b* to point *e*), perhaps the most profound driver of lowering average costs over time is learning and technological change. This is shown graphically in Figure 2.5 by the shift from AC_1 to AC_2 and from MC_1 to MC_2. There are several forces that can be behind this process, for example:

- *Learning by doing and learning by watching*: as workers perform the same job over and over, they gain experience, which means that they take less time to complete specific tasks. In addition, managers become more adept at scheduling the production process from the flow of materials to the organisation of the firm itself. Engineers also learn from experience and, over time, will improve the design and efficiency of machinery, create better and more specialised tools, faster computer chips and so on;
- *Improvements in material inputs*. Learning by doing and watching also affects businesses which supply the firm – so improvements are continually being made by the firm's suppliers who may pass some of the benefits of this onto the firm in the form of more effective and cheaper material inputs; and
- *New technological products*. Advances in technology may create whole new products which can revolutionise the costs of production for certain industries. For example, the internet has resulted in a large productivity boost for many firms which have been able to change the way they interact with their customers. One such case is the airline business, where

passengers now book their tickets directly on-line, rather than go through a travel agent. As a result average costs have come down substantially.

2.7 Cost functions for electric power

Electricity consumption in OECD countries has consistently risen by around 2.5% each year requiring large increases in electricity production (Table 2.1). For example, consumption in the United Kingdom has over trebled from around 117.5 terawatt hours of electricity in 1960, to 351 twh in 2008. However, according to the International Energy Agency, despite this growth, up until the last decade at least, real electricity prices actually *fell* in the United States and Europe (see Table 2.2). The framework we have developed so far can be used to help understand these observations.

Learning and technical change: an historical study of the United Kingdom's electricity industry, suggested that the consumption of coal was 10-25 pounds per kilowatt hour (lbs/kwh) in 1891, in the first decade of the twentieth century it was 5lbs/kwh, and by 1947 it was 1.5lbs/kwh (Hannah, 1979). Today, it is about 0.7 lbs/kwh (Stern, 2007) suggesting that there has been around a 10 fold increase in the efficiency of coal power generation over this period. This means for each input unit of coal, around 10 times the electrical output is produced.

Table 2.1 Electricity consumption for selected OECD countries (twh)

	1960	1973	1990	2000	2008	Av. An. % change (1973-2008)
Australia	17.6	52.5	134.3	179.9	223.1	4.2
Germany	106.5	337.6	481.0	501.4	540.8	1.4
France	65.2	160.0	323.3	410.4	462.2	3.1
UK	117.5	242.5	284.4	340.3	350.5	1.1
US	688.0	1715.9	2712.6	3589.8	3907.9	2.4
OECD	-	3886.2	6578.5	8486.8	9513.0	2.6

Source: IEA, *Electricity Information 2010*

Table 2.2 OECD Indices of real electricity prices for end-users

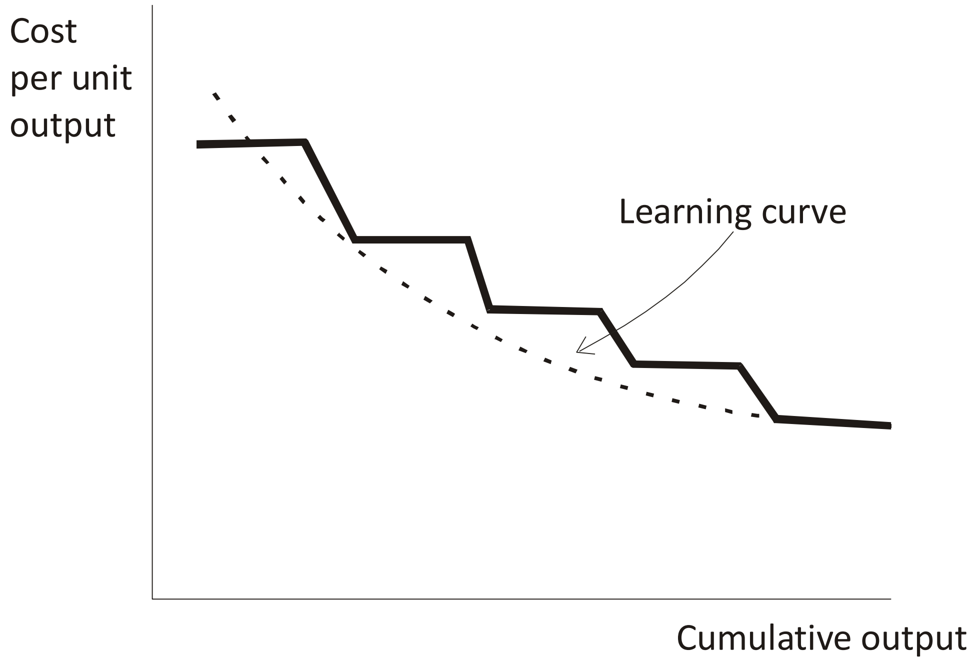
	1980	1990	2000	2009
OECD Europe	102.5	107.0	89.7	120.3
United States	126.9	118.7	95.5	110.2

Source: IEA, *Electricity Information 2010*

Table 2.2 shows energy prices falling between 1980 and 2000 (an index measure of 102.5 to 89.7 in OECD Europe), and then rising to 120.3 in 2009. This seems consistent with the idea that technological innovation and increasing returns to scale mean that increases in output can actually be associated with falling prices. However, the rise in prices over the last decade is a counter point to this and may reflect increasing costs due to increasing prices for fossil fuel inputs; new carbon-related regulations, and/or increased charges to prepare for a new wave of capital expenditure after the deregulatory push of the 1980s and 1990s shifted the incentive away from investment in new long-lived capital. Indeed, the falling prices of the 1980s and 1990s, have been attributed by some researchers to this later feature – which enabled lower prices in the short-term through a process known as 'asset sweating' but left an aging energy infrastructure, now in need of a new injection of resources, likely to push up costs (Helm, 2010).

While the physical properties of coal have stayed the same, learning and 'technology' have increased the marginal product of 'materials' in the production function. Köhler et al. (2006) provides a meta-analysis of empirical studies of learning rates across electricity generation technologies and set out estimates for the cost reduction associated with a doubling of capacity over certain periods and geographical locations. For many technologies, learning rates appear higher in earlier stages. For example, early post-war coal development in the United States (1948-1969) shows rapid learning in contrast to the period (1960-1980) and high rates of learning in gas drop off as the industry matures. Between 1982 and 1997, significant costs reductions were also observed for wind and solar PV technologies in the United States and Europe. The results of studies in this area have suggested a 'rule of thumb' that each doubling of capacity corresponds with learning leading to unit cost reductions in the order of 20 per cent, for typical generation technologies, with the exception of nuclear power (Grübler et al., 1999; IEA, 2000, and McDonald and Schrattenholzer, 2001).

Figure 2.7 Learning curve for electricity generation



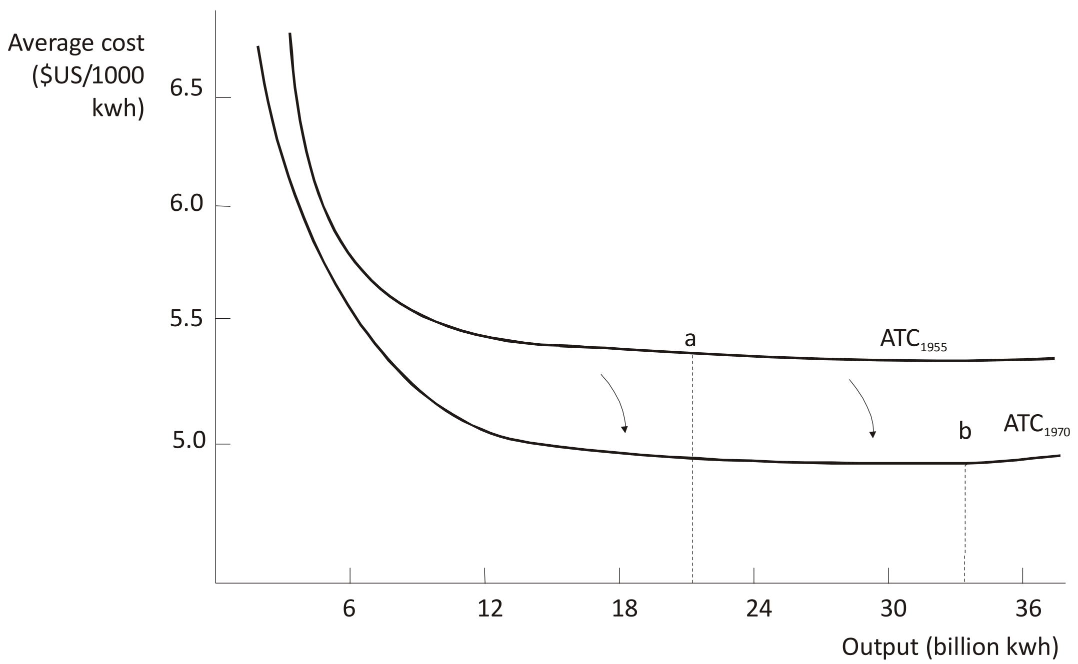
Economies of scale: an influential study of scale economies in the electricity generation sector was based on the years 1955 and 1970 for investor-owned utilities with more than $US1 million in revenues. The costs of operation were generated and the results classified according to the scale of plant operations with median output (measured in kwh) in each category summarised in Table 2.3. Values of less than 1 for the elasticity of supply over all output ranges suggest that firms of all sizes exhibited positive returns to scale, although this declined (as expected) with increasing output.

Table 2.3 Scale economies in the electric power industry

Output (million kwh)	43	338	1109	2226	5819
Elasticity of supply	0.59	0.74	0.84	0.9	0.96

Christensen and Greene (1976)

Figure 2.8: Average costs of production in the US electricity power sector



Source: Christensen and Greene (1976) 1970 $US

The estimated average cost curves associated with the 1955 and 1970 data are given by ATC_{1955} and ATC_{1970}. In 1955, the point of minimum average cost occurs at point *a* at around 20 billion kilowatts. However, as there were no firms of this size in 1955, no firm had fully took advantage of returns to scale in production. However, the curve is relatively flat from around 9 billion kilowatts and higher, a range in which 7 out of 124 firms produced. When the same cost functions were estimated with the

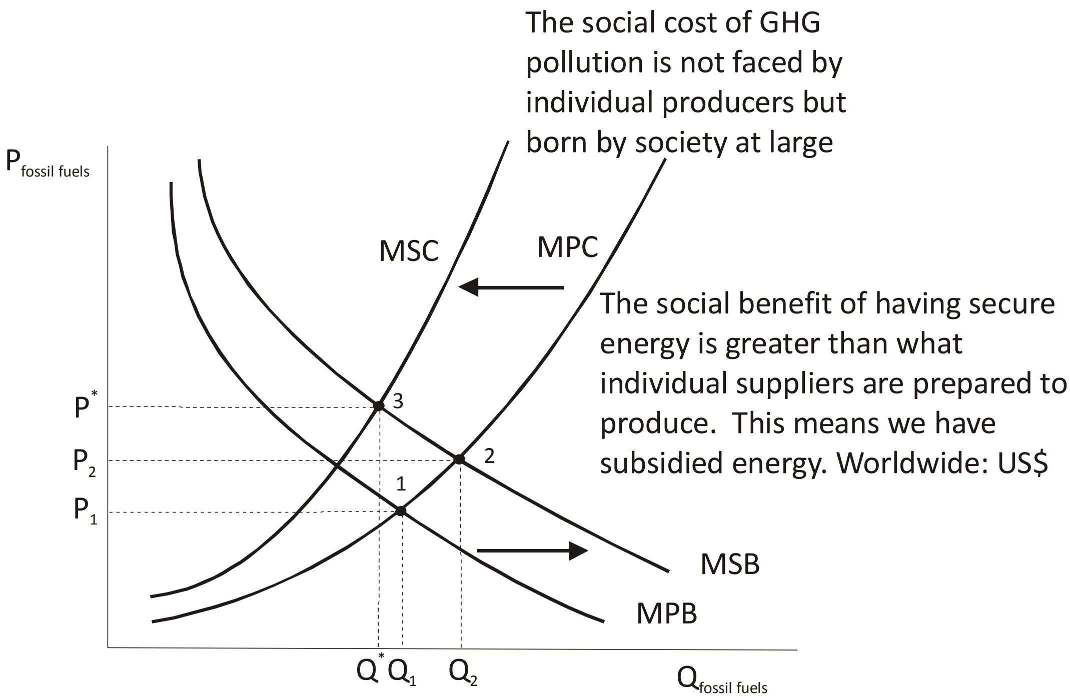
1970 data, it was clear that the average costs had fallen for the industry with the flat part of the curve beginning at around 15 billion kwh and around 24 out of 80 firms producing in this range. This means many more firms were operating in the part of the curve where returns to scale are not an important phenomenon, indeed 5 firms were operating a point of diseconomies of scale beyond point *b* at around 34 billion kwh. This suggests scale economies were less important for explaining falling average costs in 1970 compared with 1955. For firms already exploiting returns to scale, declining average costs must be explained by other factors such as falling prices for coal and oil or effects of learning and technological improvement.

2.8 The theory of market failure

One interesting observation from Table 2.2 is the rise in relative prices for electricity for end users in Europe compared to the United States over the last decade. Given that we would not necessarily expect production costs to be that different across countries how can we explain these differences? One possible explanation can be provided by the theory of market failure and the case for government intervention in electricity markets.

When society values something more highly than the sum of the amount that the individual or company value it, economists call this an *externality* (i.e. the value is external to the decisions made by the individual agent). These can be positive, as in the case of education or research and development, or negative as in the case of GHG pollution. In the case of the positive externality, society demands more of the good or service in question than will be provided naturally by market interactions. However, in the case of the negative externality, society demands less of the goods or services produced (in our case high-carbon energy from fossil fuels) than what will naturally be provided by the market. This is because energy supply firms do not automatically face the costs their GHG impose on others by increasing the risks of global warming. These externalities can therefore be described as leading to *market failure*: failure to adequately protect the environment; failure to support education or R&D; and failure to supply adequate healthcare – all these are good examples of (bad) market failures. Diagrammatically, the negative externality associated with climate change and fossil-fuel energy production is shown in Figure 2.9 by the deviation of the marginal private cost curve (MPC) from the marginal social cost curve (MSC).

Figure 2.9 The theory of market failure



However, energy production also has a positive externality associated with it because of the large public benefit of having continuous, uninterrupted energy supplies; this requires producers to maintain a surplus capacity above what they would provide as normal profit-maximizers. This means a marginal social benefit curve (MSB) lies above the marginal private benefit curve (MPB) of energy production. This theory of externalities helps explain the evolution of energy provision. Historically, governments have subsidized energy production to ensure that a stable supply is guaranteed at reasonable prices. This has shifted the 'free market' equilibrium from 1 to 2 in Figure 2.9. For example, the Global Subsidies Initiative has estimated that the size of global energy subsidies for fossil fuels could be in the order of US$600 billion per annum in 2006 (Doornbosch and Knight, 2008). Now that society has become aware of the climate change problem associated with the burning of fossil fuels (the MSC moves outwards with time as our understanding of the higher costs of climate change increases), the socially desirable level of production moves from Q2 to Q*. Note that moving to this point requires imposing a higher price on fossil fuels *and/or* lowering the existing subsidies used in the first place to ensure a stable and secure energy supply. Note that the socially desirable, or optimal, level of pollution is positive. This means that society is prepared, in this case, to tolerate some pollution in exchange for the benefits of the energy provided. However, this need not be the case. The optimal level of pollution would be zero when the MSC curve was above all points on the MSB curve. This would become the case in the event that costs of climate change become larger and more immediate than currently understood. Because most of the costs of climate change occur in the future and vary across geographic locations – differing views as to how to deal with the external costs of GHG are common. While in an idealised world, the magnitude of the externalities involved in energy production might be able to be estimated through some sort of scientific evidence, in practice, the degree to which a society values these externalities is significantly informed by normative political processes. Some of the theoretical and practical dimensions of this are discussed later in this thesis, however, suffice to say for now that the changing balance of subsidies and environmental charges are likely to be important driving forces behind the change in relative prices observed in Table 2.2 and thus the nature of the technologies that underpin the energy system.

2.9 Technology and economic growth theory

The next major vein of study on the nature and direction of technological change to be reviewed draws on the body of work which investigates the question: what makes economies grow? At the heart of this lies an understanding of the process by which economic change occurs, and the extent to which it can or should be shaped by government policy. This section will be organised as follows: first, a brief history of economic growth theory will be presented, beginning with the classical economists of the industrial revolution then moving onto the post-war development of neoclassical growth theory. The main limitations of the neo-classical model – particularly that technological progress is independent of the activities of economic agents - are then reviewed, which provides the context for a review of post-neoclassical, ‘endogenous’ or ‘new’ growth theory. While there are several currents of research which flow from this point, their common theme is that firstly, technological advancement is central to explaining economic growth; secondly that incentives significantly impact on the development of new technologies; and thirdly, that investment in capital (and its inherent technology) is linked to other areas of the economy through the diffusion of capital (i.e. that there are significant technological spillovers, or positive externalities).

From this Chapter on *Equilibrium*, the foundation principles underpinning the field of *evolutionary economic geography* can be fully appreciated – that history, institutions, scale and geography matter in understanding how and why economies grow or not in the diversity of ways they do. Chapter Two thus provides a solid basis on which the critique of neoclassical concepts can be made. From here, Chapter 3 on *Evolution*, is a natural next step in responding to the limitations of equilibrium thinking and more fully understanding what makes the economy grow and how growth can be shaped towards a 'greener' nature.

2.10 Classical growth theory (late 1700s to early 1900)

The foundations of classical economics were laid down by a number of celebrated scholars writing in the context of the industrial revolution including: David Hume (1742[1987]), John Stewart Mill (1848[1909]), David Ricardo (1817[1821]) and Adam Smith (1776[1904] and (1759[1790]). The basic theoretical framework they worked within set out that economic output can be described by the amount of primary inputs: capital (K), labour (L) and natural resources (N) available and the productivity of these inputs, which can be expressed through a production function of the form:

$$Q = F(K,L,N) \qquad (2.9)$$

David Ricardo made familiar the notion of diminishing returns: that bringing an additional acre of land into production would generate a diminishing increase in output as production. Robert Malthus (1798) focused on the fixed amount of land (N), which, he theorised, would ultimately constrain agricultural production, the availability of food, and thus put a cap on population (the labour force) and ultimately the potential for economic growth. Malthus's theory – which earned economics its moniker 'the dismal science' - has been carried forward in a form by the 'Club of Rome' and Limits to Growth theorists (Meadows *et al.*, 1972 and Meadows *et al.,* 2004). At the time it was written, Malthus's work seemed logical as well as consistent with past empirical experience. The world catapulting into the modern scientific era was, however, about to radically change.

Rather than focusing on natural resources, Adam Smith chose to concentrate his theory on how increasing amounts of labour and capital stimulate growth. This was through a direct effect on output, but importantly also through the indirect effect of the market mechanism – the process of exchange which would permit 'the greater division of labour and the great increase in the quantity of work that results' (take a moment to inspect a £20 note if you have the chance).

At the time of these works, many scholars were also shocked by the social horrors and environmental despoliation caused by the industrial revolution. While this spurred Friedrich Engels, a wealthy cotton mill owner, and Karl Marx to write the politically charged *Communist Manifesto* (1848[1888]) – Marx's *Das Kapital* (1867[1938]) focused on the role of capital accumulation and specifically on technological innovation in the steam, iron and steel industry, positioning him as one of the prescient classical economists regarding technology and growth theory.

Despite these antecedents to modern growth theory, understanding the process of economic growth is not held to be a particular strength of the early theorists who are generally perceived as being more focused on understanding resource allocation or class conflict, than on the process of growth per se.

It is at this point, sometime around 1900 and WWII, that theory is often characterised as dividing into two distinct paradigms:

- The mainstream, or neo-classical approach based around increasing mathematical formalisation of economic behaviour through the equilibrium analysis of the utility or profit maximising behaviour of individuals and firms. Under this theory, technological change is generally perceived as an abstract process which lowers costs by increasing efficiency; and
- A minority or heterodox approach which placed innovation at the centre of understanding the process of economic change, most significantly represented by the work of Joseph Schumpeter who described the process of '*creative destruction*' whereby a gale of technological innovation sweeps away old methods and businesses, introducing more productive new ones.

2.11 Neo-classical theory (1950s – 1980s)

The major strengths of neo-classical growth theory are its simplicity and internal consistency. Based on the model set out by Robert Solow (1956) and Trevor Swan (1956) growth in economic output is modelled as a function of growth in two inputs:

capital and labour; and how effectively these inputs are used through the use of technology. Subject to the *law of diminishing marginal returns*, more inputs, mean more output, so the growth in the economy will depend on the accumulation of capital and labour inputs over time. Accumulating physical capital requires investment, funds for which are derived from savings; and the accumulation of labour depends on the size of the labour force and on their capabilities, the latter of which becomes more important, the less manual power is required to do the job in question. The rate at which the capital stock and labour force grow, are both a function on the incentives on one hand to invest rather than consume (interest rates) and to work rather than leisure (wage rates) on the other. The relationship between inputs and outputs is shown by a *production function* for the entire economy, and while this aggregational leap requires some additional and awkward assumptions to be imposed - the conceptual framework it provides is a production function of the form similar to Figure 2.4. The key components for growth in output can therefore be expressed by the following expression, know as the *Cobb-Douglas* (1928) equation:

$$GDP = Y = Q = A \, . \, L^{\alpha} \, . \, K^{\beta} \qquad (2.10)$$

Here GDP in any one time period is equivalent to income (*Y)* which is the same as output across the economy (*Q*) which is a function of labour (*L*), capital (*K*) and *total factor productivity* (*A*). α and β are the *output elasticities of labour and capital* which describe how much output changes for a given change in either input and are constants which are determined by the available technology. When α and β add up to 1 then there are constant returns to scale in the economy; when their sum is less than 1, then there is decreasing returns to scale; and when their sum is greater than one, it implies that increasing returns to scale are present. Assuming perfect competition and constant returns to scale, α and β can be shown to be labour and capital's share of output. Total factor productivity (A) refers to all the forces that increase output that are not explained by labour and capital. For example, a year of good weather will typically mean agricultural output is higher than in a year of drought. If all inputs are considered, then A can also be thought of as representing a measure of the increase in output attributable to technological advancement – getting more output out of the same inputs. However environmental services are not always considered as inputs in economic models – so, if this was the case, A would include the change in production to good weather, or improved ecosystem services, in addition to technology.

In this model, the growth of L is taken to be exogenous (that is driven by forces outside the model) and described by the population growth rate. The change in the capital stock from period to period is usually given as a constant fraction of output in each time period which, if positive, can be thought of as describing the savings and investment behaviour of economic agents. Technological progress (A), while acknowledged as a driving force of economic change is also taken to be an exogenous factor – that is, the model offers no theory or explanation of how or why A changes – it is random and uncontrollable. Furthermore, the aggregation process has introduced extra complexity as to *what exactly* the model is measuring. How, for example, does one measure units of output, labour and capital where there are vast differences in products, rates of capital depreciation and labour skills across the full scope of economic activities that constitute the economy? Furthermore, what is the impact of global capital markets, where savings and investment can be brought in from outside the economic system under investigation by the model? These real world complexities, mean that in the interests of parsimony, the basic model assumes a closed economy where all firms make identical products and product markets are characterised by constant returns to scale

Putting the issue of theoretical abstraction to one side for a moment, let us run through how the model works. If growth in the labour force is given by the rate of population growth, and technological change something that occurs independently of the model – growth in output will be the related to the change in capital stock, which is a product of savings and investment. Now assume there is a large increase in investment (financed through domestic savings, because we have also assumed a closed economy) which boosts capital and therefore growth. Output moves to a higher level and growth accelerates- however, unless the labour force is increasing too, the law of diminishing returns (see Figures 2.3 and 2.4) means that the increased growth rate will not be sustained, the marginal productivity of capital declines, investment is lowered and while on a higher level, the economy settles back down to its equilibrium growth rate.

To be sure, in passing this model down in teaching and research, the limitations imposed by these assumptions have been highlighted, and numerous empirical studies have been conducted to test its robustness as a theory for explaining change in the economy. For example, Solow himself (1956) attributed a full four fifths of post-war growth in the United States to "technological progress" (A) and other studies, after adjusting for improvements in the quality of inputs (including increasing education levels), still found more than half of output growth is attributable to technological progress (Jorgenson and Griliches, 1967; Jorgenson and Yip, 2000).

Robert Lucas (1988), the Nobel Laureate responsible for developing and applying the theory of rational expectations) describes his objective as “the construction of a mechanical, artificial world populated by interacting robots” (quoted in Kay, 2011). The models are designed to isolate analysis on particular issues of interest by excluding confounding factors, because it is too difficult to study everything at once, rather than offer a complete description of the way the economy actually works.

However, despite these qualifications, the standard model has had a profound influence on policy makers, as it has been used a framing device by advisers close to decision-makers. Several “policy implications” have flowed from the basic neo-classical growth model. The first is the so-called The ‘Golden Rule’ - that the government should aim to achieve a national savings where the rate at which the reduction in per capita consumption due to the next dollar of savings is exactly offset by the increase in per capita consumption which the greater level of output makes possible.

Flowing from this is the policy ideal that once the ‘Golden Rule’ is attained, governments can do little to influence the long-run growth rate. To get to this optimal level, they should focus on ensuring the economy is operating as close as possible to the conditions of perfect competition which the model assumes, thereby improving the allocation of resources. This includes acting to correct for market failures. Such actions lead to *level effects* by increasing the long-run equilibrium output level. They can be distinguished from *growth effects*, which hold that only technological progress can change the long run growth *rate* (Lucas, 1988).

This holds important implications for attitudes towards the desirability of fiscal stimulus which are usefully summarised by Professor Cochrane (2009) from the University of Chicago:

> … if money is not going to be printed, it has to come from somewhere. If the government borrows a dollar from you, that is a dollar that you do not spend, or that you do not lend to a company to spend on new investment. Every dollar of increased government spending must correspond to one less dollar of private spending. Jobs created by stimulus spending are offset by jobs lost from the decline in private spending. We can build roads instead of factories, but fiscal stimulus can't help us to build more of both. This is just accounting, and does not need a complex argument about "crowding out". Second, investment is "spending" every bit as much as consumption. Fiscal stimulus advocates want money spent on consumption, not saved. They evaluate past stimulus programs by whether people who got stimulus money spent it on consumption goods rather save it. But the economy overall does not care if you buy a car, or if you lend money to a company that buys a forklift.

Professor Cochrane goes on to note, "… in fact economics, as written in professional journals, taught to graduate students and summaraised in the text books abandoned fiscal stimulus long ago". He goes on to argue that:

> Looking across the world, large government deficits and spending are clearly not the keys to economic health, and evidence of stimulus effects over time in the United States needs to be reconciled with this supreme lack of evidence across countries.

However, even Professor Cochrane, the arch-advocate against fiscal stimulus, acknowledges that there is still an important role for government in correcting for market failure:

> My analysis is macroeconomic, and does not imply anything about the specific virtues or faults of the Obama teams's spending programmes. If it's a good idea to build roads, build roads. If it's a good idea for the government to subsidise green technology investment, then do it (but keep in mind the internet did not spring from industrial policy to improve the post office, the word processor didn't come from a public-private consortium to rescue the typewriter industry and that a huge carbon tax is more likely to spur useful green ideas, and the only way to spur conservation.

Overall, the outcome of this programme of research and teaching has generated a macro-economic policy culture supporting a general belief in small government and non-intervention – even in the presence of a major financial crisis and recession or depression. This has had important implications for the policies that might affect the nature and direction of technological change, because it has contributed to a default *laissez faire* policy position of "leaving it to the market" unless there is some very strong logic for policy makers to g intervene in their society's economic system.

Another major empirical problem for the neoclassical theorists, is that the model is unable to explain heterogeneity between countries – particularly between rich and poor counties. One of the key insights of the neoclassical framework, is that in capital poor countries, the marginal product of capital will be high relative to rich countries which have already attained a high level of capital accumulation. According to theory, returns from investing in these capital poor countries would be higher than in capital rich ones, and so investment would flow in, leading to a convergence at the long run equilibrium growth rate. Instead, the vast record of historical experience points to increasing divergence between rich and poor rather than convergence (Lucas, 1998). There are, however, some important examples of growth following the neoclassical pattern. These include: the European countries during the post-war reconstruction years, Japan and South Korea from 1965 onwards and, more recently, perhaps the 'catch-up' growth currently being experienced by China. Gossman and Helpman (1994) term this type of growth as belonging to a medium term or *transitionary phase*, where capital accumulation plays an important role in growth between technological breakthroughs. After this capital accumulation catch-up phase is complete, the long-run growth rate is determined by the rate of technological innovation, which requires investments in research and development.

Although in the standard macroeconomic model, the long-run growth rate is perceived to be beyond the influence of policy, the microeconomic theory of market failure does provide a rationale for government intervention to improve the allocation of resources. With this modification, market failures especially in the area of research, development and deployment of new technology, and in education, mean that not only can government influence the level of output in the medium term, it can also influence the long-run growth rate as well. To explore this further we now move onto post-neoclassical endogenous or 'new' growth theory and further towards research currents in economic geography.

2.12 Post neo-classical growth theory (1980s onwards)

In this section we pick up on the second major current in economic research, mentioned earlier, which sits in contrast to the neoclassical school, which builds significantly on the ideas of Joseph Schumpeter (1942) that:

1) Economic incentives impact on the development on new technologies; and
2) Investment is linked to other areas of the economy through the diffusion of technologies.

This is done first in the context of 'new' or 'endogenous' growth theory which endeavours to respond to the weaknesses of the neoclassical growth models by trying to include into the model theories which better explain the role of technological innovation (Romer, 1986, 1990) and the role of human capital (Lucas, 1988). The basic proposition is that agents will not invest in new technologies unless they see it as being profitable – whether this is 'off-the-shelf' technology or basic research and development. These models attempt to show how the rate at which agents invest in technological innovation significantly influences economic growth.

When considering new growth models, it is important to understand the three elements which are thought to drive technological change. They are:

- investment in physical capital;
- investment in human capital; and
- investment in research and development.

What these different types of investment have in common, is that they all are a result of decisions by agents in the economy to act based on incentives. While there may be some overlap, it is useful to outline the key characteristics of each category:

Physical capital includes all tangible productive assets, such as machinery, plant and equipment. De Long and Summers (1991) postulate that if the economy is well below its technological frontier, there are likely to be substantial gains to be made from investing in new technology and new capital. Note that physical capital embodies technological characteristics, but here we are talking about the diffusion of a technology, rather than investment in the generation of a new technology.

*W*hile many leading theorists differ in their definitions of *human capital*, it is generally understood to be to stock of human know-how resulting from education and training. Romer (1989) broadly defines human capital as research technology; Lucas (1988) defines it as general knowledge; and Grossman and Helpman (1994) suggest that it can be thought of as a measure of the effectiveness of the labour force. Pomfret (1997) has also emphasised health and nutrition in building human capital. While most obviously relevant for developing countries, with weak educational institutions, this is also an issue for advanced economies where mental health and dietary problems may be impeding economic growth.

Research and development: is defined by the OECD (2008) as the "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications". It can also be thought of as an investment flow which adds to the stock of human capital. It can be thought of as including the following components: the retraining of skills; general process development; specific, applied industrial research; development of new technologies; research into the adaption of new technologies and market analysis.

As human capital accumulates, the productivity of the labour force can be considered to increase, expanding the research and development being conducted and potentially leading to the deployment of new technological innovations which get manifested in the stock of physical capital. This can lift both the level and rate of growth in the economy.

2.13 Technological externalities

Technological externalities or *spillovers* can be said to exist where the market supplies too little of the technological investment in question. In such cases, neoclassical theory suggests there is a role for the government in supporting technological change.

For example, technological externalities in physical capital could arise where diffusion of an innovation is being held back due to the lack of critical mass and *network externalities*, or where *path dependency* from investment areas where high sunk costs are a feature of the market.

Secondly, technological externalities in human capital are likely to exist because the benefits to society of a highly educated or trained individual are greater than the sum of the benefit of that education to the individual. For example, Theodore Schultz (1975) investigated the ways in which education and experience influence people's ability to perceive and interpret events and incentives, and reallocate their resources accordingly. Education helps not only help create and secure job opportunities, but can assist with family planning, staying healthy as well as contributing to the general stock of innovation-producing human capital.

Thirdly, technological externalities in research and development are likely to exist because technologies are often *nonrival*, meaning one person's use of the technology need not exclude another person from using the same technology; and *nonexcludable*, which means property rights with respects to the technology are often difficult to enforce. Because firms are assumed to be profit maximisers, they will only invest in research and development if they can capture sufficient economic rents from the effort. As this investment is likely to have broader applicability which would benefit the rest of the economy, positive spillovers are likely to exist. Isaac Newton's "standing on the shoulders of giants" is an apt metaphor here.

2.14 The 'New' Paradigm

As already mentioned, the 'new' growth models arose as a response to the confining and unrealistic assumptions of neoclassical growth theory. The word endogenous, seeks to highlight that the 'new' models set out to include forces such as technological change into the explanation of economic growth in a more meaningful way. This followed the same trends in other branches of economics, in particular industrial organisation (Dixit and Stiglitz, 1976) and trade theory (Krugman, 1980). Dixit and Stiglitz introduced the notion of *monopolistic competition,* where firms offer slightly differentiated products which mean they have a small amount of market and pricing power. They also allowed for increasing returns to scale to allow for the situation where firms have fixed costs. Paul Krugman took this notion and applied it to international trade and industrial location ('new trade theory' and 'new economic geography' (Krugman, 1991a, 1991b; Helpman and Kruman, 1985). Of course, there was nothing particularly 'new' about the notion of increasing returns, and its explanation as to why people and industries might tend to locate in particular clusters – and that this would be, not coincidentally, where growth might also be located (Fujita, et al., 1999). What this wave of research represents is a reassertion of microeconomic foundations onto the macroeconomic models which had assumed away too much of the real economy in the quest for increased aggregation and the formalisation of behavioural relationships which, over time, had lost touch with the actual mechanics of economic change.

2.15 Endogenous growth theories

In addition to technology being an endogenous feature of new growth theories (i.e. something that responds to incentives, rather being left exogenous or, metaphorically, 'descending like manna from heaven' to influence economic growth), Schumpeter's idea of *creative destruction* also plays an important conceptual role in new growth theories. Hirschman (1958) first applied this concept to a formal growth theory by postualting that new technological knowledge and artefacts would destroy the usefulness of old investments and facilitate other further investments based on the new idea. Kennith Arrow (1962) also highlighted how knowledge benefits not just the firm investing through 'learning-by-doing' but also those in the wider economy who 'learn-by-watching'. This spillover knowledge is regarded as an explicit factor of production in new growth theories and is the technical escape route from the Malthusian trap into a world of increasing returns. For example, with this theory we can better explain snowballing virtuous cycles of growth which help understand why economic outcomes can vary so much across different countries and tend to be centred in certain areas within countries.

Paul Romer has developed several models of endogenous growth which place particular importance on investment in education and training and research and development in improving the production process and thereby stimulating the rate of long-run growth. In his model (1990) he assumes knowledge to be partially rival – that is, monopolistic profits can apply to the firm that creates the knowledge but for others externalities occur. In this model, knowledge is responsive to incentives and Government policies which work through stimulating this investment, can also affect economic growth.

Robert Lucas (1988) differs from Romer in his treatment of the proximity of the learning process to the production process. Defining human capital as a *public good*, he stipulates that externalities in production occur due to average level of human capital, which helps drive the growth rate. The more technologically advanced the production activities, the greater the externalities. An early quotation from Thomas Jefferson (1813) making such a point has become well-known:

> If nature has made any one thing less susceptible that all others of exclusive property, it is the action of the thinking power called an idea, which an individual may exclusively possess as long as he keeps it to himself; but the moment it is divulged, it forces itself into the possession of everyone, and the receiver cannot dispossess himself of it. Its peculiar character, too, it that no one possesses the less, because every other possesses the whole of it. He who receives an idea from me, receives instruction without lessening mine; as he who lights his taper at mine, receives light without darkening me. That ideas should freely spread from one to another over the globe, for the moral and mutual instruction of man, and improvement of his condition, seems to have been particularly and benevolently designed by nature, when she made them, like fire, expansionable over all space, without lessening their density at any point, and like the air in which we breathe, move, and have our physical being, incapable of confinement or exclusive appropriation.

Furthermore, this body of work suggests that if a person is working with others with a high level of education, the pay-off from getting a higher-level of education is will be greater and *visa versa.* The incentive to invest in one's own human capital depends on the decisions of others. Viewing human capital in this way may be particularly relevant in understanding growth (and the lack thereof) in developing countries where education is low.

2.16 The theory of induced innovation

Schumpeter distinguished three stages in the process of technological change.

1) Invention: the act of creation of a new technology;
2) Innovation: the commercial introduction of the new technology; and
3) Diffusion: the gradual introduction of the new technology

The theory of induced innovation is a hypothesis which seeks to explain the direction of the technological change underpinning invention through the impact of factor prices (Ahmad, 1966; Kamien and Schwartz, 1968; Binswanger, 1974). According to the theory, increased use of an input leads to an increase in the proportion of cost that that factor occupies in the production process. Increasing prices for that factor may also follow, along with the diminishing marginal productivity as it is used more in proportion to other inputs. The higher proportion of input costs and higher unit prices for that input due to scarcity, stimulate effort in research and development with respect to that input. This in turn leads to diminishing returns to research and development in that area, but also drives technological change in order to lower production costs and increase profits. Taken in terms of Figure 2.3, the theory can be seen as modelling the quantity of research and development undertaken on each input, rather than the input itself on each axis.

It is worth noting at this point that, aside from the addition of the spillover externality with 'new' growth theory, and the explicit modelling of research and development by the induced innovation theorists, these two groups of theory broadly maintain the same form and feel of their neoclassical counterparts. Technological change derives from research and human capital, which are responsive to incentives – usually exclusively modelled as price incentives. 'Technology' is put alongside labour and capital as a stock variable in the production function (equation 10) or built into the efficiency in which other inputs are used. Because technological 'spillovers' exist the policy and microeconomic implications of this analysis aligns neatly with the neoclassical framework and the divergence between marginal private and social benefit in Figure 2.9, which justifies government action. This sits in contrast to the general conclusion taken from macro-economic studies (Cochrane, 2009), which de-emphasise the microeconomic foundations of growth in the macro-economy.

2.17 Conclusion

In the introduction to Part One, competing notions as to the role of technology in society were introduced in dialogue form, with the 'free-to-choose' proponents on one side, and the technological determinists on the other. Behind each of these conceptions are ideas or theories from the social sciences, which this thesis aims to illuminate, make explicit and critically discuss. Chapter 2 has introduced some of the main theories which trace the path of neoclassical economic theory in this debate, and how it has shaped some of the major currents in policy-thinking. One important manifestation of this is the so-called 'golden rule' of macroeconomic policy, that governments can do little to influence the long-run growth rate in the economy, other than help achieve a level of national saving where the rate of reduction in per capita consumption from the next dollar of savings is exactly offset by the increase in per capita consumption which the extra output makes possible. It is argued, that despite the rich vein of microeconomic studies in the area of market failure, particularly in the area of innovation, such prescriptions as the 'golden rule' have helped propagate a laissez faire culture of 'letting the market decide' in policy circles. One manifestation of this are the current debates over ‘austerity versus fiscal stimulus’ – at play is the state’s perceived ability to play a constructive role in the allocation of capital in the economy.

One of the recent major counter-movements to this neoclassically-based laissez-faire policy culture have been the so-called ‘Green Growth’ strategies, implemented by many governments as a response to the 2008 financial crisis and economic recession. Faced the escalating economic crisis, in 2009 governments around the world had allocated around $US 512 billion to green investment measures across transport, energy and building projects (Bernard et al., 2009).

Supporting this shift in thinking, the OECD (2012) has outlined four key elements providing the rationale of applying green growth strategies in the energy sector.

The OECD’s message to national governments is that tailor-made energy policies to manage the transition to green growth in the energy sector make an important part of environmental and economic policy. This would seem to go some way towards calls from within economics and beyond to ‘end the taboo and have an industrial policy again’ (Coyle, 2011). However, as the OECD notes, the challenges to design and implement such a policy package with a consistent framework are considerable (OECD, 2012:13):

> Many energy systems are “locked-in” to high carbon production and consumption patterns that can be difficult to break for reasons that go beyond simple economics. Making reform happen will require attention to some common political economy challenges…

Having articulated the basic framework of ‘simple economics’ in Chapter Two, Chapter Three will go on to explore the evolutionary elements of what a ‘consistent policy framework’ for implementing green growth strategies might look like. This conception of a consistent approach, is what is set out in Chapter 1.

Chapter 3 Evolution – path dependency and new path creation in a complex adaptive system

3.1 Introduction: Inside the technological 'black box'

Given how deeply impregnated our world is by technological objects, it is easy to take for granted the nature and processes from which these objects have become established. Fundamentally, there seems to be something inherently human about technology and the process of finding new and better ways of doing things. Some theorists have gone so far to suggest that technology is not just the driving force of economic change, but the driving force of all history (technological determinism) – and others, in biological anthropology, have observed (with a good dose of hubris attached) that technology can be considered the evolutionary feature that separates humanity from every other creature on earth giving us the power to control and shape the world around us. For example, Aunger (2010:762) writes: "the best chimpanzees can do on the technological front is use small stones to break nuts open on large stones, whereas humans build sky-scrapers and rocket themselves to the moon". When one thinks of what our lives would be like without airplanes, computers, washing machines or refrigerators the significance of technology is immediately apparent. This is not to mention the innovations that gave us agriculture, an alphabet and printing. Despite its fundamental underpinning of modern life, the role of technology has been curiously underplayed in mainstream economics – viewed as important, but exogenous; or seen through some relatively abstract or aggregate measure of capital accumulation. Such conceptualisations of technology within economics has led to the description of the innovation process as a "black box" and left to economists outside the neoclassical mainstream (e.g. Rosenberg, 1999), and to other disciplines (e.g. MacKenzie et al, 1985; Winner, 1985; Bijker and Law, 1992; Bijker *et al*. 1987).

This notion of a "black box" is exemplified in the section above on 'new' growth theory where we saw how human capital was added to the neo-classical model to help explain a large proportion of economic growth left exogenous in the Cobb-Douglas production function. However, even in these 'endogenous' models, technology is still viewed as a fairly abstract aggregate concept related to research and development or education and training. But for many practical purposes, such as an interrogation of the forces behind change towards low carbon development – a more relevant unit of analysis is likely to be a specific technology such as wind turbines, power stations, electrical appliances, and so on. To proceed along this second vein of research in the social sciences, we can bring together a group of theories which provide greater contextual detail than neoclassical theories – which this review will broadly classify under the banner of *evolutionary theories*.

3.2 What is technology?

Despite its pervasiveness, technology can lend itself to a variety of definitions – thus the need to explicitly state what we mean when we speak of 'technology'. Generally speaking, it can refer to: a specific naturally occurring *object* such as a reed used as a straw for drinking or a man-made *artefact* such as an electric light bulb; it could be a *set of activities or processes*, such as electrical power generation, or finally it can refer to a set of *general knowledge* or skills associated with the production or use of technologies, such as the engineering expertise associated with power plant design and use, as well as the broader social and cultural processes associated with the electricity industry (Kuper and Kuper, 1996; Winner, 1985).

So far, the way technology has been conceptualised within neoclassical theory is as an improvement in labour or capital (or some other input) which allows the individual or firm, and by extension the entire economy, to get *more with less*. Technologies are embodied in inputs and products (such as energy or an appliance) which make up the production function and, in the case of consumables, are subject to individual preferences which are the focus of demand. However, despite placing technology and technological change at the centre of what drives the economy forward, the neoclassical model has surprisingly little to say about *what it actually is*. Indeed, an important limitation of the neoclassical explanation of the economy is that it does not seem to capture particularly well the qualitative dimensions of technological change and economic growth. As Rosenberg (1999:3-4) writes:

> The great bulk of the writing by economists on the subject of technical progress – both theoretical and empirical – treats the phenomenon as if it were solely cost reducing in nature, that is, as if one could exhaust everything of significance about technical change in terms of output per unit of input that flow from it. Technical progress is typically treated as the introduction of new processes that reduces the cost of producing an essentially unchanged product.

For instance – an economy may build its energy network on technologies which significantly differ between countries – France's electricity is 80 per cent nuclear, in

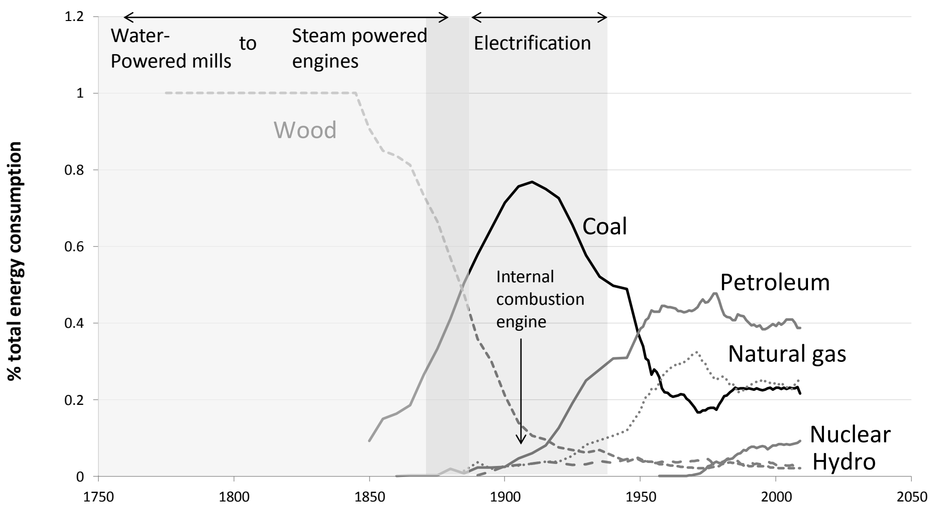
Russia natural gas dominates, in Brazil biofeuls are used in cars rather than petroleum; the Danish specialise in wind turbines and in Australia coal is the preferred energy source. These are important differences, because while two countries may be otherwise equal in terms of GDP and GDP growth, there are large differences in *how* they source their growth. Furthermore, differences between product quality and the variety of products available, while not contributing necessarily to GDP growth, may have a major impact on economic welfare in a broader sense. Low carbon energy, sourced from stable and preferably domestic suppliers, is qualitatively different from oil shipped in from an unstable state with conflicting political values to the importing country. These qualitative differences are not easily picked up on by the price mechanism. This lack of recognition may then find political expression as hitherto un-priced and escalating externalities start to be to be accounted for; or as agents struggle to secure contested political and natural resources associated with specific technologies. To understand these differences better we need a more detailed theory and taxonomy of technology and technological change.

3.2.1 General and specific purpose technologies

The first step we will take in further defining the nature of technology will be to classify it along a spectrum which identifies the breadth of its application using Bresnahan and Trajtenberg's (1996) notion of general purpose technologies (GPTs). These are seen to have three characteristics. Firstly, a GPT should be pervasive, in that it should spread to most sectors of the economy. Secondly it should get better with time, that is be subject to continual improvement; and thirdly, a GPT should make it easier to invent or produce new products or processes.

While almost all technologies have these characteristics to some degree, this concept is valuable at placing technologies along a spectrum ranging from general to specific purpose, which can give an indication of its potential productivity implications. In the non-energy space computer technology provides one of the most ubiquitous examples of a GPT. In the energy space, moving from general to specific we might have electricity; the electric motor; the electric lamp; and the electric toothbrush. Each of these technologies is necessary for me to effectively brush my teeth before bed, but some are more specialised (or general) than others. The more 'general' the GPT, the greater the potential for *innovation complementarities* and the greater the potential effect on economic growth. Such complementarities are said to exist when the productivity in a down-stream sector increases as a consequence of innovation in the GPT; these complementarities magnify the effects of the innovation, and help propagate them through the economy. In addition to electricity, commonly referred to GPTs for energy include: water, steam power; and the internal combustion engine. The use of the GPTs has influenced profoundly the underlying structure of energy demand in the economy with the advent of electricity in around 1890 and automotive transport in around 1909, with implications for coal and petroleum consumption respectively (Figure 3.1).

Figure 3.1 **History of Annual Energy Consumption in the United States 1775-2009**



Source: US Energy Administration Annual Review, 2009; Jovanovic and Rousseau, 2005

3.3 Process and product innovation: distinguishing between incremental (marginal) change versus radical (non-marginal) and qualitative change

In getting a fuller appreciation of the nature of technological change, we can also distinguish between *process innovations* and *product innovations* (Kamien and Schwartz, 1982:2). Process innovations are technological advances in equipment, techniques or software that reduce the cost of producing existing products or produce new, or significantly altered products (OECD, 2005). Product innovations more explicitly involve the development of new or improved products. Equivalently, the former may be thought of as an upward shift in the production function (as in Figure 2.4), and the later, as the creation of a new production function. In practice, the classification of innovation will depend on the perspective of the actors and level of analysis. For example, a new electricity source such as solar, wind, nuclear or geothermal energy may represent a new product innovation for the energy supplier – but for the energy consumer – say a manufacturing business they represent changes to input costs of doing business – a process innovation. In Figure 3.1, the shift from water powered mills, to steam powered engines, then to electricity as an energy supply source for the United States between 1869 to 1939 involved large qualitative shifts in energy supply. For those engaged in the production of energy, this involved the decline of old products and businesses and the rise of new ones – Schumpeter's process of creative destruction in action. However, for a manufacturing company, these changes meant a decline in costs and an increase in the flexibility of energy supply.

This distinction between incremental and revolutionary change underpins Schumpeter's attack on the primacy of price competition in defining a competitive market:

> But in capitalist reality, as distinguished from its textbook picture, it is not that kind of competition which counts [price competition] but the competition from the new commodity, the new technology, the new source of supply, the new type of organization (the largest-scale unit of control for instance) – competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives (Schumpeter, 1975[1942]:84).

Product innovations can have radical consequences for the sectors they affect. In the diagram above, water mills go out of business and are abandoned or transformed into tourist attractions as manufacturing becomes concentrated in large firms closer to markets; then manufacturers of steam engines face their own crisis and decline as energy consumers switch from steam to electric power, and industry is reconfigured again. We can think of many other examples, aeroplanes replace ocean liners for international transport; compact disks replace vinyl records; computers replace typewriters, electronic watches replace mechanical ones, and so on. This introduces the notion of non-marginal change into the analysis – where a product or service is either newly created, or effectively destroyed by a superior technological substitute. The more general purpose the technology for a given product innovation, the more profound its potential affect will be across the economy, boosting the so-called 'multifactor productivity' of the standard macroeconomic growth model.

3.4 Socio-technological change

In understanding the social dimensions of technological change, it is helpful to consider technology as having two inherent components: one relating to its *physical form* or properties; and the other related to a socially derived *functional identity*. (Faulkner and Runde,2009). A technology's physical characteristics are perhaps its most immediately obvious defining features. For example, a motor-car is an object which transports people from place to place propelled by the work of a motor; a telephone is an instrument for communicating verbally across distances and a light bulb (the very symbol of innovation) a device for illumination. Less obvious, perhaps, is the importance of individual agency at assigning *technological identities* to objects.

Drawing on John Searle's theory of social reality (1995, 1999, 2001) it is possible to highlight how people assign functions to objects or other entities. For example, Searle focuses on the use of pieces of paper for the functioning of money as one manifestation of this, however there are many others – a straw for drinking could just be a reed by a river bank, coal just a dirty rock; or a watch may just be an aesthetically pleasing trinket – each requires human agency and knowledge to assign it its purpose. The relevance of this second dimension is to highlight that if you do not know how something works, then it is not fulfilling its technological function, and it is not a technology (at least in the terms that it was designed for). For example, compact disks may be used as coasters or to scare away birds from fruit trees rather than for data storage. Following this logic, we can say that to have a meaningful identity, a technology must have both a form (its physical properties); and a function (people must understand how to use it).

Faulkner and Runde (2009) go on to articulate a taxonomy of technological *change* comprising of three elements:

1) Technological change manifested in the form of an object;
2) Technological change manifested in the function of an object; and
3) Technological change manifested by both 1) and 2).

The most obvious manifestation of technological change is change in the form of an object – either by the creation of a new one (the introduction of personal computers); or the adaptation of an existing one (desk-top PCs to laptop PCs). However, change in how objects are used is also a vital element in technological change. For example, a pilot will be trained to use jet engines to fly planes; but an engineer in an electricity power plant will use a similar technology to burn gas to create heat and turn a turbine. Similarly, computers can be used differently depending on a wide range of users: from writing, to a mechanism of transaction, to an instrument of war. In Denmark, the wind energy cluster evolved out of declining boat manufacturing businesses looking for opportunities to mould fibreglass. The key insight here is that we should think about technological change in broader terms than simply changes in the physical form of the object to include also the the rules and routines, both formal and subconscious, that govern the use of those objects - in other words on *institutions.*

3.4.1 Using institutional economics to help understand technological change

The tradition of institutionalism in economics has existed at least since the early twentieth century and the work of Thorstein Veblen who characterised institutional forces as 'settled habits of thought common to the generality of men' (Veblen, 1919:239). More recently, Rogers Hollingsworth (2000:601) describes institutions as the 'basic norms, rules, conventions, habits and values of a society' that organise and regulate human activity. Geoffrey Hodgson (1993:253) provides a definition of institutions as:

> ... the commonly held patterns of behaviour and habits of thought, of a routinized and durable nature, that are associated with people acting in groups or larger collectives. Institutions enable ordered thought and action

> by imposing form and consistency on the activities of human beings. ...institutions play an essential role in providing a cognitive framework for interpreting sense data and in providing intellectual habits or routines for transferring information into useful knowledge.

This institutional economics literature has also been informed by the Regulation School (Boyer, 1990; Boyer and Hollingsworth, 1999); related institutionalist streams within political economy (Maurice *et al.* 1986; Streeck, 1992; Zysman, 1994; Lane, 1997; Lazonick, 2001); the 'national business systems' approach (Wever, 1995; Pauly and Reich, 1997; Whitley, 1999; O'Sullivan, 2000, 2005;Lam, 2000, 2005); the national innovations systems literature (Freeman, 1987; Lundvall, 1992; Nelson, 1993), and the literature on the varieties of capitalism (Albert, 1993; Hall and Soskice, 2001).

In the domain of understanding technological change, what brings these threads of literature together is the view that technology, in addition to consisting of objects or artefacts, is also made up of the social relations and practices, the assumptions, beliefs, language and so on involved in that object's design, manufacture and use.

This institutionalist literature also formed the foundation for the challenging of the triumphal tales of scientific and technological progress (e.g. Kuhn, 1962). This 'social constructivist' body of work attempts to show scientific consensus or progress not as a product of disinterested inquiry, but as the pursuit of social interests.
In the 1980s Bruno Latour (1987, 1991, 1993) took these arguments a step further by proposing his 'actor network theory' which insisted not only (reasonably enough) on the central role of technological objects in framing the process of technological

change; but also (less reasonably) on the need to credit machines and instruments themselves with agency and motivation. This somewhat bizarre turn in the study on the nature and direction of technological change helped inspire other attempts in the sociology of technology to "recuperate" the persons and things marginalised or obliterated by the heroic tales of progress: women; technicians; routine investments; buildings and so on.

Elsewhere in the innovation literature, the *large technical systems* (LTS) approach developed the notion of the 'seamless web' as a metaphor to explain how the interactions between "heterogeneous elements" can explain the dynamics of big infrastructure systems such as electricity, rail and telephone networks (Hughes, 1983, 1987; Mayntz and Hughes 1988). A related approach is the *sectoral systems of innovation* framework which defines "system" as a group of firms active in developing and making a sector's products and in generating and utilising a sector's technologies' (Breschi and Malerba, 1997:131; Malerba, 2002). In yet another related approach, the *technological systems approach* looks at how 'networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology' (Carlsson and Stankiewicz, 1991: 111; Carlsson, 1997).

This work has culminated in what can be grouped under the banner of the "geographies of science", the focus of which is on the conditioning of the processes of technological and economic change by national institutional and geographical factors, and the way in which science and technology is distributed and moves between locations under study (Meusburger, et al., 2010).

It is well worth noting at this point that there are a range of views and analytical benefits regarding where to draw the line between seeing technology itself as an institution, which guides and shapes human action, versus seeing it as being distinct, albeit surrounded by, institutions.

In one of the most widely accepted, but stripped down definitions of institutions, Douglas North (1990:3-5) does not explicitly include technology in the humanly devised, formal and informal 'rules of the game' that constitute his conception of institutions. The important distinction that he does make is between the 'rules' and the 'players':

> The purpose of the rules is to define the way the game is played. But the objective of the team within the set of rules is to win the game.

In this context, technological change seems to be subject to humanly devised changes in the rules of the game (e.g. policies targeted at low-carbon technologies, such as carbon pricing) thereby giving ontological scope for human agency to shift technological pathways. This notion is developed further and made explicit by Gertler (2004:7-8) in his characterisation of institutions as:

> Formal regulations, legislation, and economic systems as well as informal societal norms that regulate the behaviour of economic actors: firms, managers, investors, workers. They govern the workings of labour markets, education and training systems, industrial relations regimes, corporate governance, capital markets, the strength and nature of domestic competition, and associative behaviour. . . . Collectively, they define the system of rules that shape the attitudes, values, and expectations of individual economic actors. Institutions are also responsible for producing and reproducing the conventions, routines, habits, and 'settled habits of

> thought' that, together with attitudes, values, and expectations, influence actors' economic decisions. . . . Although these institutionally shaped attitudes, values, and conventions influence choices and constrain decisions regarding practices, they do not wholly determine them. There is still a major role here for individual agency to produce a variety of responses within the same sector, region, and nation-state.

In contrast to this view where actors may select a variety of technological pathways; the social constructivist might argue that the individual is so deeply rooted within their social circumstances (including its embedded technologies) that they have little control to shift pathways. This view emphasises the formidable role of *path dependency* and *behavioural* barriers to technological change.

This discussion about institutions and technology brings us to one of the key points of contention in the social science discussion of technology: the degree to which society is shaped by technology (technological determinism); versus the degree to which society shapes or chooses different technologies (implicit in the rational actor model and the neoclassical theory of externalities). It is true that we inherit a world full of institutions and technologies: but what shapes technological development before it has its 'effects'? If technological objects are embedded in broader social institutions – how can we sensibly talk about technological change when so much else is involved than just the object? Perhaps these difficult questions help explain the enduring popularity of the neoclassical approach, despite its limitations, but to find potential answers to them – rather than assume them away - we must delve deeper into studies on the evolutionary nature of technological change.

3.5 Why is economics not an evolutionary science?

The alternative of the mainstream economic vision of the economy based around equilibrium with one of continual evolution can be traced back to Marx's *Capital* (1867[1938]) with his analogy of the economic system as a biological entity that is ever changing, in contrast to a chemical reaction, tending towards equilibrium.

Although, Marx viewed technological change as something that capitalists reacted to, rather than drove, he has been credited with providing one of the first glimmers of the *theory of competition through innovation* which was developed later by Schumpeter (Kamien and Schwartz, 1982). Indeed, in delivering his graveside eulogy, Engles claimed, "Just as Darwin discovered the law of evolution in organic nature, so Marx discovered the law of evolution in human society" (quoted in Bowles, 2004:400). However, Marx was not the only late nineteenth century scholar with an interest in applying evolutionary ideas to the social sciences. Thorstein Veblen (1898) posed the question, "Why is economics not an evolutionary science?" Prescient for his time, the essence of his criticism was that economic theory centred too heavily on static equilibrium analysis and offered little insight into the mechanics of change. As one of the forefathers of institutional economics, he remarked, "All economic change is a change in the economic community – a change in the community's methods of turning material things into account. The change is always in the last resort a change in the habits of thought" (quoted in Coyle, 2006:182).

While aside from the notable exceptions of the Austrian economists Joseph Schumpeter (1911[1982], 1942[1975] and 1954[1994]) and Freidrich Hayek (1974) and a few others others, including John Kenneth Galbraith (1958), for much of the twentieth century evolutionary theory remained very much on the edge of economic thought. More recently, the earlier doubts which had been expressed regarding the ability of the standard model to adequately explain change in the economy exploded into a full-fledged crisis during the near collapse of the financial system in 2008-2009 which was underpinned by a regulatory system based on the theoretical foundations of equilibrium and competitive markets (see conclusion).

Schumpeter, for example, was adamant that not only did perfect competition not actually exist outside the world economic models, but that it was also undesirable from policy standpoint:

> Thus it is not sufficient to argue that because perfect competition is impossible under modern industrial conditions – or because it always has been impossible – the large scale establishment or unit of control must be accepted as a necessary evil inseparable from economic progress which it is prevented from sabotaging by the force inherent in its productive apparatus. What we have got to accept is that it has come to be the most powerful engine of the progress and in particular of the long- run expansion of total output not only in spite of, but also to a considerable extent through, this strategy which looks so restrictive when viewed from the individual case and from the individual point of time. In this respect, perfect competition is not only impossible, but inferior, and has no title to being set up as a model of ideal efficiency. It is hence a mistake to base the theory of government regulation of industry on the principle that big business should be made to

> work as the respective industry would in perfect competition (Schumpeter, 1975[1942]:106).

Here Schumpeter makes the point that institutions built on the notion of perfect competition have within them sown the seeds of "sabotaging the force inherent in its [the economy's] productive apparatus". He argues that a degree of monopolistic competition (large-scale unit of control) is a desirable market structure in order to enable the firm to accrue the funds to invest or recoup the cost of innovative research and development. Schumpeter's argument is that this means that there is a logical incompatibility between entrepreneurial activity and perfect competition, as perfect competition implies the immediate elimination of excess profits through imitation. This underpins his idea that firms compete primarily through innovation, rather than through prices, because firms in most markets (which are beset with market imperfections in practice) realise the destructiveness of price competition on profits and tacitly tend to avoid it if at all possible.

In this area, one of the most prominent recent notions about how the economic landscape evolves over time has been the *theory of path dependence*. This is the basic idea that decisions taken today or in the past influence future decisions, closing off some options and opening up others, an idea championed particularly by Paul David (1985, 1986, 1988, 1992, 1993a, 1993b, 1994) and Brian Arthur (1988, 1989,1994a, 1994b, 1994c, 1994d). Although introduced by these authors as a way of characterising the evolution of technologies and technological standards, the idea has since been adopted and applied in a wide variety of other social science disciplines as a model of social, cultural, institutional, organisational, and political, as well as economic and technological evolution (Martin, 2010). Indeed, Martin goes so far to suggest that the spread of this concept, can be seen as part of a more general "evolutionary turn" across the social sciences reflecting a growing interest in how socio-economic systems change over time. This has involved a corresponding exploration of ideas, models, and metaphors drawn from modern evolutionary sciences, including evolutionary biology, complexity theory, and panarchy (e.g. Gunderson and Holling, 2002; Garnsey and McGlade, 2006;Wimmer and Kössler, 2006). Notions including: variety, novelty, selection, fitness retention, mutation, adaption and population dynamics thinking have been taken from evolutionary biology; the notions of far from equilibrium adaptive systems, emergence, self organisation, fitness landscapes and hysteresis have been taken from complexity theory; and adaptive cycles and resilience from panarchy (e.g. global governance systems theorists). What these various strands of theory all have in common is that, in a non-trivial sense, history matters.

Within economic geography, this evolutionary turn has had a significant influence (e.g. Boschman and Martin, 2007; Grabher, 2009; MacKinon et al., 2009) and the concept of path dependency identified as "one of the most exciting ideas in contemporary economic geography" (Walker, 2000:126). Ron Boschma and Koen Frenken (2006:280-81), major exponents in the emerging paradigm of evolutionary economic geography, see path dependency (along with generalised Darwinism and complexity theory) as a defining characteristic of their approach:

> … that it explains a current state of affairs from its history.... Thus the current state of affairs cannot be derived from current conditions only, since the

> current state of affairs has emerged from and has been constrained by previous states of affairs. Evolutionary theory deals with *path dependent* processes, in which previous events affect the probability of future events to occur (Boschma and Frenken, 2006:280-81, emphasis in the original).

Boshma and Martin (2007) echo the same question Veblen asked some 100 years earlier: "why is economic geography not an evolutionary science?" Here they argue for an economic geography which studies the processes and mechanisms by which the economy transforms itself from within. Three of the main criteria they list for research in this area include that firstly, there must be a focus on change rather than a static or comparative static analysis. Secondly, it must deal with irreversible processes, rather than '*dynamic'* in the neoclassical sense where markets frictionlessly and instantaneously adjust up and down demand and supply curves. Thirdly, they argue that it should focus attention on the generation and impact of novelty as the ultimate source of self-transformation. It is the creative capacity of economic agents and the creative function of markets that drive economic evolution and adaptation.

3.6 What is path dependency?

While the notion of path dependency has had a profound effect in the social sciences, it has benefited, or suffered (as you may), from a plurality of interpretations, so, as to not to misunderstand, misuse or abuse the notion, it is important to be clear what it is we mean by it. Two main views will be contrasted – a canonical view encompassing the work of David and Arthur based around the idea of ‘lock-in’ around a stable equilibrium, and an alternative view which emphasises the change and evolution of different pathways.

As set out by Harris (2004) and Page (2006) a path dependent process can be described in the following way:

$$\text{Path dependent process:} \quad x(t+1) = F_x(t)(h(t)x) \tag{3.1}$$

Where $h(t)x$ = {$x(t)$, $x(t$-1) .... x(0), $y(t$+1), $y(t$-1).... } is the history of past outcomes of *x* from some initial time (*t*=0), when the activity in question first emerged, up to the present time *t;* and any other factors, say *y*, that also shape the development of *x* over time; and $F_x(t)$ is the “outcome function” that maps the history $h(t)x$ into the next outcome. This outcome function is key in distinguishing path dependency theory from neoclassical theory, as it describes the extent and manner to which the history of *x* influences *x*’s future trajectory, that is, its evolution.

Although David’s model differs in certain respects from that of Arthur (Table 3.1), both share three fundamental commonalities which Martin used to characterisea “canonical model”. Firstly, the ”accidental” origin of new paths: path dependence is viewed as a nonergodic stochastic process in which initial small “random” or “chance” events, or “historical accidents”, have significant long-run effects on the technological, industrial and institutional structure of the economy. This view contrasts with mainstream neoclassical theory in which the past has no influence on current outcomes and the economy converges to a unique equilibrium no matter where it started from.

Table 3.1 Processes generating lock-in in the Canonical Path Dependence Model

David's Model "Network Externalities"	Arthur's Model "Increasing Returns Effects"
1. *Technical interrelatedness*: the reinforcing effects of complementary and compatibility among difference components of a technology and its use. 2. *Economies of scale*: the benefits associated with the increasing use of a technology – such as a decline in user costs – as the technology gains in acceptance relative to other systems. 3. *The quasi-irreversibility of investments*: the difficulties of switching technology-specific capital and human skills to alternative uses	1. *Large initial fixed setup costs*: in effect the inertial of sunk costs 2. *Dynamic learning effects*: learning by doing or using and learning by interaction tend to entail positive feedbacks. 3. *Coordination effects*: which confer advantages to going along with other economic agents taking similar actions. 4. *Self-reinforcing expectations*: when the increased prevalence of a product, technology, process, or practice enhances beliefs of further prevalence.

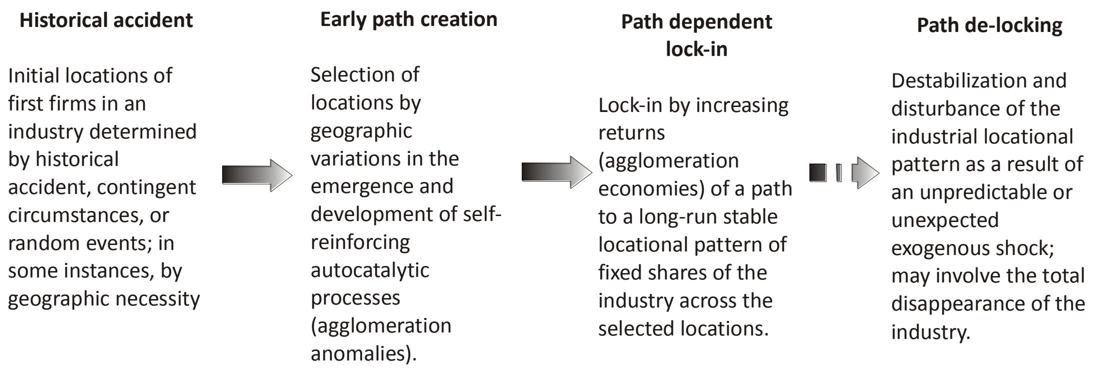
Source: Martin (2010)

Secondly, the notion of *lock-in*: once a path is "selected", path dependency is said to occur if that path or event becomes "locked-in" through the emergence and operation of various autocatalytic network effects (David's phrase); or through "increasing returns effects" (Arthur's phrase); and thirdly, the canonical model appeals to exogenous shocks to unlock paths. Once a industrial location or technology has achieved "lock-in" then it is assumed to persist and remain stable until it is dislodged by an exogenous "external shock" of some kind.

3.7 Equilibrium or evolution?

Arthur's version of this model, as he has applied it to the study of industrial location is set out in Figure 3.2 Here the outcome of multiple possible equilibria is determined by the "chance" location of the initial firms. Once agglomeration effects set in due to increasing returns, the technology or industry locks-in on to one of a multiplicity of equilibrium states, or "basins of attraction" as David calls them (David, 2005:151). In their model, once this stable equilibrium state is attained, it takes a exogenous shock to dislodge it. From here, a new equilibrium state is 'selected' based on how the cards have fallen in the new economic landscape. This description of economic and technological change has also been described as a *punctuated equilibrium model*. It strength is that it allows the application of the neoclassical equilibrium concepts while it is in a 'stable state', its weakness is that it offers little insight into the process of change *between* stable states (if such states do indeed exist outside the model).

Figure 3.2 The canonical path dependence model of spatial industrial evolution



Source: Martin, 2010 (based on Arthur)

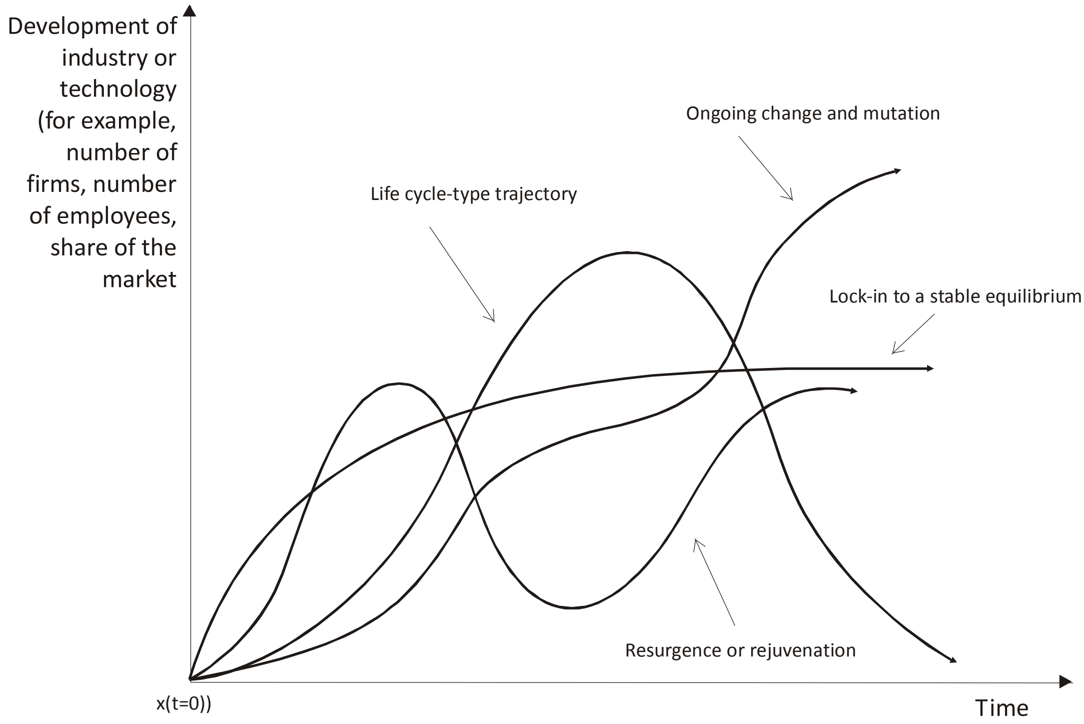
As Martin (2010) points out, there is thus a curious contradiction in the model, in that path dependence seems to matter only once a new industry has emerged, but plays no part in shaping that emergence or where it takes place. This is graphically expressed in Figure 3.3 as 'lock-in to a stable equilibrium'. Also Martin observes that attributing "de-locking" of a pathway to some random, exogenous event, does not seem particularly enlightening. The trouble with this, is that once a stable state is achieved, it is as if history comes to an end, until an exogenous shock disturbs it onto a different path. Thus, while this literature claims to "be taking history seriously", its weakness is that it adopts what Ulrich Witt (2003) has called the "virgin market assumption" – that the initial emergence of a technology or industrial zone takes place by chance with no reference to pre-existing technological, social, geographical or economic structures (i.e. it says nothing about the world at $x(0)$ in the model in equation 3.1.

The initial de-locking and locking-in of a particular path may arise because of the shifting preferences of markets or the entrance of new competitors and technologies, which are constant features of economic life. For example, many technologies and industries exhibit a 'life cycle-type trajectory' of gestation, growth, maturity and decline. It may happen that after initial agglomeration economies have been fully developed, diseconomies begin to set in – property prices and labour costs may rise in that area, the natural resource base may become stressed or exhausted; or the profitability of the sector may fall due to increased competition and firms may diversify into other areas of business - for example, Google moving into clean energy technology; or General Motors from combustion engines to electric motors. This life-cycle conception of the rise and fall of technologies in the path dependence literature, is also connected with Raymond Vernon's *product cycle* (1966), which has also informed related product life cycle theories. Here the consumption of a product goes through a process of introduction, growth, maturity, saturation and decline; and similarly, for the local production of a product. This occurs as the firm sources its parts and labour at first from the nearby area in which the innovation was invented, but then shifts production away from this 'home' location as the product becomes more adopted in world markets. Ultimately, the original country of origin of the innovation may actually become an importer of the good, such as in the case of personal computers in the United States.

Once off major events, such as the recent financial crisis and recession, or the collapse of communism, can produce sudden and obvious shocks that may lead to a reconfiguration of pathways. However, path disrupting change seems also to occur as an incessant process, *in addition to* occurring at "critical junctures" or in sudden "gales of creative destruction" (Schumpeter, 1942 [1975]:82-83):

> Capitalism, then, is by nature a form or method of economic change and not only never is, but never can be stationary. And this evolutionary character of the capitalist process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change alters the data of economic action; this fact is important and these changes (wars, revolutions, and so on) often condition industrial change, but they are not its prime movers.

Figure 3.3 Some stylized alternative evolutionary paths of an industry or technology



Source: Martin (2010)

> Nor is this evolutionary character due to a quasi-autocratic increase in population and capital or to the vagaries of monetary systems of which exactly the same thing holds true. The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organisation that capitalist enterprise creates.

The canonical model of path dependency has also been questioned more recently by Witt (2003:124):

> [S]ome doubts should be raised about the plausibility of both the theoretical underpinnings of, and the empirical evidence for, technological or industrial 'lock in'.... sooner or later there will always be new rivals who threaten the market dominance of a technology or variant. The erosion of market dominance under competitive pressure by new technologies supports Schumpeter's empirical generalisation that an incessant process of creative destruction characterises modern industrial capitalism.

However, despite his critique of the canonical model, Witt also invokes the language of multiple equilibria in his own characterisation of lock-in, albeit with the qualification "that it is by historical standards a transitory state of affairs" (Witt, 2003:125).

In contrast, Setterfield (1997:66) argues that multiple equilibria is inconsistent with "taking history seriously":

> One characteristic property of an equilibrium time path is that once it has been reached, a system will display no endogenous tendency to deviate from it... Once reached then, equilibrium implies a state of extreme stasis—an "end to history", as it were, since in the absence of shocks any subsequent evolution of the system is pre-determined by the equilibrium time path that has been achieved. Along this time path the precise sequence of events of which economic activity over time is comprised does not matter, since it will have no effect on the subsequent outcomes of the system. It appears, then that the invocation of equilibrium as a solution concept—even qualified by the caveat that any equilibrium achieved is path dependent—entails an

> intolerable departure from the strictures of historical time, according to which sequential patterns of activity *do*, in principle, matter.

However, as Martin points out – Stetterfield too, ends up suggesting that for heuristic reasons, we treat equilibrium as a "temporary" outcome of path dependent processes that may yet give rise to a subsequent endogenous process of 'innovating out' of equilibrium" (Setterfield, 1997:67-68). This raises the awkward question of what exactly "equilibrium" means in this context, as the more "short-run" and "transitory" an equilibrium becomes, the less powerful and relevant equilibrium seems to become as an analytical or metaphorical concept. Therefore, if the very concept of equilibrium is inconsistent with the theory and nature of an evolutionary (historical) system as Martin (2010) seems to suggest, then where does this leave the whole of neoclassical theory? If not some sort of (albeit transient) equilibrium, what is the evolutionary theorist's governing metaphor for the economic system?

While we have defined technology as being nested within the economic and social system, to properly answer these questions, we need to first more clearly explain what we mean by the "economic system" and by "change".

With the theory of path dependency we have seen how decisions in the past may influence our decisions today, but to take the next step to understand what moves the system from one pathway to another we need a framework which can draw out in greater detail the forces of change stylised in Figure 3.3, whether they be continual and incessant in nature; characterised by stability; once-off gales of creative destruction; or simply destruction, with no creation. We also need a theoretical concept which can better explain the reality of continual change in the economy which addresses the problems inherent in *lock-in* and *punctuated equilibrium* as well as agency and the scope of individuals, firms or citizens to shape the process of technological change. While several veins of research in the field of evolutionary innovation theory deal with these issues, including: technological innovations systems theory (Jacobsson and Bergek, 2004; Hekkert *et al.*, 2007); and new path creation (Garud and Karnøe, 2001); in the next section, focus is given to Strategic Niche Management (Schot and Geels, 2008) and the related Multi-Level Perspective on systems innovation (Geels, 2002).

3.8 The mechanics of change

So far in this review, change has been discussed without explicitly providing a definition or nomenclature for what exactly is meant by the term. For example, within the neoclassical theory of production and consumption, economic change is something that is mostly thought of happening in a marginal fashion - ‘little-bit by little-bit’ - an idea reinforced at a more formalised level by the common analytical use of differential calculus. In this type of analysis, change occurs up and down demand and supply curves, expanding and contract output, adjusting to more efficient technologies and processes, with prices going up and down, as the system self-adjusts towards equilibrium. The main source where flexibility is limited is the case of fixed costs and plant size when moving between the short and long-run. At the macroeconomic level, change can be seen as movements along, or shifts in the production function, and expressed through aggregate measures such as the level and growth rate of GDP, giving rise to notions such as the 'steady-state' growth rate with its accompanying policy recommendations.

An alternative view of change is presented by the theory of path dependency, where a decision made today may preclude, or make it difficult, certain decisions tomorrow once a specific technological path has been established. For example witness the difficulty some countries, such as Germany, in moving away from nuclear power despite strong policy statements to do so. In this case change often takes on a qualitative dimension and is conceptualised as involving very non-marginal shifts in economic resources.

As we move towards evolutionary theory, the definitions around change and its components become more refined. For example, while essentially meaning "change" McKelvey and Holmén (2006:2-3) use the term *economic transformation* to mean:

> ... a non-reversible process, encompassing quantitative and qualitative changes in components and connections, driven by opportunities and innovations. Such economic transformation may well be driven by processes of complexity and self-organisation as well as processes of actors acting, adapting to contexts. Moreover, the concept of transformation, as used here, may result from very different processes, including ones driven by very large and discontinuous changes as well as ones driven by very small changes, which follow upon an existing trajectory.

Less all-encompassing, Geels and Kemp (2006) in the same volume provide greater clarity still by distinguishing three different types of change according to its scope and underlying mechanisms:

Reproduction is seen to be a type of incremental change occurring along existing trajectories. Reproduction only involves change at the regime level (Figure 3.7), not at the landscape or niche levels. The existing sociotechical system forms a stable context for the interaction of social groups. Existing rules are reproduced by incumbent actors and elements of the system are refined. The orientation of dominant actors, key technology and knowledge base do not change fundamentally. This situation at the regime level is stabilised by the high sunk cost of existing investments, role expectations in networks, regulations and standards, contracts and cognitive routines (rules of thumb). Despite changes being small, incremental innovations do occur and can result in major productivity improvements over time. Rosenberg (1982:62) describes a similar process:

> A large portion of the total growth in productivity takes the form of a slow and often invisible accretion of invisible small improvements in innovations (...) such modifications are achieved by unspectacular designs and engineering activities, but they constitute the substance of much productivity improvement and increased consumer wellbeing in industrial economies.

The second category of change is t*ransformation*. This is change in the direction of trajectories involving action at the regime and landscape level, but with little influence from niches. Change in this area can be driven by exogenous landscape changes which create pressure on the existing regime leading to a reorientation of innovative activities; or by endogenous changes in regime rules. For example, shifts may occur in technical problem agendas and visions underpinning goals and guiding principles of engineers and scientists; relative costs and incentive structures may be altered through regulations and policies, shifting the perceptions of where opportunities lie. This reorientation is not likely to occur in a mechanical way but be subject to negotiations, power struggles, and shifting coalitions of actors. In the face of growing pressure for change, incumbent actors are likely to downplay the need for transformation, which changes in social networks often vital to start the transformation process. New actors may help particularly to challenge existing assumptions and place issues on the problem agenda (Van de Peol, 2000) and by expressing concerns over negative externalities of the existing system, precipitate a response from within the regime (Van de Poel, 2003). However, these new players (or outsiders) do not develop competing technologies to replace the existing system, so the survival of the incumbent regime is not threatened, and it is they who enact the change in trajectory. Over time, a new system may grow out of the old one through cumulative adjustments.

The third type of change is termed t*ransition,* and is a change describing the shift from one socio-technical system to another. This is seen to be a discontinuous shift to a new technological trajectory and encompasses interactions between niches, the regime and the landscape, to which incumbents are unable to adjust. For example, a change in the economic landscape may create major problems for incumbents in the existing regime. Unable to adapt through transformation, a *window of opportunity* opens for new innovations, which have developed in market niches to be carried forward by new social groups. The transition invokes shifts in the knowledge base, technologies, infrastructure, regulatory framework, consumer behaviour and social groups. If the new innovation breaks though and replaces the existing system, this will be accompanied by *creative destruction* and the downfall of some incumbent actors. Once the transition has taken place, a new period of dynamic stability and reproduction sets in.

While it would be wrong to suggest that these meanings are universally attached to these words in the evolutionary literature (for example, "transition", has been used to describe movement between two states of the same system); for the purposes of clarity, this review will follow the definitions set out by Geels and Kemp (2006).

3.9 The contribution of network or systems theory

"System" is another word we have assigned implicit meanings to throughout this review without formally providing a definition. For example, we have used the neo-classical micro-economic utility and profit maximising market system of the individual or firm bounded by price and quantity; there is the macro-economic system inherent in the models of growth theory; and there are the socio-technological systems conceptualised in the evolutionary, institutional approach of path dependency theory.

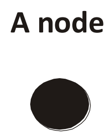
While the "market-system" is often the core conceptual construct in which the action of economic life tends to take place, it is very often assumed to be simply "out there" and is very loosely defined, if at all in standard analysis. In the neoclassical model, markets are usually portrayed as the context within which the acts of buying and selling take place. In this market consumers and producers 'optimise' to make decisions taking as cues cost and price information which drives the economy to a unique equilibrium (Figure 2.1).

Alternatively, if we view the economy as an "evolutionary system" where firms compete in struggle for profits or survival, then we need to specify the processes for variation, selection and replication. As pointed out by Coyle (2006:188) the adoption of such an evolutionary system as an analytical construct for the economy raises a number of questions, not least: what are the sources of change? What are the criteria for a variation to succeed in a given environment – how is "fitness" specified and what are the mechanisms for selection? How are "successes" passed onto other business units? What "units" should we be analysing – the firm? the manager? the market penetration of a product? How does the economic environment which shapes and constrains these actions evolve and how do the units interact with one another?

To begin to address these questions, we will turn now to network or systems theory which has recently become a focus for economic research in this area (e.g. Beinhocker, 2007). This builds on a long tradition in physics, computer science, biology and sociology, and is underpinned by the work of the Hungarian mathematicians Paul Erdös and Alfréd Rényi in the 1950s and 60s (for a review see Watts, 1999). The basic framework can be set out as follows:

Consider the following object:

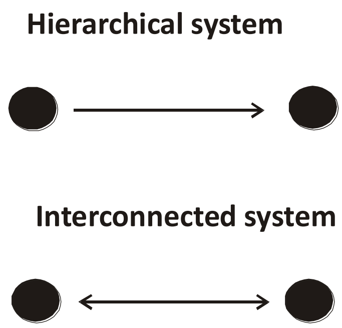
Figure 3.4 A node



Nodes are fundamental units of *graph theory*, which, in the abstract, can be treated as featureless and indivisible objects. Alternatively, they can also be assigned qualitative structure depending on the application they are being used for. For the purposes of this example, consider the node above as representing either an individual, social group, or firm: an economic *agent*.

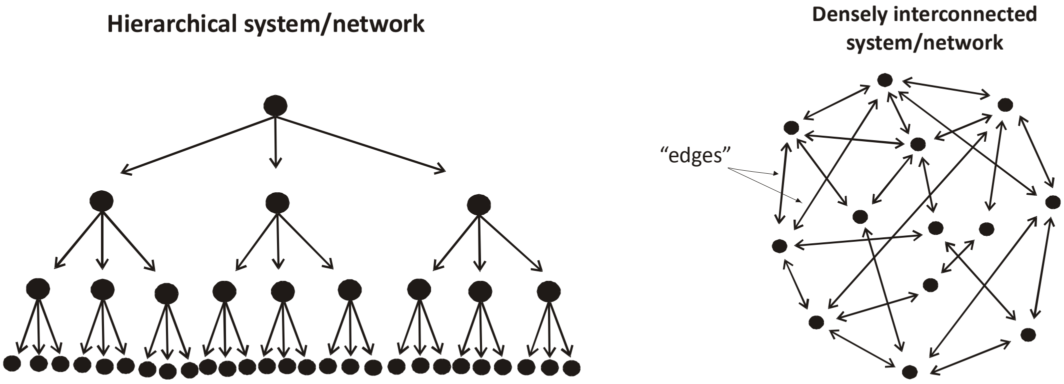
Put two nodes together and we have a basic *system*. Now, depending on the nature of the relationship between these nodes we can describe either a *hierarchical network*, or an *interconnected network* (Beinhocker, 2007: 155).

Figure 3.5 Nodal relationships



In the hierarchical system, a command node issues instructions to a subordinate node. Information regarding the outcome of these instructions will flow back to the command node through the subordinate node, but the instructions flow only one way. In an interconnected system, directions and response information can flow back and forth from either node. These basic systems can be built into something more complex:

Figure 3.6 Two basic systems: hierarchy versus interconnectivity



Within the hierarchical system, layers of command form from the top down, nodes further down the hierarchy receive commands from above, and then send response information back up the hierarchy to await further instruction. An advantage of a hierarchical system is that the density of connections are limited, thereby increasing the predictability of decision-making and enabling system-wide directional changes to be made more easily by the highest level command node.

Consider a simple example: let us imagine each node represents an individual in an organisation, which has recently decided to implement a new strategic decision, say to adopt energy efficiency measures. If we take the figure above with 40 nodes, this means that in the extreme case of no hierarchy and a completely interconnected network, 1600 meetings would have to take place and everyone agree to the course of action with everyone else. Alternatively, in a hierarchical structure, a command is issued from the CEO which gets passed down through each layer of management which meets with their subordinates, agrees, then passes the information on to the next layer and so on. In the case of the figure above we have one meeting between the CEO and his top lieutenants; then three meetings between these lieutenants and the lowest level of management who have nine meetings with their staff. All up 13 meetings are required to coordinate the entire system. On the other hand, the disadvantages of hierarchy are that information may degrade as it moves up and down the levels (think of a game of 'Chinese whispers'), the highest command node may become out of touch with reality at the lowest levels, and a poor performer at the top can do a lot of damage to the system.   Within a socio-economic context, examples of such structures might exist at the household level, in large corporations or government bureaucracies; or even extend to the entire economy, as in the case of the planned economy of the former Union of Soviet Socialist Republics.

In an interconnected network, there are no control nodes, instead each node communicates to the other nodes it is connected to which may or may not respond depending on their own characteristics. Information is decentralised and dispersed around the system travelling between nodes that are linked. A common way to explore such systems is by assigning nodes a value of 0 or 1 (no or yes, for example) dependent on a set of rules. Such *Boolean networks*, have been a focus for research, particularly the work of Stuart Kauffman and the Santa Fe Institute (Kauffman, 1993). In the social sciences, such interconnected networks have been used as a metaphor for the *market economy*, where individuals trade with one another as rational utility or profit maximising agents. The nature of network interactions is voluntary and reciprocal, decentralised and complex, so that it is impossible for any one agent to understand it in its entirety. An important corollary of this type of system is the principle of *subsidiary*: that decisions should be made by the node which is affected by the outcome of that decision. This idea has been used to support the notion of *free markets* as the antithesis to a hierarchical command and control system defined by rules from above. For example, Hayek (1974) argues that the *market system* coordinates:

> …a sum of facts which in their totality cannot be known to the scientific observer, or to any other single brain. It is indeed the source of the superiority of the market order, and the reason why, when it is not suppressed by the powers of government, it regularly displaces other types of order, that in the resulting allocation of resources more of the knowledge of particular facts will be utilized which exists only dispersed among uncounted persons, than any one person can possess.

Another important corollary of this type of analysis is as a way of quantifying *network effects*. In the neoclassical analysis these were modelled as *network externalities:* when the increased use of a good, increases the value of further usage. Classic examples include, establishing a telephone or fax machine network, or the QWERTY keyboard. Here the benefit to each successive customer of choosing one technological variant over another is greater the larger the number of users of that technology.

Stuart Kauffman (1993) has used this logic to derive a theory which seeks to explain *tipping* or *turning points*. He argues that a transition phase is initiated in networks when the ratio of the number of *edges* or connecting relationships with the number of nodes is equal to one. At this point a network goes from being *sparsely connected* to *densely connected.* This type of analysis can then be used to model economic change not as a smooth linear process, as in the neoclassical model (based on calculus), but as a non-linear process. It has been used to explain why, for example, social networks on the internet suddenly take off and others do not; why the stock market is so volatile; why fashions emerge; and why political movements can swing from obscurity to popularity in a short space of time (e.g. Farrell, 1998).

A related advantage of this logic is that it can also help explain the observation of path dependency. As discussed above, new technologies, especially in energy markets, often require a vast amount of complementary infrastructure, products and other services in the supply chain. Thus decisions to support a particular technological pathway can induce similar supportive decisions in other related networks. For example, the shift from the internal combustion engine vehicle to electric vehicles may be particularly costly and difficult due to the threat this posses to the established related industries of manufacturers, mechanics, engineers and labour unions.

Within the evolutionary economic model the “selection environment” is taken as the market within which economic agents operate (Metcalfe, 1998). Much more than the neoclassical place of exchange and interaction between consumers and producers, in the evolutionary model this also includes everything else which goes into the formation of market institutions: governments, regulators, lobbyists from rival firms, environmental pressure groups, universities, international trade agreements, law courts, corporate governance, federal-state relations and the impact of politics and events such as natural disasters and wars – most of which the neoclassical model leaves as exogenous despite their profound impact on economic life.

Here there is an important point of differentiation between economic evolution and the notion of evolution as applied to biology. In biology evolution is perceived as being a blind process driven forward by random variety upon which the selection environment acts upon – a process of “design without the designer” - an emergent, self organising order with no role for a central organising intelligence (such as a God). However, with respects to social systems Beinhocker (2006:249) points out:

> ...there is nothing fundamental in the nature of the evolutionary algorithm that says intentionality and rationality cannot play a role, nor does anything say that the process must be completely random. At its core, evolution is an iterative process of experimentation, selection, and then amplification of things that work.

What Beinhocker argues is that in human society evolution is a goal-oriented purposive process where we consciously try to effect evolutionary outcomes: whether this is to gain market share, win an election – or at the biological level simply to reproduce and pass on our genes. In the economy, this means consumers, producers, technologies and the market institutions of their selection environment all are seen to *co-evolve.* This means that in addition to the principles of variation, selection and replication, we need to add *interaction* in a *self-adaptive system*. People, firms and other institutions become caught up in a self-conscious and mutually reinforcing system as they seek to mould their selection environment.

These notions have given rise to the concept of the *techno-economic paradigm* (Freeman and Louca, 2001), and reviewed by Coyle (2006:195):

> The firms in an industry shape their own environment through trade associations, lobbying, standard setting, links with universities, law suits and so on. Political action and the legal framework are vital to the environment. The law of tort and the limited liability company played a vital role in nineteenth century industrialisation, for instance. Cars and airplanes needed governments to build roads and airports, to set the rules of the road and run air traffic control. The shaping of the competitive environment is also cumulative... the invention of computers gave birth to computer science, and computer scientists develop the new innovations in the computer industry.

However, what was once a source to promote system change, as new techno-paradigms spread into the economy, can also become a source of stability as these new agents start to put more effort into tailoring their environment, such as lobbying for protection from overseas competition, or tax concessions, rather than investing in new research and development. The inherent difficulty of change – be it at the individual or firm level – is what is behind Schumpeter’s notion of *creative destruction* – that the inbuilt resistance to change builds up until firms are no longer to control the environment around them and the system suddenly reaches a turning or tipping point which brings in a new competing system of economic actors (see Gladwell, 2000).

From this discussion on systems, we have begun to draw together several strains of research which seek to understand the *mechanics of economic change*. While it is clear that there is not, as yet, any universal synthesis for this body of work - as there is in the neoclassical model presented earlier –with different authors emphasising different faces of the same evolutionary processes using a variety of terminology - we will now move onto a body of literature that does offer a framework for synthesising many of these concepts: Strategic Niche Management and its related Multi-Level Perspective.

3.10 Strategic niche management and an integrative evolutionary multi-level perspective on technological transitions

Strategic Niche Management (SNM) and its related Multi-Level Perspective (MLP) arose out of the sociology of technology and was originally developed to understand technological transitions and regime shifts (Schot et al., 1994; Schot and Geels, 2008; Rip and Kemp, 1998; Kemp et al., 1998; Kemp et al. 2001; Geels, 2002, 2005; Kemp, 1994; Levinthal, 1998; Schot, 1998). As Geels (2002:1259) points out, the Multi-Level Perspective is not meant as ontological description of reality, but as a set of analytical and heuristic concepts to understand the mechanics of socio-technical change. It integrates many of the main concepts which are touched on to varying degrees and with differing emphasis and focus elsewhere in the literature and thus can be seen as a good foundation to approach the broader literature.

Within MLP, three interrelated dimensions are important:

- *socio-technical systems*: the tangible elements of the technology needed to fulfil societal functions;

- *social groups*: the actors who maintain and refine the elements of the socio-technical systems; and
- *socio-technical rules (or regime)*: formal and informal rules that guide and orient activities of social groups.

In this framework, actors in social groups are not assumed to act autonomously, as they do in the neoclassical model, but rather, in the context of social structures and by normative, formal, and cognitive rules. These rules form a coordinating context that guides and orients action. On the other hand, rules are reinforced and changed through action and enactment. Rules do not exist individually, but are linked together in semi-coherent set of rules called *regimes*. Rip and Kemp (1998:340) and Geels (2004) have widened the original concept of *technological regimes* first set out by Nelson and Winter (1982) to indicate that rules, including cognitive routines (Dosi, 1982) are not only embedded in the minds of engineers in their research and development activities, but are also in elements of the socio-technical system including scientists, users, policy makers and special interest groups. Rules include the problem agendas (reducing carbon, for instance), guiding principles, rules of thumb, standards, government regulations, sense of identity, and the role of expectations.   Social groups interact and form networks with mutual dependencies, resulting in the alignment of activities. This intergroup coordination is graphically represented as the meso-level in Figure 3.7 with the concept of *socio-technical regime*.

System stability can arise from mutually reinforcing established networks and ways of thinking. Although skills can be updated, and contracts broken or changed, corecompetencies (Leonard-Barton, 1995) and legally binding contracts (Walker, 2000) can also become sources of rigidity in a shifting environment. Systems are also stabilized because they become embedded in society through institutions. People change their lifestyles to suit them and formal regulations and infrastructure created to serve them. The alignment between these heterogeneous elements leads to technological momentum (Hughes, 1994) and *lock-in* reinforced by *social relationships* of mutual role expectations and embedded interests such as industry associations (Hughes, 1987:76-7; Unruh, 2000). The *material aspects* of socio-technical systems also contribute to stability, because of *sunk costs* - once investments are in place they are not easily abandoned (Walker, 2000). This means, for many reasons, socio-technical systems are characterised by stability, not by any means inertia, but dynamic stability, meaning innovation still occurs but is of an incremental nature.

Because these stabilising mechanisms can lead to lock-in, it can be difficult for radical innovations to diffuse. So how does this model theorise the emergence of new socio-technological pathways?

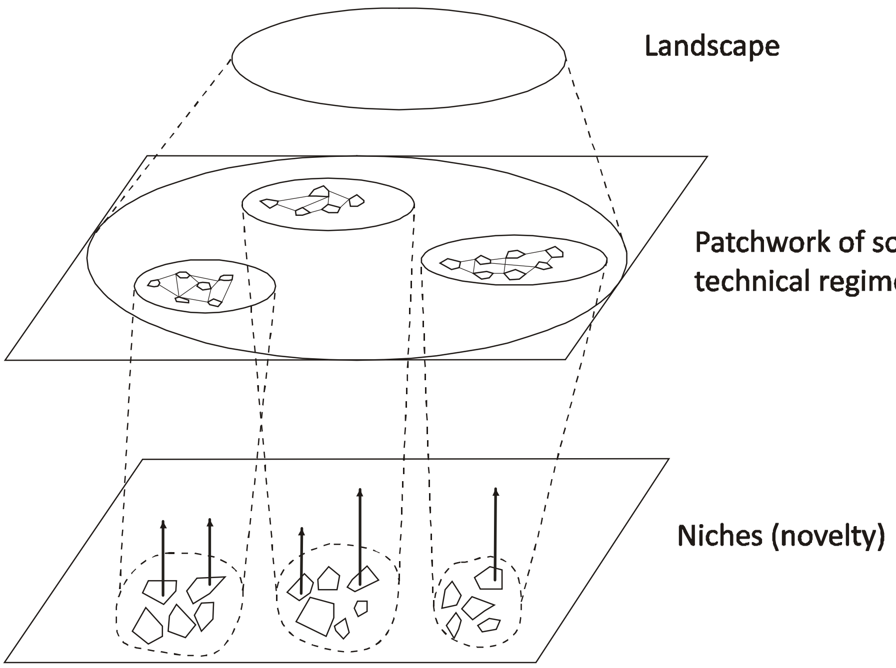
Strategic Niche Management theorists argue that for many new technological innovations market opportunities are not readily available as new technologies may differ radically from incumbent system. In many cases, there may be no established markets and no fixed preferences. For diffusion to take place, consumers must be introduced to new products and associated behaviours, firms and organisations must realign production routines, supporting infrastructure may need to be installed and, most likely, new regulations and policies need to be passed to govern all these interactions, all of which take place within a cultural discourse (Lie and Sørensen, 1996; Nelson, 1994, 1995). To prepare the new technological innovation for the market, a technological niche may provide a protected space or "incubation room" to nuture a specific set of interactions between actors, issues and objects. As Rosenberg (1976:195) notes:

> ...most inventions are relatively crude and inefficient at the date when they are first recognised as constituting a new invention. They are, of necessity badly adapted to many of the ultimate uses to which they will eventually be put.

Within the niche, different selection criteria and public support for the technology can exist separate from broader market forces. SNM work conceptualises a bottom up process in which novelties emerge in technological niches, then conquer market niches, and eventually replace and transform dominant technologies and regimes (Schot and Geels, 2008). Within the literature three crucial internal niche processes have been identified (Schot et al., 1994; Kemp et al., 1998; Kemp et al., 2001; Hoogma *et al*., 2002):

- *Technical learning processes* relate to research and development into the technological object; the assessment of new markets and the nurturing of new user preferences; policy experimentation to facilitate a new regulatory regime and also investigating what complimentary infrastructures are available or are necessary for the niche to develop;

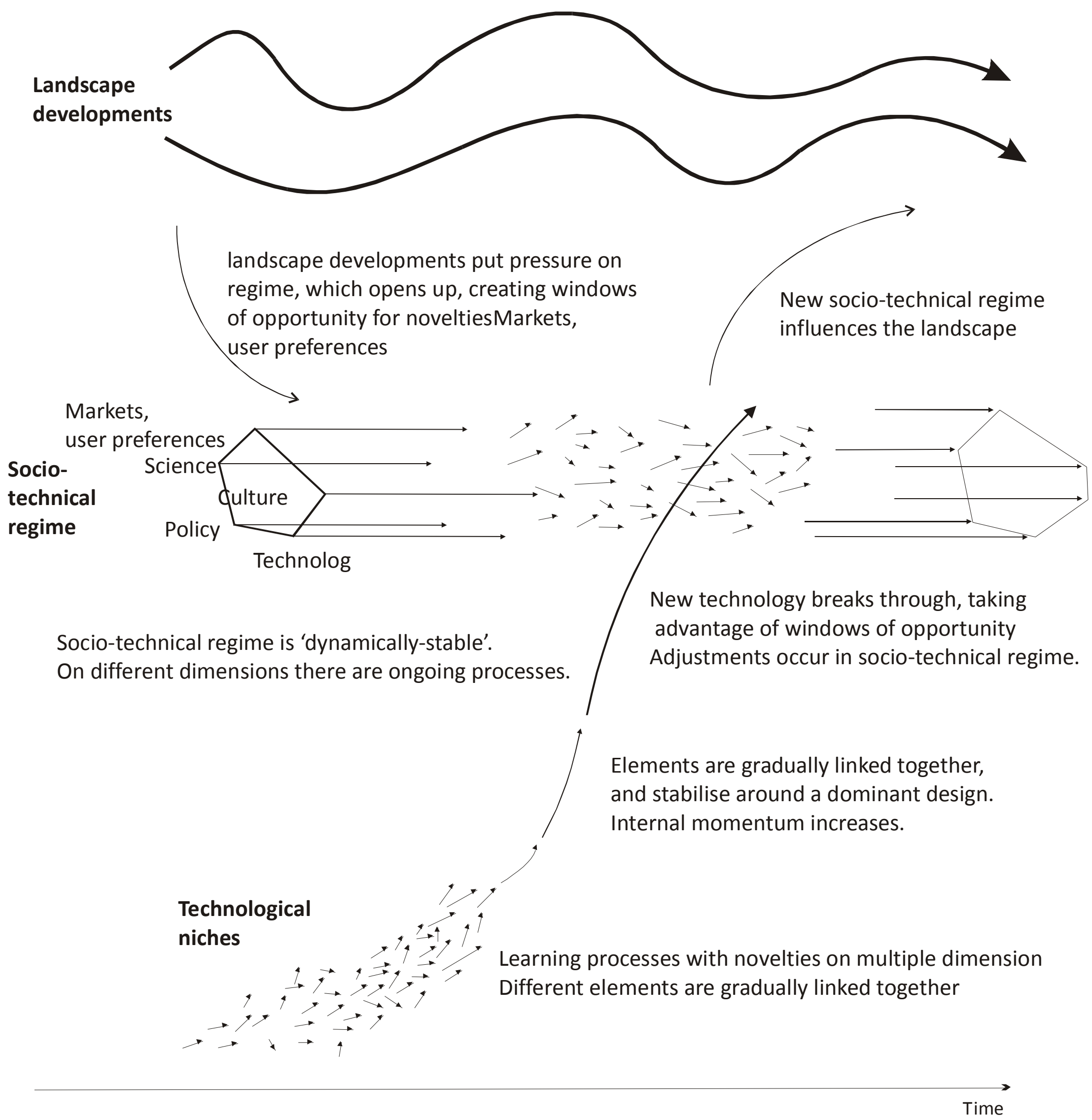
Figure 3.7 Multiple levels in a nested hierarchy



Source: Geels (2002:1261)

- The *building of socio-technological constituencies* involves the formation of social groups which may include: scientists, engineers, entrepreneurs, financiers, early adopters amongst consumers, policy makers and new societal coalitions (lobby groups) to support the new innovation and invest in its development; and thirdly,
- *The articulation of visions and expectations* to provide direction to learning processes, attracting attention and legitimising protection from the broader market. Expectations of the future need to be built and shared by actors and their content gradually substantiated through project developments.

Figure 3.8 A dynamic (phased) multilevel perspective on system innovations



Source: Geels (2002:1263)

In this framework it is argued that niche innovations are rarely able to bring about great transformations without the help of higher order forces and processes. Thus, for niches to develop they should also ideally be responding to changes at the landscape, or macro level, in a way that the established regime cannot. This broader largely exogenous environment is formed by the *socio-technical landscape*.

The context of this landscape is heterogeneous across different locations and may include aspects such as economic growth (or decline), broad political coalitions, cultural and normative values, environmental problems and resource scarcities (or abundances). It also includes the large-scale material context of society, for example, the material and spatial arrangements of cities, factories, highways, and electricity infrastructures (Rip and Kemp, 1998). Such landscapes are generally beyond the influence of actors, and cannot be changed at will, usually taking decades to shift.

The three conceptual levels in Figures 3.7 and 3.8 can be understood as a nested hierarchy, but the key point of the MLP is that transitions come about through the interplay of processes at different levels in different phases (Table 3.2). Both internal niche dynamics and external development at the regime and landscape level are important for wider breakthrough and diffusion.

Having tapped into innovation theory to investigate the mechanics of change in the economic system we now move onto *complexity theory* which is another related research programme attempting to bring many of these heterodox research currents under a coherent epistemological banner. As will be discussed, this research agenda has been identified as holding great promise for building on the natural affinities of physical and social systems, which has been identified as a ‘constant dream of geography’ (Thrift, 1999:32).

Table 3.2 Dynamic phases in the Multi Level Perspective

Phase 1	Radical innovations emerge in *niches,* often outside or on the fringe of the existing regime. There are no stable rules (e.g. dominant desgn), and actors improvise and engage in experiments to work out the best design and find out what users want. The networks that carry and support innovation are small and precarious. The innovations do not (yet) form a threat to the existing regime.
Phase 2	The new innovation is used in small market niches, which provide resources for technical development and specialisation. The new technology develops a technical trajectory of its own and rules begin to stabilize (e.g. a dominant design). But the innovation still forms no major threat to the regime, because it is used in specialised market niches. New technologies may remain stuck in these niches for a long time (decades) when they face a mismatch between the existing regime and the landscape.
Phase 3	A wider breakthrough in the new technology occurs, and competition begins with the existing regime. On the one hand, this depends on internal drivers in the niche. Improvements in the price/performance ratio are an important driver, as well as support from powerful social groups. On the other hand, external circumstances at the regime and landscape levels are crucial, creating windows of opportunity for novelties in niches. Social, cultural, or economic changes at the landscape level may put pressure on the regime, or the existing regime may be plagued by increase internal problems that cannot be solved by incremental improvements. Such tensions create opportunities for the breakthrough of innovations.
Phase 4	As the new technology enters mainstream markets it enters a competitive relationship with the established socio-technological regime. If successful, this leads to replacement, something that is likely to be accompanied by the phenomenon of *stranded assets* in the former (path dependent) regime. Replacement often happens in a gradual fashion, because creation of a new socio-technical regime takes time. The new system may then eventually influence wider landscape developments.

Source: Geels and Kemp (2006:232)

3.11 What are complex systems and why is 'complexity theory' important?

The study of *complex systems* has been increasingly put forward since the 1960s as an alternative scientific paradigm to what has been termed the *mechanistic* approaches such as the "clockwork" theories of Newtonian physics in the physical sciences and neoclassical economics in the social sciences. In contrast to such "reductionist systems", as say, a rubber ball rolling around into the bottom of a bowl (as described by Newton's Laws of Motion), complex systems exhibit unpredictable *emergent* properties. Common examples include the co-ordinating ability of ants to form giant colonies capable of food gathering, distribution and defence; the flocking of birds or schools of fish that use simple rules to travel and avoid predators; the neural interconnections which underpin the development of thoughts and personality in the human brain; and the herding behaviour and other "anomalous" patterns exhibited in stock markets that cannot be explained by the underlying value of an individual stock. The unifying logic behind these phenomena is that the relationships between their elements come together in a way which can only be classified at higher levels than the individual units (Coveny and Highfield, 1995:7).

What is more, change in a complex system can result in observations that are very difficult if not impossible to predict, especially in cases where phenomena are highly sensitive to initial system conditions. One of the most famous expressions of this notion was put forward by Edward Lorenz in a talk delivered to the American Association for the Advancement of Science in 1972 titled, "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas," which later gave rise to the popular notion of the *butterfly effect*, related to chaos theory. In this case, the inherent difficulty in predicting weather events was highlighted.

In one seminal work, Warren Weaver (1948) describes two types of complexity:

- *Disorganised complexity*: arises from a system of many parts, where the random interactions of elements of the system mean that the system as a whole has properties that can be identified with statistical methods, for example, gas molecules in a container.
- *Organised complexity*: arises due to non-random or correlated interactions between the elements in a system. These elements combine to create differentiated structures which can then interact with other systems. The coordinated system manifests properties which are not carried out or dictated by individual elements – these properties *emerge* with no “guiding hand”.

This second type of complexity, which has long been studied by biologists in the context of evolutionary theory, has attracted particular focus for researchers in the area of *complex adaptive systems* (e.g. Jencks, 1996). Johnson (2007) outlines the following attributes for such systems:

- The number of elements, types of elements, and the relationship between the elements in the system are non-trivial (i.e. it has to be big enough for emergence to occur);
- The system has a memory, or includes feedback;
- The system can adapt itself according to its history or feedback;

- The relationship between the system and its environment are non-trivial and non-linear;
- The system can be influenced by or adapt itself to its environment; and
- The system is highly sensitive to initial conditions.

Chris Langton, quoted in (Lewin, 1993:12-13) describes complexity in the following terms:

> From the interaction of the individual components [of a system] ... emerges some kind of property ... something you couldn't have predicted from what you knew of the component parts ... And the global property, this emergent behaviour, feeds back to influence the behaviour ... of the individuals that produced it.

Roger Lewin (1993:backcover), a major proponent of complexity theory, postulates:

> Complexity theory is destined to be the dominant trend of the 1990's... This revolutionary technique can explain any type of complex system - multinational corporations, or mass extinctions, or ecosystems such as rainforests, or human consciousness. All are built on the same, few rules.

As Thrift (1999:34) notes, most writers on complexity theory then go on to usually lay claim to a whole series of fields of study which they assert are part of this impulse, including: chaos theory, fractal modelling, artificial life, cellular automata, neural nets and the like. This includes a companion vocabulary which can be both technical and metaphorical – chaos, attractors, fractals, emergent orders, self-organisation, implicate order, autopoiesis (a self-creating system), and so on. Thrift thus cautions those who seek to use “complexity theory” as a unified theoretical anti-reductionist response, as - to a certain extent, any definition of complexity is likely to be beholden to the perspective brought to bear upon it. While recognising that exciting academic cross-fertilisation may occur between the physical and social sciences in this area, care also needs to be taken to not naively accept a theory developed in one field for application in another without an independently thought-out and robust case for doing so. On this point Thrift emphatically states that complexity theory ‘*does* have interesting and even important things to say’ (Thrift, 1999:32-33, emphasis in the original):

> Here, furthermore, is a body of theory that is preternaturally spatial: it is possible to argue that complexity theory is about, precisely, the spatial ordering that arises from injections of energy. Whereas previous bodies of scientific theory were chiefly concerned with temporal progression, complexity theory is equally concerned with space. Its whole structure depends upon emergent properties arising out of excitable spatial orders over time. And here, most of all, is a body of theory which asks questions about `instability, crisis, differentiation, catastrophes and impasses' (Stengers, 1997: 4) in ways which suggest that there is an obvious affinity between the `natural' and `human' sciences, a constant dream of geography.

Such a movement is not, however, altogether as new as the recent ‘complexity hype’ of Lewin might suggest. Scholars since at least the time of the Scottish Enlightenment and the work of Malthus, whose ideas helped inspire the work of Charles Darwin, have sought to conceptualise the economy as a spontaneous (or emergent) system - in that it is a result of human action, but not the execution of any human design (e.g. Adam Smith's *invisible hand*) with individuals, firms and governments processing information and adapting their behaviour giving rise to spatially distinctive patterns of economic development over time. For example, the *Austrian School* economist Fredrick von Hayek in his 1974 Nobel lecture argued:

> Organized complexity here means that the character of the structures showing it depends not only on the properties of the individual elements of which they are composed, and the relative frequency with which they occur, but also on the manner in which the individual elements are connected with each other... In the explanation of the working of such structures we can for this reason not replace the information about the individual elements by statistical information, but require full information about each element if from our theory we are to derive specific predictions about individual events.

In this statement Hayek emphasises that to fully ascertain the working of the economic system, the researcher should look, in addition to quantitative 'statistical information', to qualitative 'full information' on each element of the system. Here Hayek draws attention to the distinction between the human capacity to observe and predict the behaviour of simple systems (such as in Newtonian physics) and the more complex systems found in economics, biology and psychology. Hayek, (1974) also also highlights the importance of recognising the limitations of prediction when dealing with complex systems where only 'pattern predictions' are possible as contrasted with the more precise predictions that can be made of non-complex phenomena.

> Often all that we shall be able to predict will be some abstract characteristic of the pattern that will appear - relations between kinds of elements about which individually we know very little. Yet, as I am anxious to repeat, we will still achieve predictions which can be falsified and which therefore are of empirical significance.

3.12 Three emergent patterns of complex adaptive systems in the economy

As Brian Arthur (1999:2) notes, once the complexity outlook is adopted with its emphasis on the formation of socio-technological structures rather than their given existence, problems involving prediction in the economy look different. Rather than basing forecasting on rational expectations, forecasting models are formed from the bottom-up, taking the decisions made by individual agents, who are not always aware of the expectations of others or 'rational' response, as their basis. Despite the potential heterogeneity of expectations across agents, complex adaptive systems tend to have signature emergent patterns that are common across many types of system which can assist in this forecasting task. Here we will review three such signature patterns which have been highlighted in Beinhocker (2006:168-181): *oscillations*, *punctuated equilibrium*, and *power laws*.

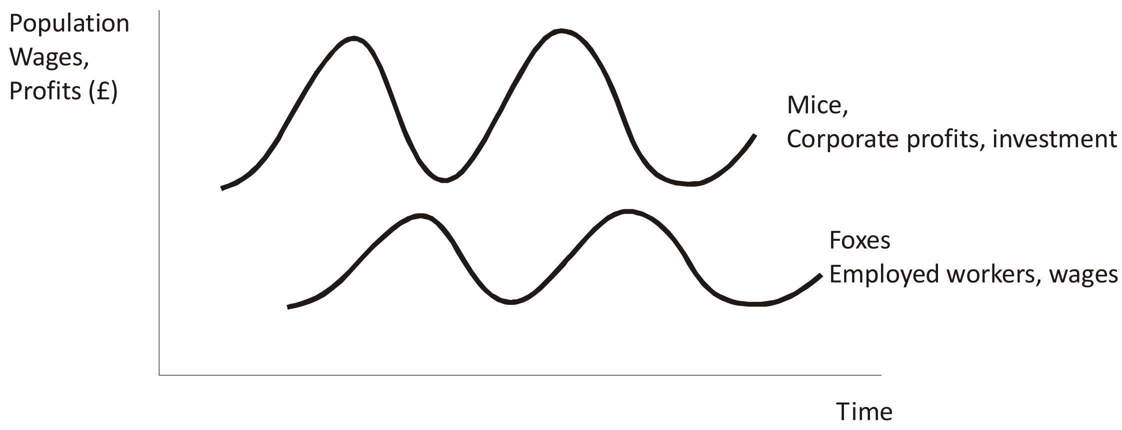
3.12.1 Oscillations: no equilibrium in sight

Oscillations are a common feature of most complex adaptive systems. One of the most regular and pervasive of such patterns in the economy is that of the business cycle. Schumpeter (1954) outlined that a typical cycle had four stages: expansion, crisis, recession and recovery. Following on from this work he proposed a typology of business cycles based on their periodicity:

- The Kitchin inventory cycle of three to five years (Kitchin, 1923);
- The Juglar fixed investment cycle of seven to eleven years, commonly identified as 'the business cycle' (Juglar, 1862);
- The Kuznets infrastructural investment cycle of 15-25 years (Kuznets, 1930); and
- The Kondratiev waves or long technological cycle of 45-60 years (Kondratiev, 1935).

The question is, are these cycles random perturbations around a long-term trend simply driven by exogenous factors, or are they driven endogenously from within the economic system itself? To answer this question let us first take a step back to consider the nature and driving force behind an oscillating system. This goes back to the pioneering work of Thomas Malthus and his essay on the *Principles of Population* which helped inspire a Ukrainian chemist and an Italian mathematician to build a model to describe the relationship between a predator and its-prey in a biological system - the so-called *Lotka-Volterra* model. This model shows how as a population of mice grows, foxes eat more mice, causing the fox population to rise and the mouse population to fall. This decline in mice, leads to less food per fox, and eventually the fox population falls, allowing the mice population to rise again, thus creating oscillations of fox and mice populations. This dynamic system never changes, but oscillates ad infinitum, with the ups and the downs emerging endogenously from within the system itself, rather than any outside force. Indeed, this model is a good description of reality of many predator prey relationships, which are in a continual state of dynamic flux. Richard Goodwin writing in the 1950s was one of the first social scientists to apply the logic of predator-prey relationships to the relationship between employment and corporate profits and investment.

Figure 3.9 Lotka-Volterra / Goodwin Model of a time-lagged oscillatory system



Author, based on Goodwin (1990)

In an economy based on a network of supply and demand relationships, such oscillating behaviour has been demonstrated to emerge from what psychologists have termed the *anchor and adjust effect*. Such models describe decision makers as "anchoring" on a decision and then adjusting the decision based on new information. While departing from the rational agents assumption of the neoclassical school, such models are simple in structure and intuitively appeal to how decisions are actually made. For example, with inventory management where there are time delays along the supply chain, the anchor-adjustment rule causes individuals to both overshoot and undershoot in placing new orders, which in turn leads to the emergent behaviour of cyclical patterns (Beinhocker, 2006:171-172). Such models proliferated following seminal articles by Lichtenstein and Slovic (1971) and by Tversky and Kahneman (1974). The models seem to be descriptive of a wide variety of judgment tasks: intuitive estimation of numerical expressions (Tversky and

Kahneman, 1974), forecasting (Bromiley, 1987), stock management (Sterman, 1989), risk assessment (Lichtenstein et al., 1978), preference for gambles (Lichtenstein and Slovic, 1971), predictions of spouse's preferences (Davis et al., 1986), causal attribution (Einhorn and Hogarth, 1986), judgment under ambiguity (Einhorn and Hogarth, 1985), judgments of experienced real estate agents (Northcraft and Neale, 1987) and auditors (Butler, 1986). Given the volume and variety of studies, anchor-and-adjustment appears to be well-established empirical phenomenon.

If such effects are in fact playing out on the macro-economy, the causes of the business cycle lie in the way people's adaptive inductive decision-making rules interact with the dynamic structure of the economy (as opposed to the deductive rules of the rational agent). If valid, one implication of this is that business cycle management though monetary and fiscal policy is only a symptomatic treatment for business cycles, and indeed may lead to exacerbating the boom and bust cycle once worked into agents adaptive expectations. Rather, if governments wished to smooth the business cycle they should look to the structure of decision-making in the economy itself – to either: reduce time delays between decision makers and to increase the system-wide transparency of decision-making.

In this respect, some have suggested that information and communication technologies may have contributed to the dampening of the business cycle (McCarthy and Zakrajsek, 2002). The hypothesis is that computers have enabled companies to speed order processing, adopt just-in-time inventory practices, and electronically link producers with their supply chains. In this case, the authors' suggest that new ICT technologies have worked to alter the structure of decisions in the economy, dampening the oscillations of the business cycle. Such research however, must also be evaluated in light of the recent financial and economic crisis – the worst since the Great Depression of the 1920s.

3.12.2 Punctuated 'equilibrium' –stability and flexibility in the evolving economy

In contrast to the idea of gradual, incremental change, the notion of punctuated 'equilibrium' is that the system can be characterised as following relatively long periods of stability, 'punctuated' by short bursts of radical change.

The concept was first articulated by Niles Eldredge and Stephen Jay Gould in the context of their observations that biological evolution seems not to have followed a smooth path, but instead is characterised by long periods of stasis interrupted by sudden mass extinctions, followed by vibrant bursts of new species origination (Eldredge and Gould, 1972). In building their theory, the authors drew attention to the 'five great extinction events' of the last 500 million years (the five most extreme points in a continuous oscillating cycle of species extinction and origination) the largest of which saw the extinction of up to 96 per cent of all marine species on earth. However, these results should also be viewed in the light of recent studies which have shown a lack of any significant correlation of the series with itself over time, casting doubt on such 'macroevolutionary theories of periodicity or self-organized criticality' (Alroy, 2008). Another problematic technical feature of Gould's original notion of *punctuated equilibrium* is that biological evolution is never in a mathematical sense in equilibrium. Indeed, as we discussed earlier in the context of *path dependency*, the notion of equilibrium is inconsistent with that of an evolutionary process which incessantly changes with time.

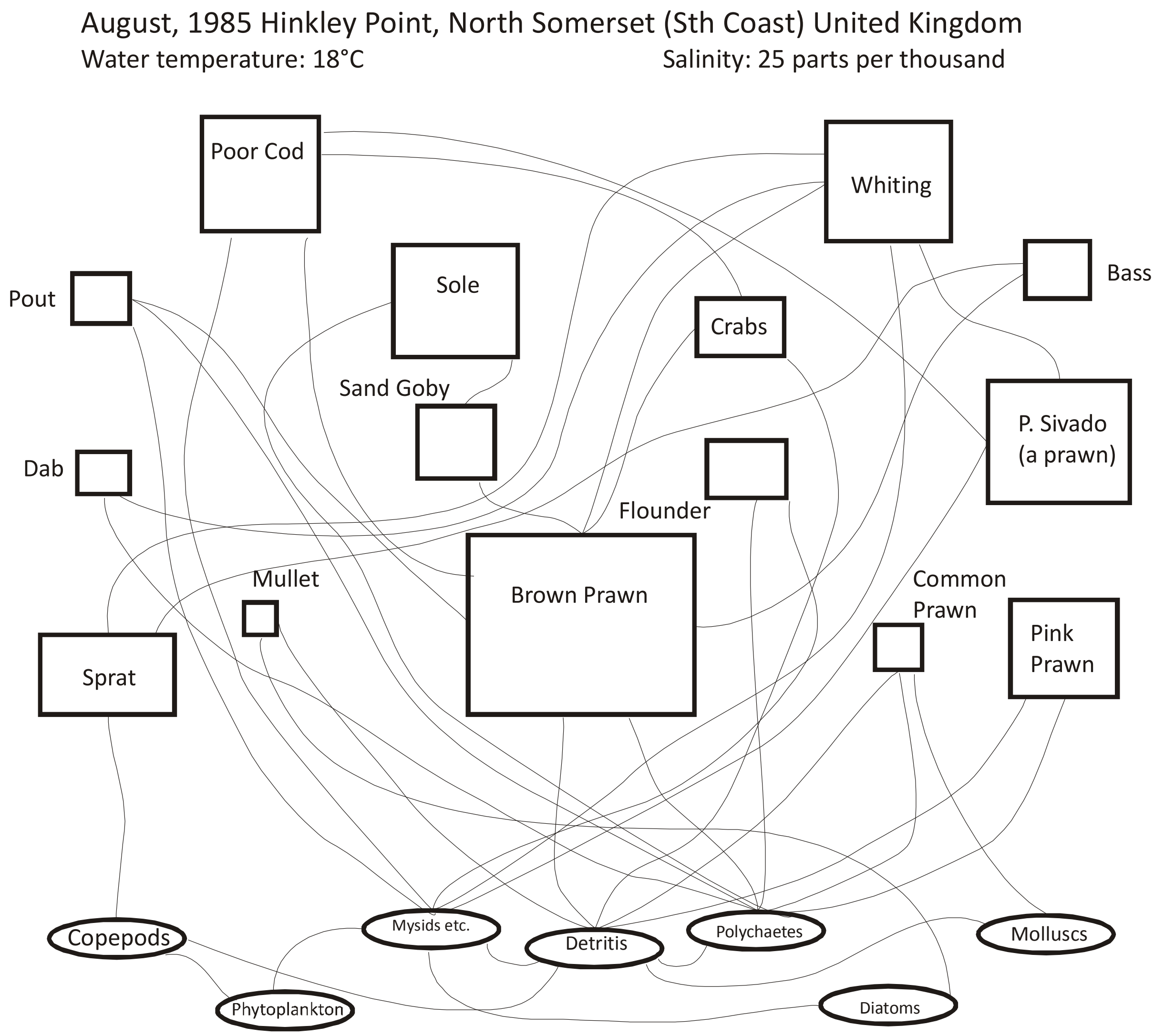
Despite these issues, the use of 'punctuated equilibrium' as an organising metaphorical concept (something akin to Schumpeter's 'gales of creative destruction') has crept into the vernacular of the social sciences. Three areas where it has had a significant influence include: in systems and network theory (e.g. Newman, Barabási and Watts, 2006); the study of the evolution of government policy (Baumgartner, 1998); and the evolution of conflicts (Cioffi-Revilla, 1998).

In the work of Watts and Newman from the SantaFe Institute, networks have been shown to self organise into a structure that has very dense and very sparse connections (Beinhocker, 2006:173-5). Some research has suggested that the cascading effects can flow from a system which exhibit a few very densely connected nodes (Jain and Krishna, 2002a, 2002b). This follows on from the study of *keystone species* in biology, which are species that are densely connected to others in a food web. The more densely connected, the greater their impact on the overall system. The idea is that the system is subject to random perturbations which affect different nodes (species) in the network. Impacts on nodes with fewer connections on the system will be minor, but the effect of small changes on nodes with a higher number of connections will be greater. This is put forward as an explanation of sudden large changes in systems which are generally characterised by stability.

In nature, examples of such keystone species might be a type of plankton or shrimp which form the foundation of a food web and upon which many other sea creatures feed upon, species which in turn are fed upon by other larger fish up the food chain. For example, a collapse or explosion in the population of shrimp would radiate widely through the marine ecosystem, eventually even effecting apex predators such as sharks. Another example, might be a species which is insignificant in terms of biomass, but fulfils a vital ecosystem function such as the predation of some sea stars on sea urchins, mussels and other shellfish, which otherwise have no predators. If the population of sea stars is removed the mussel population expands uncontrollably driving out other species, while the urchin destroys coral reefs causing massive ecosystem change. In Figure 3.10 a snapshot is taken from a marine food-web off the coast of Somerset during the summer of 1985 showing the relationships between the different species and the brown prawn, the 'beating heart' of ecosystem.

In this model it is noteworthy that total species abundance is strongly related to exogenous seasonal effects such as water temperature and salinity in the Severn estuary (where the samples were taken). One interesting feature of this time series data is an explosion in total species abundance in late 1998 (three times its usual seasonal peak) following a slightly lower than normal drop in salinity (due to increased rainfall and flow in the river Severn). While more than one contributing factor is likely to be at play here, it is a good example of how a relatively small variation beyond a certain threshold in one variable can induce very large changes in others.

Figure 3.10 Nodes in a biological complex adaptive system



Source: Seaby and Henderson, 2000

This idea of *system thresholds* has been developed most notably in the social science literature by Mark Granovetter (1978), Granovetter and Soong (1983); Thomas Schelling (1971, 1978); and Jonathan Crane (1989) and popularised in Malcolm Gladwell's *The Tipping Point*. The authors use this approach to help explain observed patterns from riot behaviour, strikes, innovation diffusion, voting patterns, migration, self-organising racial segregation in the suburbs and teenage pregnancy. Combining the notions of *keystone technologies* or *keystone institutions* with this understanding of *threshold effects*, can provide the basis of a theory that explains *non-marginal change*, or how small changes, can suddenly act to drive rapid *emergent behaviour* in a system.

The idea of *punctuated equilibrium* has also been applied in an interesting way to the study of the dynamics of public policy. Baumgartner and Jones (1993) first presented the notion that policy dynamics is characterised by long periods of stability with only incremental change punctuated by sudden radical shifts in policy paradigm. In this theory of understanding events, periods of stability are characterised as being reinforced by decision makers who follow an adaptive path due to the constraints of the costs calculation and their own cognitive and informational limits (Simon, 1957) in predicting future events and their consequences. This is seen to create a "stickiness" in institutional cultures supported by sets of vested interests which tend to persevere until overthrown by a new political paradigm such as through a shift in party control of government and, or public opinion (Lindblom, 1977; Jones, 2002; Knott, Miller, & Verkuilen, 2003).

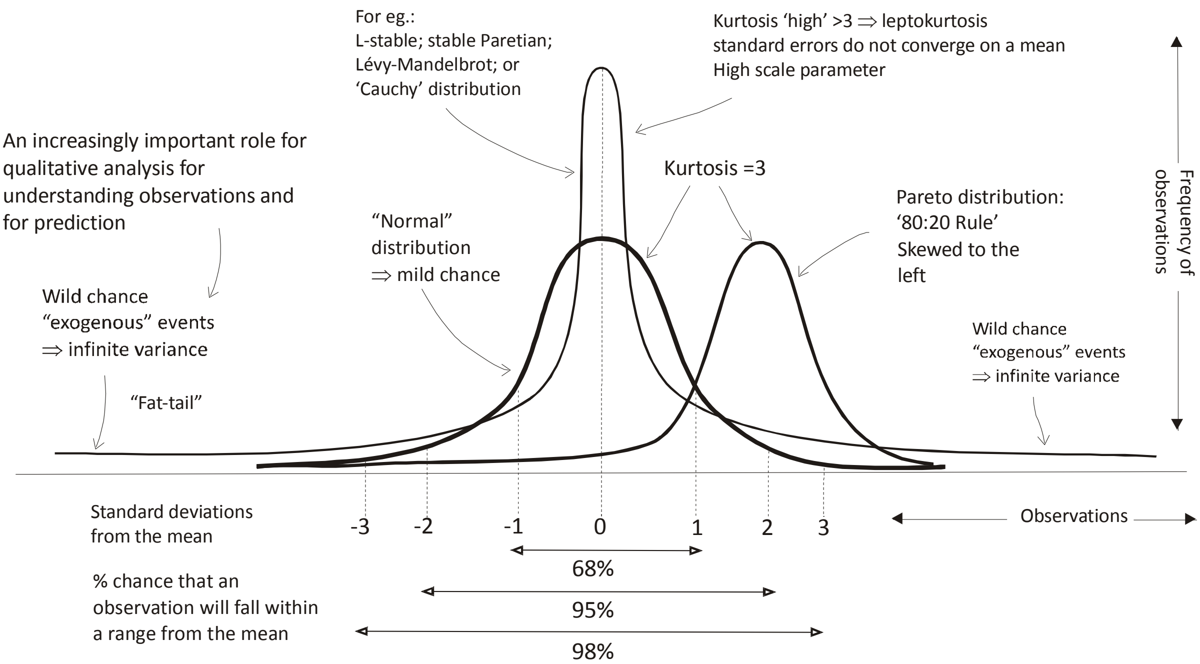
Supporting this framework, Hall (1993) has outlined a classificatory system of orders to characterise policy change within this dynamic process. ''First order'' changes occur when the calibrations of policy instruments, such as increasing the passenger safety or automobile emissions requirements manufacturers must follow, change within existing institutional and instrument confines. ''Second order'' changes involve alterations to dominant types of policy instruments utilized within an existing policy regime, such as switching from an administered emission standard to an emissions tax. ''Third order'' changes involve shifts in overall abstract policy goals (such as the shift in many countries to sign the Kyoto Protocol). Hall linked first and second-order changes to incremental processes and usually the result of activities endogenous to a policy subsystem while third-order changes were 'paradigmatic' change and driven by forces outside the control of actors.

3.12.3 Power laws: a theory of unexpected events

When the frequency of an event varies as a power of some attribute of that event – it is said to arise as a result of a *power law*. The conceptual crux of the *power law* is the tendency, in certain probability distributions, for a small number of extremely rare, but high impact events to overwhelm the standard statistical analysis based on a *normal distribution* (see Figure 3.11).

To recap, a normal distribution is what you get if you combine lots of observations which are characterised by little variations, each one *independent* of the last and each negligible when compared to the total. While individual observations matter and can differ from each other to a large degree, cumulatively across time and across the population, the observations settle into a regular bell-shaped pattern. For example, the toss of a coin: heads or tails; in biology certain physiological properties such as: blood pressure; height, the growth of hair, nails and teeth; and in physics the velocities of molecules in the ideal gas. More controversially, economic models such as the Black-Scholes assume *approximate normality* for changes in stock market price indices; and commodity price changes. In contrast, phenomena which correspond to *power laws* do not fit a normal distribution but instead are characterised by highly *leptokurtic* distributions with long probability tails (so-called 'fat-tails'), reflecting observations outside the probabilistic logic of normally distributed events. Such “outlier” observations are often excluded from analysis, on the basis that they have been influenced by *exogenous* events or *experimental error* as they do not correspond to what is, usually, a well-behaved system; or because they are by nature “too hard to predict” therefore beyond the scope of scientific analysis.

Figure 3.11 Power laws: a graphical representation



Source: Author

Let us take an example from financial markets (Mandelbrot and Hudson, 2005:24):

> From 1916 to 2003, the daily index movements of the Dow Jones Industrial Average do not spread out on graph paper like a simple bell curve. The far edges flare too high: too many big changes. Theory suggests that over that time, there should be fifty-eight days when the Dow moved more than 3.4 percent; in fact, there were 1,001. Theory predicts six days of index swings beyond 4.5 percent; in fact, there were 366. And index swings of more than 7

> percent should come once every 300,000 years; in fact, the twentieth century saw forty-eight such days. Truly, a calamitous era that insists on flaunting all predictions. Or, perhaps, our assumptions are wrong.

Mandelbrot goes on to highlight how on October 19, 1987, one of the worst days of trading during the twentieth century, the index fell 29.2 per cent – with a probability, according to standard models based on a normal distribution of less than one in 10^{50}, odds so small, Mandelbrot writes, that they have no meaning: "It is a number outside the scale of nature. You could span the powers of ten from the smallest subatomic particle to the breadth of the measurable universe – and still never meet such a number". The challenge for science in this area, therefore, is how to systematically understand *and predict*, such unexpected events – which nevertheless regularly seem to occur. In contrast to a theoretical understanding which uses a normal distribution at its foundation, the distributions which underpin *power laws* have been put forward as an alternative framework for understanding problems associated with unlikely but high impact events (e.g. Madelbrot *et al.*, 2005; Beinhocker, 2006).

The first use of distributions based on power laws took place in the social sciences, by an Italian called Vilfredo Pareto, whose name also is honoured with the articulation of the *Pareto equilibrium* – the theoretical point at which no member of society can be made better off without making someone else worse off and part of the foundation of mainstream neoclassical analysis (Figure 2.1). Pareto's investigations of the distribution of income across society, led him to construct a histogram which was negatively skewed, with a long tail stretching off to the left, reflecting his observations that the vast majority of wealth and income was concentrated in the hands of a small number of people; while the bulk of people lay in the bulging 'low-income' part of the diagram. This relationship he expressed as the following equation:

$$y = x^{-v} \tag{12}$$

Where *y* is the number of people having income *x* or greater than *x* and *v* is an exponent Pareto estimated to be around 1.5 and gave rise to the so-called 80:20 rule, where 80 per cent of wealth is said to be concentrated in the hands of 20 per cent of the population. Indeed, this builds on observations made as early as Aristotle in his *Politics*, where he comments that the balance of wealth in the richest part of society should not be allowed to exceed five times the wealth of the middle class which must remain strong in order to guard against corruption and oppression (Book VI). Pareto's theory on income distribution was put forward in 1909: he argued that it reflected some sort of natural law describing how wealth was distributed through any human society, in any time, in any country. Pareto did not stop there, however, and went on to assert:

> There is no progress in human history. Democracy is a fraud. Human nature is primitive, emotional, unyielding. The smarter, abler, stronger and shrewder take the lion's share. The weak starve, least society becomes degenerate: one can compare the social body to the human body, which will promptly perish if prevented from eliminating toxins (quoted in Mandelbrot, *et al*. 2005: 153).

Pareto's theories found fertile ground in the emerging fascist movements of Europe, and to quote his biographer Franz Borkenau (1936:18):

> In the first years of his rule Mussolini literally executed the policy prescribed by Pareto, destroying political liberalism, but at the same time largely replacing state management of private enterprise, diminishing taxes on property, favouring industrial development, imposing a religious education in dogmas.

As Mandelbrot writes, it was inflammatory stuff and while this aspect of his work was passed over in silent distaste by the economic mainstream, and while most economists willingly adopted his seminal work in other areas such as equilibrium theory, this close relationship with fascism burnt his reputation in liberal democracies. At his death in 1923, Italian fascists were beatifying him, while Karl Popper called him the "theoretician of totalitarianism", leaving evolutionary social theory with some very heavy Darwinian-'survival-of-the-fittest' baggage to carry around with it into the twentieth century.

Let's now formalize these relationships a little more clearly. A *power law* describes the characteristics of a set of observations where the frequency of some attribute of those observations varies as a power of those observations:

$$f(x) = a.x^k + o(x^k) \qquad (13)$$

Where a and k are constants and $o(x^k)$ is an asymptotically small function of x^k where k is typically called the *scaling exponent*. Now, if something is shared between a sufficiently large set of participants, there must be a number *k* between 50 and 100 such that *k%* is taken by (100-*k*)% of the participants. The number *k* may vary between 50, in the case of an equal distribution among participants to nearly 100 when a tiny number of the participants account for almost all of the resource. There is nothing particularly magical about *k*= 80 per cent, as in the case of the so-called 80:20 rule aside from a general observation that some systems share a *k* somewhere in this region of intermediate imbalance in the distribution. In varying degrees it is often used as an organising metaphor in a range of situations from the profits on customers; to the the rise of economic and political oligarchy; the magnitude of earthquakes, the size of meteorites, or sand grains or pebbles on a beach, and the frequency of extreme weather events.

A more contemporary analysis of income distribution highlights how certain kinds of economic activity can lead to a concentration of output among very few individuals in professions such as comedians, performance musicians, writers of economic text books and the popularity of PHD graduate schools (Rosen, 1981). For example, if a medical surgeon is 10 per cent more successful at saving lives than his average colleague, people are more than 10 per cent willing to pay for his services. This 'convexity in returns' means that business will tend to concentrate in the hands of the top performers and the income of surgeons will follow a power law. In another influential paper highlighting the importance of power laws, Internal Revenue Service data for the period 1966 to 2001 was analysed to assess where the benefits from American productivity growth went (Dew-Becker and Gordon, 2005). The startling results were that only the top 10 per cent of the income distribution enjoyed a rise in real income (excluding capital gains) equal to or above the average rate of economy-wide productivity growth; while the bottom 90 per cent fell behind, or were left out of sharing in the productivity growth entirely. More precisely, the wage and salary income of workers at the 90th percentile showed an increase of 34 per cent; at the 99th percentile incomes rose 87 per cent; at the 99.9th percentile incomes rose 181 percent; while at the 99.99th percent, incomes rose a staggering 497 percent. These observations prompted Paul Krugman to cast doubt on the standard assumption that productivity growth is the engine for increasing standards of living and point to the fallacy of the 80:20 rule, which points to an altogether too equitable view of society (Krugman, 2006). Indeed Krugman argues how the battle for the share of economic prosperity is not so much between owners of labour or capital; or highly educated graduates versus unskilled labour; but between highly the educated workforce (at the 90th percentile) and a new class of business plutocrats – the contrast between graduates versus oligarchs.

The notion is that while the majority of observations inhabit a certain range, there are 'long-tails' in the probability distribution which mean the once in-a-while occurrence of an extreme observation happens with much greater frequency than the quickly dipping off curves of the normal distribution imply: an extreme in income; a particularly violent earthquake or intense storm outside the standard norms of prediction. Indeed, the impacts of global warming on climate change can be easily articulated within such a framework of an increasing probability of unexpected extreme events (a 'thick-tail' getting thicker).

But if systems are prone to such large 'unpredictable events' – what do power laws suggest is the value in prediction or forecasting?

The random walk model of the normal distribution so useful for prediction, relies on three essential claims: first is the so-called Martingale condition, that your best guess for tomorrow's observations are today's and past observations; secondly, that tomorrow's price observations are independent of yesterday's observations; and thirdly, that all observations, taken together vary in accordance with the regular bell-shaped curve. Mandelbrot's work suggests that while the first condition may be useful, the second two in many cases are simply false. In terms of the principles we have discussed in this review, this is the equivalent of recognising the empirical reality of path dependence; and secondly, dispensing with the rational actor model. What seems necessary, therefore, is a type of reasoned history – drawing on past observations within an analytical framework to make predictions based on a full suite of quantitative and qualitative tools. Fittingly, for our context here, Mandelbrot (2005:276) concludes with an example taken from the consequences of extreme weather:

> On the night of February 1, 1953, a very bad storm lashed the Dutch coast. It broke the famous sea dikes, the country's ancient and proud bulwark against disaster. More than 1,800 died. Dutch hydrologists found the flooding had pushed the benchmark water-level indicators, in Amsterdam, to 3.85 meters over the average level. Seemingly impossible. The dikes had been thought to be safe enough from such a calamity; the conventional odds of so high a flood were thought to have been less than one in ten thousand. And yet,

further research showed, an even greater inundation of four meters had been recorded only a few centuries earlier, in 1570. Naturally, the pragmatic Dutch did not waste time arguing about the math. They cleaned up the damage and rebuilt the dikes higher and stronger.

3.13 Conclusion: Out of Equilibrium

Part One of this thesis has described the main features of the treatment of technological change through the contrasting theories of mainstream neoclassical equilibrium analysis with more evolutionary based theories. While it should be acknowledged that there is some overlap between these two bodies of theory – particularly in the areas dealing with increasing returns to scale, it is argued here that this distinction is not only a useful a pedagogic device, but it also crystallises some of the most important competing theoretical narratives that both explicitly and implicitly frame and therefore shape public policy.

In this Chapter, the 'evolutionary-turn' in the social sciences has been summarised. Starting with a brief overview of some of the major foundational evolutionary social theorists, such as Marx (1967[1938]), Veblen (1898, 1919), and Schumpeter (1982[1911] and 1974[1942]) – Paul David's (1895) and Brian Arthur's (1994a) theory of *path dependence* is explored. This theory illustrates one of the most fundamental points of inconsistency between the 'mainstream' and 'heterodox' paradigms – the logical contradiction between the notion of 'equilibrium' with that of a historically embedded, constantly *evolving* adaptive system. Indeed, so profound is this point, many social evolutionary theorists themselves have found it difficult to find an alternative governing metaphor for the economic system. The crux is that once a system has reached equilibrium it implies a stasis where there is no impetus for change emerging from within the system. This is logically inconsistent with the notion of an evolutionary system where the engine of economic change – technological innovation – is constantly in flux.

This reluctance to let go of the language of mainstream economics has given rise to heuristically confusing attempts to re-engineer the concept of equilibrium into evolutionary terms – for example, lock-in to one of a multiplicity of different "equilibrium pathways" through increasing return effects (Brian Arthur); or to various economic "basins of attraction" (Paul David). Such efforts can be grouped under the notion of a "punctuated equilibrium" – whereby the evolutionary process of ongoing change is interrupted by a temporary stasis - a momentary utopia or "end of history" to borrow Fukuyama's (1992) turn of words . Economic geographers have pointed to this inconsistency, and questioned just how useful the idea of equilibrium is as a heuristic tool in the evolutionary process, if it only exists but only for the briefest flash of a theoretical moment (Martin, 2010).

The title of this conclusion reflects the growing dissatisfaction with the outcomes generated from regulations informed by economic models built on notions of equilibrium which in the context of the 2008 financial crisis and economic recession, have spilled over into a crisis for economic thinking. For example, writing in *Science*, Brian Arthur (1999:4) puts forward that:

> …after two centuries of studying equilibria – static patterns that call for no further behavioural adjustments – economists are beginning to study the general emergence of structures and unfolding patterns in the economy.

One response to this agenda has been the inauguration of the Institute for New Economic Thinking by George Soros who's own idea of *reflexivity* – that markets tend to influence perceptions of reality, which in turn feedback into markets – has a strong evolutionary basis. The agenda Soros seeks to influence in this regard is (Rappeport, 2009):

> To inspire a groundswell of support from students that will "shift demand" at universities to include economic ideas that are more reality based and less focused on rigid mathematical models.

In stronger words, Martin Wolfe (2009) from the Financial Times writes:

> Another ideological god has failed. The assumptions that ruled policy and politics over three decades suddenly look as outdated as revolutionary socialism.
>
> "The nine most terrifying words in the English language are: 'I'm from the government and I'm here to help.'" Thus quipped Ronald Reagan, hero of US conservatism. The remark seems ancient history now that governments are pouring trillions of dollars, euros and pounds into financial systems.
>
> "Governments bad; deregulated markets good": how can this faith escape unscathed after Alan Greenspan, pupil of Ayn Rand and predominant central banker of the era, described himself, in congressional testimony last October, as being "in a state of shocked disbelief" over the failure of the "self-interest of lending institutions to protect shareholders' equity"?

The purpose of including these statements is they suggest that the long-held dissatisfaction with the mainstream neoclassical paradigm expressed by 'evolutionary' or 'heterdox' economic theorists has spread out of the academy and into the popular discourse – with potentially profound implications for politics, policy and regulation. In Table 3.3 below a synthesis is presented as to what have been summarized as the key points of differentiation between these agendas.

Table 3.3 Ideas that distinguish evolutionary theory from equilibrium theory

	Evolutionary theory	**Equilibrium theory**
Dynamics	Open, dynamic, nonlinear systems, far from equilibrium	Closed, static, linear systems in equilibrium
Agents	Modelled individually; use inductive rules of thumb to make decisions; have incomplete information; are subject to errors and biases; learn and adapt over time	Modelled collectively; use complex deductive calculations to make decisions; have complete information; make no errors and have no biases; have no need for learning and adaptation (they are already perfect)
Networks	Explicitly model interactions between individual agents; networks and relationships change over time	Assume agents only interact indirectly through market mechanisms (e.g. auctions)
Emergence	No distinction between micro and macroeconomics; macro patterns are the emergent result of micro-level behaviours and interactions.	Micro and macro economics remain relatively separate disciplines
Evolution	The evolutionary process of differentiation, selection, and amplification provides the system with novelty and is responsible for its growth and	No mechanism for endogenously creating novelty or growth

	complexity	
Ethics and society	Observed: satisficing altruistic punishers in evolving social groups	Utilitarian: optimising rational self-interested individuals
Time and equilibrium	Path-dependency: many unused resources and new business plans in response to threats	Full employment forever: higher GDP growth ruled out by assumption; no double dividend for policy
Uncertainty	Non-linear: catastrophic surprises are inherent in complex systems	Normal: distributions derived from the past; use of "certainty equivalence"
Technology	Induced: by climate policies	Exogenous: CGE and growth models have a limited role for feedbacks via technology
Treatment of values	Values formed by social groups; multiple values; no optimum;	Individual independent preferences; Monetized social welfare; an optimal solution;
Treatment of location effects	Place of pollution and transmission of effects over distance is critical; geography matters; diffusion of effects can makes clean-up difficult	No treatment of place in elementary theory; all activity at points in space; limited consideration of transport costs and diffusion effects
Treatment of temporal effects	Non-linear systems assumed with chaotic behaviour; time and duration of pollution and effects essential to problem; dynamic analysis; irreversibilities (through accumulation of stocks)	Existence of equilibrium assumed; limited treatment of time lags in elementary theory; static analysis a strong feature; implicit symmetry in timing; and reverse flows possible if costs overshoot
Theoretical	Highly context specific; maturing but fragmented	Based on coherent theory; generally applicable to many

consistency	theory; emphasis on pragmatic solutions rather than grand theory building	problems; draws on massive body of economic theory

Sources: Beinhocker (2006:97); Barker (2008)

Such tensions have been present for a long time, and the mainstream equilibrium paradigm can very usefully be thought of as being lock-into in its own path-dependent evolutionary process. For example, in 1993 a *Financial Times* journalist wrote:

> If the profession is misunderstood, it has nobody but itself to blame. It worships mathematical technique, but pays little attention to the behavioural and institutional forces at play in the real world – which is too messy to model with tidy equations. It has lost its relevance by trying to pretend economics is a "hard science" totally divorced from such related subjects as politics, psychology and sociology. (M. Prowse, 'A wake-up call from Laura Tyson', January 18, 1993, quoted in Coyle, 2006).

However, just as a useful technology may not break through into the socio-economic mainstream it is also a realistic outcome that the ideas of evolutionary theory, such as manifested in economic and political geography (e.g. Nigel Thrift, 2005) will not break through into the academic, business and political mainstream.

For many, a stronger evolutionary approach in the social sciences offers a way forward towards a more pragmatic regulatory culture – a shift away from an ideaologically driven 'market-based logic', towards more 'evidence-based policy' approach informed by 'what works' garnered from policy experimentation and learning.

Viewing the economy through an evolutionary lens attempts to change the debate away from the battle ground between those who believe in strong interventionist action versus more 'market-based' *laissez-faire.* Instead, the common finding in this strain of research is that socio-technological structures can crystallize around small events. Furthermore, the idea of lock-in around development pathways suggests that governments should seek to push the system gently towards economic structures that can grow and emerge naturally – as Brian Arthur puts it, what is needed from government is "not a heavy hand, not an invisible hand, but a guiding hand" (Arthur, 1999:2).

Part Two

Empirical Analysis

Four papers on the shift to the

low carbon economy

Introduction to Part Two

MICHAEL SANDEL: *We're living with the economic fallout of the financial crisis and we're struggling to make sense of it. One way of understanding what's happened is to see that we're at the end of an era, an era of market triumphalism. The last three decades were a heady, reckless time of market mania and deregulation. We had the free market fundamentalism of the Reagan-Thatcher years and then we had the market friendly Neo-Liberalism of the Clinton and Blair years, which moderated but also consolidated the faith that markets are the primary mechanism for achieving the public good. Today that faith is in doubt. Market triumphalism has given way to a new market skepticism. Almost everybody agrees that we need to improve regulation, but this moment is about more than devising new regulations. It's also a time, or so it seems to me, to rethink the role of markets in achieving the public good. There's now a widespread sense that markets have become detached from fundamental values, that we need to reconnect markets and values. But how?*

Professor Michael Sandel,

2009 Reith Lecture 'Markets and Morals'

If the dialogue in the introduction to Part One, provided an example of how individuals can view themselves as consumers, rather than citizens; and how leaders of public opinion and policy have taken on what some call the 'values-neutral' market-based logic inherent in the neoclassical theory of consumer choice; then in his Reith Lecture, three years later, Professor Michael Sandel crystallizes these sentiments with his argument that 'without quite realising it, without ever deciding to do so, we drifted from having a market economy to being a market society'.

In Part One, the theoretical background to understand such concerns was established by contrasting the treatment of the nature and direction of technological change first, as described by equilibrium-based neoclassical theory in Chapter Two; and then secondly, through the evolutionary-based 'history-matters' logic of path dependency and complex systems theory in Chapter Three. This review of the literature contributed to a synthesis of some of the main theories of social and political change presented in Chapter One. In the search for a new paradigm to replace what Sandel calls the era of market triumphalism, it is suggested that economics can look to putting the politics back into the study of economics - a reinvigorated *political economy*; an agenda, as argued in Chapter One, geography is well placed to contribute to.

However, rather than viewing the models of neoclassical economics as the anti-thesis of more 'realistic' evolutionary institutional approaches, it was argued in Chapter One that they can be seen to operate within specific boundary conditions of the evolutionary model. It was suggested that the neo-classical framework is good at describing short-term incremental change within a stable technological regime, but evolutionary theory is more relevant for understanding long-term change between regimes and in explaining differences between geographic regions. For example, after correcting for market failure through 'getting the prices right' the mainstream neoclassical model is disinterested regarding qualitative elements of technological change. There is little choice to be made between, say, nuclear energy, or a more distributed network based on micro generation such as wind, biomass and solar energy or between electric vehicles or petroleum-fuelled cars.

The policy prescription is to simply put price incentives in place and 'let the market decide'. It is suggested that this approach tends to favour the criteria of economic efficiency over other social values such as equity or environmental protection; and favours incumbent agents and their associated technologies over more radical technologies and new agents.

Under an evolutionary institutional approach, the qualitative dimensions of the system can be separated out into technological 'niches' and 'regimes' which can be actively supported or undermined. Evolutionary methods emphasise the socio-political and socio-cognitive dimensions of technological changes as well as quantitative technological and economic facts.

For example, a broader political debate over the issue of climate change and the relative desirability of low or high carbon technology, would encourage actors to change their behaviour not just because they can avoid paying a pollution charge; but because it becomes morally right thing to do. Vigorous political debate over disputed social objectives also has the power to make explicit competing values and shift institutions to support those values that best reflect societal norms. This shifting of values is much more profound than, say, the implementation of an emissions trading scheme, which is, after all, merely a mechanism to realise such values.

However, empirical studies have also highlighted price-based policy as an important driver of clean energy technology. Thus it can be argued, that while the tool kit is significantly broadened with an evolutionary approach the theoretical dialectic between the neo-classical and evolutionary approaches may exaggerate the differences with regard to the driving forces of clean energy technology. Such observations provide the impetus to develop a more integrated approach which positions neoclassical axioms within a broader evolutionary model. This would seem to offer a more robust framework to explain past energy investments, and a platform for predicting the future response to different policy scenarios, than using either theoretical approach on its own.

This epistemic perspective informs the empirical part of this thesis in Chapters 4 to 7. First, in Chapter 4, socio-technical change is investigated in the context of the diffusion of energy efficient lighting in Germany. Germany was chosen as a country to base the case study as it is one of the global technological leaders in lightbulb manufacture, combined with having a highly tech-savvy and environmentally conscious consumer population. This research also focused on Germany as a result of a research sabbatical undertaken at the Institute of Psychology, Department of Personality and Social Psychology, at the University of Otto-Von-Guericke, in Magdeburg which facilitated part of the work.. In this paper, it is suggested that price incentives h had a limited effect on encouraging the diffusion of CFLs and that non-price regulatory action was very effective at changing consumption. What is particularly interesting is that the *announcement* of the staged CFL ban seemed to have a significant positive impact on CFL diffusion around a year in advance of the ban's actual implementation. The implementation of the ban actually prompted an increase in the sales of the about-to-be-banned incandescent lamps – a behavioural response attributable to a group of light bulb 'hamsters' or hoarders (although monthly CFL sales were still growing over this period). These observations suggest that the ban of the incandescent bulb sent a strong moral signal to consumers that traditional bulbs were 'bad'. It is also argued that the ban on incandescent bulbs supported a much deeper institutional shift in the forces acting on light bulb purchasing behaviour than would have been possible using price incentives alone.

In Chapter 5 the relationship between the expression of environmental value in 'the economy' is distinguished from the externalities inherent in 'the market' in the context of the case for the creation of a market for CO_2 pollution permits to incorporate these broader environmental values into market transactions. In making this case, the advantages and disadvantages of emissions trading are compared and contrasted with other policies such as taxation and direct regulation as well as considering the political economy of the various options.

Chapter 6 builds on this framework to look at the political economy of implementing a domestic mandatory emissions trading scheme in Australia – the CPRS. In this chapter, the influence of 'Kyoto' – the international treaty of the UNFCCC - is identified at having exhorted a powerful norm over Australian politics, however this did not necessarily support the implementation of emissions reducing policies- an observation the paper calls 'the veil of Kyoto'. This highlights the importance for meaningful domestic mitigation legislation *in addition* to norm building.

In the final Chapter of Part 2 the political economy of climate change and greenhouse gas reduction in Russia is examined. What makes Russia especially significant as a case study is that, according the accounting rules of the Kyoto Protocol, GHG emissions in Russia have fallen around 51% between 1990 and 2008. With around 36% of electricity generation in Russia coming from zero carbon sources such as hydroelectricity and nuclear energy, this means Russia can be said to have undergone a virtually unparalleled shift to a lower carbon economy, albeit for reasons far removed from climate policy. These drivers are explored in detail and a forward GHG mitigation agenda is identified, taking into account Russia's unique social and economic interests.

Chapter 4 On the question of individual freedom versus state control in climate policy: a study of the diffusion and regulation of CFLs in Germany

4.1 Introduction

The technological diffusion of compact fluorescent lamps (CFLs) is now progressing at a rapid pace worldwide. Introduced around 130 years ago, conventional incandescent lamps convert only around 5 to 10% of the energy they consume into light, the remainder being emitted as heat, and are far more inefficient than virtually every other lamp on the market.

For the consumer, lighting may represent up to a fifth of household electricity consumption. Although CFLs are costly up front, they can last up to 12 times longer using a fraction of the electricity compared to an incandescent lamp. The most common concerns with switching over is their higher purchase price and perceptions of the aesthetic appeal of CFL light. However, this can reduce the average household's total electricity consumption by up to 10-15% and save around €50 each year, assuming 20 traditional lamps in the household are switched over to CFLs and taking into account the higher CFL purchase price (European Commission, 2009).

With climate change concerns and the economic benefits of these efficiencies in mind, after years of limited success with demand-side management programs involving information and subsidy schemes, many countries including the United States, the European Union, Russia, Brazil, Argentina, Canada and Australia are implementing phased bans of incandescent lamps. The European Commission (EC) estimates that by 2012 its regulatory ban will save around 40 TWh, or roughly the electricity consumption of 11 million households, reduce CO_2 emissions by 15 million tonnes per year and contribute €5 to 10 billion into the economy (EUROPA, 2009). In contrast, the EC estimated that to achieve the equivalent behavioural change through the price mechanism, it would have had to institute a ten-fold increase in taxation on incandescent lights.

However, the use of a regulatory ban has been heavily criticised by some as restricting consumers' basic freedom to choose and of forcing an immature technology onto the market which does not meet consumer needs. For example, German MEP Holger Krahmer of the FDP party criticised the move as 'light-bulb socialism', and in the United States a @Light Bulb Freedom of Choice Act' has been proposed in response to the ban.

This suggests the use of the incandescent lamp ban has created a powerful flash-point in the debate between 'market-based' versus 'command and control' policy mechanisms. Using theoretical insights drawn from evolutionary, institutional and behavioural economics, this paper interrogates this debate and uses the diffusion of CFLs in Germany as a case study.

To position this paper's contribution to the wider climate change literature, the mainstream economic approach to climate policy is considered alongside an evolutionary and institutional approach which highlights how systematic behavioural 'anomalies' can impede the functioning of the perfect market. This is considered alongside a review of the main barriers and incentives to CFL diffusion. This leads onto a discussion of how different institutional forces and modes of decision-making can interplay along a spectrum with imposed structure ('command-and-control') on the one hand and individual agency ('market-based') on the other. A purely market-based approach implicitly assumes that consumers have complete information and are free from self-defeating behavioural biases. In recognition of the problems with this, a more structured approach shifts decision-making to more collective processes.

These ideas are followed by a case study set in Germany involving the analysis of consumption data of different lamp types, complemented by a survey of 1711 households. This survey evaluated CFL ownership, awareness, purchasing behaviour and perceptions as to the barriers to CFL market success. It was conducted over the internet in September 2009 by Grass Roots, an international market research company using their representative database across Germany.

The empirical findings suggest that after years of little growth, a significant upswing in CFL sales and drop off in incandescent sales corresponded with announcements related to the phased ban of incandescent lamps. This begins with the surge of global media attention on CFLs following the Australian government's decision to ban incandescent lamps in February 2007. This is followed by surges in attention (as reflected in historical Googletrends search volume data integrated with news reports) related to the European Commission's announcement of the phased EU ban in June 2008 and the lead up to its implementation in September 2009 and 2010. From this data, it seems that the ban has been effective at changing behaviour *in advance*, of its implementation, lending support to the notion that it has acted as powerful framing device on the CFL purchase decision. One interesting observation which tempers this positive result is that while CFL sales steadily rise over this period, sales of incandescent bulbs have temporarily picked up in the lead up to the ban’s actual implementation showing evidence of hording behaviour, known as ‘glühbirne hamstern‘ (light bulb hamsters).

In conclusion, it is argued that the tensions highlighted in this paper should be viewed not as idealistic dualisms - for example, as ‘markets’ versus the ‘state’ or ‘liberty’ versus ‘control’ - but as instances where society has evolved institutions to help achieve ‘good outcomes’ - especially in areas where our stated intentions differ from our actions, or where public goods and externalities are present. Acknowledging that this is, in some part at least, a normative process - a caveat should be given that to help avoid authoritarian abuses, the formation of these institutions is best played out with transparent review, evaluation and public discussion through accessible, accountable political structures.

It is not the purpose of this paper to offer such a normative prescription on the ‘correct balance’ between command-and-control structure and market-based individual choice. Rather, it is the more modest aim to show how applying the heterodox insights taken from institutional, evolutionary and behavioural economics can be useful in interrogating the interrelationships between individual choice, public policy and technological change and open important avenues of investigation not easily accessed with more mainstream neo-classical ‘market-based’ based economic analysis.

4.2 Freedom versus the state and the drive for greater energy efficiency

The 'revolution in energy efficiency' began in the 1970s stemming from the fear of fuel shortages following the first oil crisis. In the United States, President Jimmy Carter appeared on television symbolically wearing a sweater indoors, declaring that the energy crisis was the moral equivalent of war. Public unease around energy security led to aggressive policies in areas such as product standards, building codes and renewable energy subsidies. However, through the 1980s and into the 1990s as the perception of shortage lessened, so too did the imperative for strong interventionist government action. Combined with the general move to liberalise energy markets, the focus shifted to the demand management - informing and supporting the decisions of consumers, rather than supply-side solutions involving manufacturers and retailers (Blumstein, Goldstone and Lutzenhiser, 2000). More recently, the imperative for energy efficiency has been renewed in response to climate change concerns and the need to reduce energy use from fossil fuels.

In the energy efficiency literature there has been a long tradition of research on the cost effectiveness of demand side management tools (see Gillingham, 2000; and the MURE database[1] for reviews in the context of the United States and European Union, respectively). The case for energy efficiency is powerful: if cost effective investments are available to reduce energy and save money, then the market should provide the incentives necessary to facilitate this, especially in the context of rising fossil fuel

[1] www.mure2.com is an information platform incorporating qualitative and quantitative assessment of energy efficiency policies in Europe. For most of the measures the following studies were used Markewitz/Ziesing (2004), IER/Prognos (2004), Bach (2001) and Kleemann/Hansen (2005).

related energy prices. However, numerous barriers exist which discourage these investments, suggesting some form of government intervention may be necessary.

For example, Howarth and Anderson (1993) and Howarth and Sanstad (1995) investigated how consumers have employed discount rates of between 20% and 200% in making energy efficiency decisions when buying appliances. This work exposed the shortcomings of the rational model: faced with product selection decisions a rational individual with complete information would not pass up an efficiency investment which could yield up to a 200% return. Furthermore, higher discount rates were observed particularly among the poor who *a priori* would have the most to gain from paying less on the life cycle costs of appliances. Applied across a wide range of energy efficient investments, such empirical observations have given rise to the so-called 'energy efficiency paradox' – the systematic existence of unexploited opportunities for improving energy efficiency (DeCanio, 1998).

This paradox is underplayed in the mainstream economic analysis of climate change which is grounded in the welfare economics of A. C. Pigou (1912). This has focused on establishing the costs and benefits of an emissions target or level of pollution and the optimal or most cost effective way to achieve it: usually through the comparison of the merits of either a system of tradable quotas (emissions trading); or through taxation of carbon intensive goods (e.g. Nordhaus, 2007; Weitzman, 1974; Delbeke, et al. 2010). Once targets are set and carbon pricing put in place, in typical neoclassical models of competitive markets perfectly informed consumers weigh up the costs and benefits of alternative products when making their purchases. Having 'internalised the externality of pollution' through such 'market mechanisms', the problem of energy policy is thus reduced to ensuring that energy prices reflect the full social costs of energy production and utilization.

Market-mechanisms also have the advantage of providing incentives for continuous improvement, whereas firms are seen to generally have no incentive to exceed the environmental mark set by a regulatory standard (Baumol, 1972). Conversely, the so called 'command-and-control' approach traditionally takes the form of legal regulations such as the special zoning of polluting activities, quantitative limits on the physical volumes of pollution, technology standards and so on. These are often criticised as not being dynamic and not providing incentives for further innovation beyond the standard. These alternative views of environmental management is often characterised as an ideological debate between 'freedom' and 'the state' politicising the means technological change is promoted in the economy (for a review see Brohé et al., 2009: 24-57).

Within the climate change and environmental literature, this mainstream economic approach has been criticised for paying too little attention to the historical, geographical, legal, cultural and political context of pollution abatement decisions (IPCC, 2007; Stern, 2006; Williams and Baumert, 2003; Victor, 2007, Carraro, 2007) and also of sidestepping the problems of path dependency (e.g. Grübler, 1998).

Michael Porter and Claas Van der Linde's (1995) work has also played an important role in challenging this mainstream approach by highlighting the positive role environmental regulations can play in promoting environmentally beneficial innovation and supporting economic competitiveness at the firm, sector and nation-state level (Palmer, Oates and Portney, 1995). That tighter environmental standards can not only reduce costs directly, but also spur further cost reducing innovation, boosting competitiveness – the so called Porter hypothesis – has inspired a large body of supportive empirical studies (e.g. Lanoie et al. 2008; Horbach, 2007; Costantini, and Crespi, 2007; and Kriechel and Ziesemer, 2009). However, many economists have rejected this case-study based approach by arguing such examples are special cases and that across the economy it is just as likely environmental regulations come at a net cost, as well as embodying a significant opportunity cost. For example, Jorgenson and Wilcoxen (1990) and Hazilla and Kopp (1990) use a dynamic general equilibrium model to show environmental regulations are necessarily cost adding because of the manner in which they depress other "productive" investment.

Other empirical research has shown that so-called 'behavioural anomalies' are systematic and strongly ingrained with human behaviour, suggesting we often act against our own self-interest giving rise to 'behavioural failure' (Shogren and Taylor, 2008). Led by Kahneman and Tversky (1979) these empirical insights have had far reaching implications for economics and how we understand individual decision-making (Baron, 2008).

In a review article on energy efficiency Tom Teitenberg (2010) highlights how viewing energy efficiency through the lens of behavioral failure sheds important light on the energy efficiency paradox and why policy instruments such as information strategies and monetary incentives frequently prove insufficient to promote even the most privately cost-effective outcomes. These 'errors of judgement' are profound in that they derive from human cognition. At stake is the capacity of people whatever their circumstances, roles and responsibilities to take action in the rational manner assumed by typical neoclassical models (Kruger and Funder, 2004:317). Taking this a step forward, Table 4.1 summarizes a selection of the main behavioural biases which may have a bearing on the diffusion of CFLs. This is positioned next to Table 4.2 which draws on the empirical literature to highlight the main incentives and barriers to the diffusion of CFLs that have been identified.

Table 4.1: Major behavioural anomalies of the rational actor model

Familiarity bias: people value what is familiar over what is unfamiliar, even when they have no objective reason for doing so, giving them a strong preference for the status quo.

Ownership bias: people value something they own more than something they do not, even when it is the same object.

Problem of confounding options: beyond a certain number of options, people make inferior decisions when presented with greater choice.

Impatience bias: people value time inconsistently, using a high discount rate such that immediate outcomes are weighted more heavily than outcomes in the future. In other words, people find it difficult to resist temptation and defer gratification, even when clearly in their interest to do so.

Herd behaviour: people are drawn towards the actions of others faced with the same decision, including strangers about whom they know nothing.

Framing bias: consumers choosing between product A and product B are influenced by the presence of C in the product range, even if they have no interest in buying C.

Cooperative instinct : People frequently act knowingly against their own best interests by cooperating to achieve common goals because they take into account the interests of other people.

Sense of justice : people will refuse offers that they perceive as unfair and will act to punish perceived unfair behaviour in others even if not directly involved and if the action involves sacrificing their own income.

Sources: adapted from Clark (2009) and Oxford Analytica (2009)

Despite awareness of the life-cycle benefits of CFLs consumers many consumers still do not adopt them due to their high up-front cost relative to incandescent lamps (Palmer and Boardman, 1998). Indeed, even in the era of high consumer awareness, where in 2009 87% of people cited the longer life expectancy of CFLs as a major advantage and 60% were also aware of the 12 month payback period to compensate for the higher up-front price, 89% still stated the high upfront price of CFLs as a significant disadvantage (Grass Roots, 2009). This result would seem to support the message from previous energy efficiency studies that people tend to employ an 'irrationally' high discount rate when making lamp purchase decisions.

Table 4.2: The incentives and barriers to the diffusion of CFL technology

Incentives to adoption	**Barriers to adoption**
Lower running costs – up to an 80% energy saving over the lifetime of the bulb with payoff period typically around 12 months to cover the higher up-front lamp cost.	Most CFLs are between 5 and 10 times the price of an incandescent lamp depending on CFL quality. Higher up-front unit purchase costs particularly is a barrier for the poor.
Longer bulb life of 6 to 10 years (6,000 – 10,000 hours) means less effort dedicated to replacing lamps.	CFLs take a few seconds to warm-up and reach full luminescence and will gradually fade over their life becoming up to 30% dimmer.
Environmental benefit from lower energy use and potential CO_2 emission reductions.	Information requirements to support adoption are costly. For example, improved metering to allow comparison between appliances.
Little heat wastage means reduced burning risk	A limited range of CFLS on the market means CFLs do not exist for all types of appliances and sockets.
Greater versatility: CFLs offer both 'warm' and 'cold' light options	Some people think CFLs are ugly and do not like the 'colder' light of standard CFL lamps.
A positive 'feel-good factor' associated with what is increasingly perceived as a pro-environment action	Health concerns relating to mercury content and flickering. There are up to 5 milligrams of mercury in a CFL and CFL's should be specially recycled. In order types of CFLs flickering was a problem which could adversely effect epileptics.
	Variable reliability due to poor quality standards

Sources: EUROPA, 2009; Bladh and Krantz, 2008; Vito, 2009

That is, even though they are aware CFLs are cheaper once operating costs are factored in, they place an over-emphasis on the upfront cost of the lamp in their purchase decision-making.

In this area, conservation psychology offers helpful empirical insights into the links between policy intervention, individual action and technological change (see for example: Geller 2002; Kaiser, Midden and Cervinka, 2008; Frantz and Mayer, 2009; Clayton and Brook, 2005; Van Lange and Joireman, 2008).

Writing in the *Journal of Environmental Psychology* Linda Steg and Charles Vlek (2009) review the wide ranging environmental agenda psychologists have engaged with. Regarding energy use, some studies have suggested that policies are more acceptable when they are perceived to fair and when they do not seriously affect an individual's sense of freedom (Steg and Gifford, 2005). Policies also tend to be more acceptable to people who are highly aware of the problem and who feel a moral obligation to address it, suggesting consumer awareness is a critical ingredient of market transformation.

In the area of feedback strategies, Corinna Fischer (2008) has shown that people are also more likely to save energy when they understand their bills and know how individual appliances effect the total amount of energy consumed, highlighting the importance of providing good information. Some studies have also suggested that policies which aim at increasing the attractiveness of pro-environmental activities are more effective than those aimed at penalising environmentally harmful activities (Geller, 2002); however, other studies show other circumstances where penalties are effective (Midden and Ham, 2009).

There is also a well-established discrepancy in social psychological research between how people think about issues (their attitude) and how they behave towards the issue. While some have argued that actions are the best indicator of attitudes (Campell, 1963; Kaiser, Hartig and Byrka, 2009) others place the emphasis on evaluative verbal statements (Eagly and Chaiken, 1993; Stern, 2000; Vining and

Ebreo, 2002). This inconsistency between thoughts and actions offers an important insight into how individuals can pursue a plurality of values which repeatedly come into conflict - for example, one might want to contribute to reducing the effects of anthropogenic climate change but also want the cheapest energy possible. Many of these conflicts are difficult to transform into a common value to enable a coherent calculus of cost and benefit as assumed takes place the mainstream economic model. This may help explain why people may vote in favour of a regulation that restricts their actions, for example drink driving or smoking laws, and in our case electric lamp purchases, despite the fact they could simply choose to alter their behaviour directly.

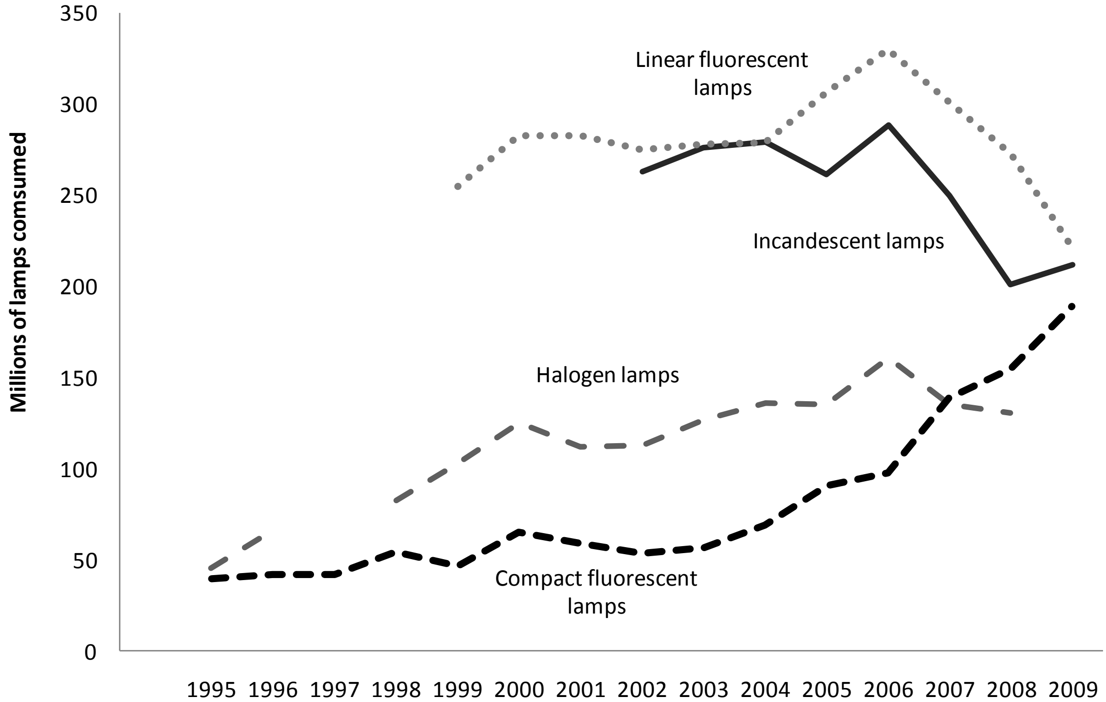
Despite these reservations towards the mainstream economic approach, a strong narrative exists in policy circles that the world is far too complex for politicians to 'select optimal policies' and, aside from providing some informational support or changing relative prices to correct for any externalities, it is best to leave people 'free to choose' and let 'the market decide' as much as possible. Market mechanisms fit comfortably within the rubric of neoclassical equilibrium analysis, where consumers select products in a way that maximise their own welfare, and by extension, best promotes the interests of society at large. On the other hand, as warned against by Mancur Olsen (1965), collective action through regulations are often cast as 'political interventions' easily corrupted by the special interests of a small powerful minority, thus working against society at large as represented by the consumer.

4.3 The shift towards energy efficient lighting in Germany

Comprising around 12% of household electricity consumption, lighting generally represents the third most significant use of electricity in the home after heating and cooling in EU countries. The four main classes of household lamp technologies include: incandescent lamps, halogen lamps, CFLs, and linear (tubular) florescent lamps (LFLs). A conventional halogen light represents energy efficiency savings of up to around 25% compared to an incandescent light and a CFL up to 80%. LFLs are also extremely efficient, lasting longer than most CFLs, and have been widely in use for some time, especially in areas demanding long operating hours such as in kitchens and industrial and public spaces.

As one of the largest and most energy efficient countries in Europe, Germany presents an important case study for the diffusion of energy efficient lighting. Germany is also characterised as an early-adopter of CFL technology, with market penetration in 2007 of 70% of households compared with 50% in the United Kingdom, 52% in France, 60% in Italy and an EU average of around 50%. In these houses the average number of CFLs in use was seven in Germany, two in the United Kingdom, two in France and one in Italy. Not surprisingly, Germany had one of the lowest lighting-consumption as-a-share-of-total-household-electricity in 2007 at 8.13%, compared with 6.43% in France, 16% in the United Kingdom and 35% in Romania (Bertoldi and Atanasiu, 2007). Palmer and Boardman (1998) provides a separate stocktake for some of these values in 1997 showing how far each country has come over this ten year period. In 1997, the proportion of households with a CFL was 51% in Germany, 23% in the United Kingdom, 55% in Italy (with no data available for France) with the average household owning two, one and one CFL respectively. More recently the survey used in this paper estimated that German CFL market penetration late in 2009 was at 84% of households (Grass Roots, 2009).

Figure 4.1 Diffusion of major electric lamp types in Germany



Source: Eurostat, 2010[3]

3 Data is sourced from the Prodcom Annual Sold (NACE Rev. 1.1) database; codes: 31501293 and 31501295 (Halogen lamps), 31501300 (Incandescent lights), 31501510 (Linear Fluorescent Lights), 31501530 (CFLs); Using the standard approach taken by the Commission, apparent light bulb consumption is taken as domestic production + imports – exports; some production data not available for earlier years limiting the comparison for every product except for CFLs as Germany has no domestic production of this class of lamp. It is worth noting that despite being a significant global producer of other electrical lamps, Europe is not a significant producer of CFLs and sources its imports mostly from China. It is also worth noting that, as explained the report by Vito (2009), a substantial proportion of halogen lamp sales are in the commercial sector and maybe underreported in Eurostat because sales of 6 and 8 packs are counted as 1 lamp and sales along with luminaires are excluded(floor standing light fixtures).

A major early policy development was the Energy Labelling Directive (92/75/EEC) which, since 1998, has required manufacturers to indicate light bulb efficiency on packaging. Over this time CFL diffusion was also supported by a range of demand-side programs (for a review of German programs see Fraunhofer ISI, 2006). For example, in Germany initiatives included: the Bright North Rhine Westphalia project where 80 utilities participated in a programme distributing 500,000 CFLs directly to customers who were then encouraged to buy more via a voucher programme; and a programme carried out by Stadwerke Hannover where consumers were given a 5.11 euro rebate for each CFL purchased.

However, despite these efforts the European Commission stated in explanation of the decision to implement a phased ban that “consumers failed to significantly move towards the more efficient choice”. It was noted that, “the higher up-front purchase price constituted a psychological barrier, even though this initial investment paid off within a year and brought even more benefits over the complete life-cycle of the CFL” (EUROPA, 2009). In Germany, this can be seen by the decade of stagnant CFL sales up to 2005-06 in Figure 4.1.

A turning point in Figure 4.1 seems to occur in early 2007 with sales of CFLs increasing from around 100 million units to 150 million units and sales of incandescent lamps dropping from around 300 million to 200 million over the same period. A major event which could help understand this was the increased media and public attention on CFLs following the announcement in February 2007 by the Australian Minister for the Environment, Malcolm Turnbull, to ban the incandescent light bulb in Australia by 2010. For example, in an article in Der Spiegel on 20

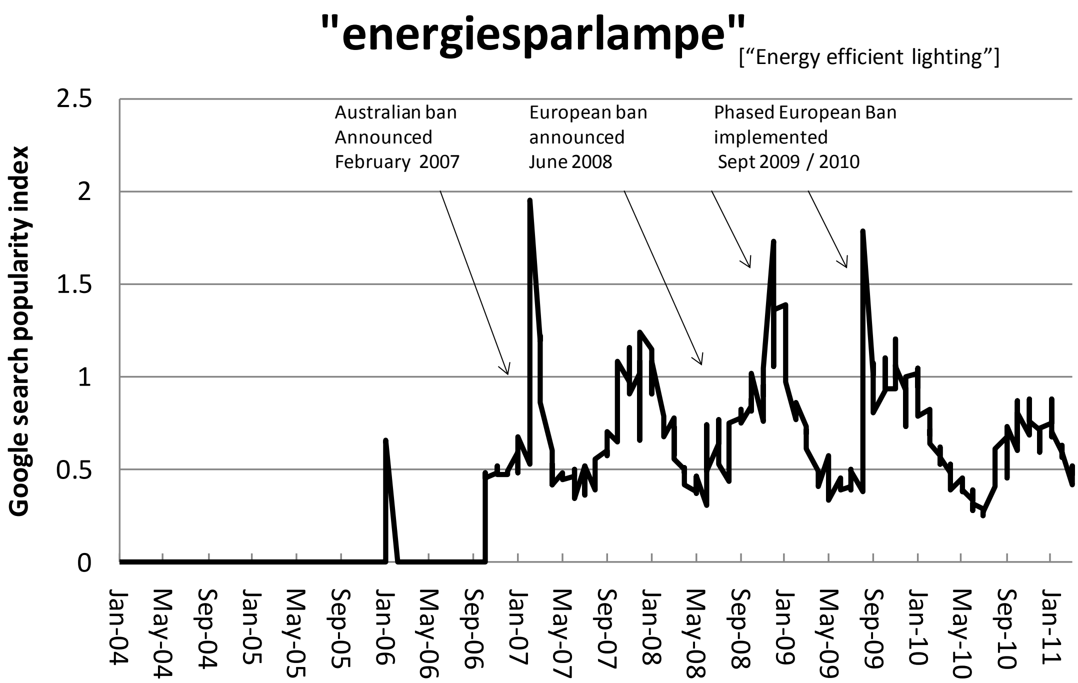
February, 2007 Björn Hengst writes how Australia, the country that rejects the Kyoto Protocol and is the largest exporter of coal in the world has suddenly moved to ban inefficient light-bulbs in 2010, reducing emissions by four million tonnes:

> Now, Australia wants to be world leader in banning conventional, inefficient light bulbs - the modern energy saving lamps are not only durable but are also four to six times more efficient. Even a small step can have a big effect, Turnbull stated: "If the rest of the world follows our lead, this will mean significant energy savings."

While the German media carried a degree of indignation at being lectured on green policies by a perceived climate policy laggard, Turnbull's announcement sparked significant debate in Europe which a year later adopted a similar ban at the EU-level.

For March/April 2007 the sales growth rate soared to 143% (compared to March/April the year before) and over the course of 2007, total sales value and volume climbed 91% and 73% respectively. These events have led some analysts to connect the two events (see Bross and Pirgov, 2010) and seem supported by data from Googletrends (Figure 4.2), which show spikes of public interest in energy efficient lighting corresponding to the announcement and implementation of the Australian and European bans. While some seasonal variation with peaks in December/January might be expected in this data due to the longer operating hours of electric lamps in Germany over the northern European winter and thus higher interest in lamp replacement and substitution, this background effect is unlikely to explain the large spikes in public interest evidenced by Googletrends for the months of February/March 2007, and September 2009/2010.

Figure 4.2 Public interest in energy efficient lighting



Source: Googletrends, author

In June 2008, the European Commission announced its own intentions to incrementally phase out incandescent lamps (Table 4.3). This announcement corresponded with an increased demand for CFLs in the months of July/August 2008 of 15% (compared to the same period in 2007); of 31% in September/October; and 13% in November/December (Bross and Pirgov, 2010). It is noteworthy to observe that spikes in CFL purchasing correspond to the increased media attention and public interest that key points in the regulatory process generate such as in the month of September.

One interesting departure from this narrative of technological transformation in the light bulb market is that while CFL sales continued to rise as the implementation of the phased ban was brought into effect, sales of incandescent lamps also experienced a spike. Over the first six months of 2009 leading up to the bad GfK, a market research firm, observed that sales of incandescent lamps leapt up by 34% (Financial Times, 2009). This seems particularly significant given the declines in both halogen and LFLs over the same period and suggests that some consumers were reacting against the implementation of the ban by stockpiling the available incandescent bulbs which were about to be taken off the market.

Table 4.3 Simplified table for European incandescent lamp phase out

Phase		**The future distribution of the following lamps will be prohibited**
1	September 1st, 2009	Frosted lamps (exception: EEL Class A bulbs) Clear lamps >= 80 Watts
2	September 1st, 2010	Clear lamps >65 Watts
3	September 1st, 2011	Clear lamps >45 Watts
4	September 1st, 2012	Clear lamps > 7 Watts
5	September 1st, 2013	Increase of quality standards
6	September 1st, 2014	Lamps with EEL Class C

Source: Bross and Pirgov, 2010

4.4 Public Awareness and the incentives and barriers to CFL adoption

In September 2009, corresponding with the first phase of the staged ban on incandescent bulbs, the international market research firm Grass Roots undertook a survey to evaluate public perceptions and the incentives and barriers to CFL adoption in Germany. Out of 9,500 people sent the survey via e-mail, 1,711 individuals responded. Participants were drawn from the firm's network across Germany and weighted to be representative of gender and age. While fairly representative, one limitation of the survey is that it was limited to participants with access e-mail – likely to be a more technologically aware and flexible group..

Overall, 96% of those asked were aware of the phased ban, 87% were aware of the long life expectancy of CFLs and 65% were aware of the higher environmental costs of recycling CFLs due to their mercury content. This last point in particular implies a relatively high level of refinement in public awareness of the advantages and disadvantages of using CFLs – supporting the notion of consumer lock-in with old technologies.

Table 4.4 summarises the key results from the Grass Roots survey. Several points are worth highlighting. First, is the observation that although 87% of respondents were aware of the higher life expectancy of CFLs and 60% understood the payback period to be less than 12 months, with 73% aware of incandescent lamps' lower life expectancy, 90% of respondents saw the 'high price' of CFLs as a barrier to them purchasing them and correspondingly, 89% saw the low price of incandescent lamps as an advantage.

These observations seem consistent with other studies mentioned earlier suggesting that consumers place significant attachment to the higher upfront cost of the lamp despite often being aware of the lower life-cycle costs of CFLs.

Table 4.4 Survey results: CFL advantages and disadvantages

Incentives for CFL adoption	Barriers to CFL adoption
60% of people thought the CFL payback period was 12 months or less.	89% mentioned the low price of incandescent lamps as an advantage.
87% people aware of longer CFL life expectancy and 73% recognised incandescent lamps' 'low life expectancy'.	90% mentioned the 'high price' of CFLs as a disadvantage.
86% recognised incandescent lamps' 'high energy use'.	40% thought the payback period was longer than 12 months.
19% and 18% of people responded that CFLs had better light intensity and optics respectively.	8% stated CFLs had lower life expectancy and 2% believed they used more energy.
12% , 9% and 8% responded that disadvantages of traditional lamps were their 'light intensity', 'optics' and 'uncomfortable light colour'.	16% believed incandescent lamps to have longer life expectancy and 10% referred to their low energy use.
	68% and 66% of people responded that 'optics' and 'unpleasant light colour' were major disadvantages of CFLs.
	57% and 69% of people responded that 'lower light intensity' and 'better light intensity' were disadvantages of CFLs .
	77% and 74% of people responded that 'a comfortable light colour' and better 'optics' were advantages of the incandescent lamp.
	65% mentioned that the 'higher environmental impact of recycling CFL' was a disadvantage.

Source: Grass Roots (2009)

This divergence between purchase and operating costs can also give rise to the problem of split incentives. Two examples are worth noting. Electricity companies may well be in the best position to advise consumers on the most energy efficient products and also create sockets and other fittings compatible with new technologies such as CFLs. However, because they profit from selling more electricity, not less, it is not necessarily in their interests to promote these products, indeed it may be in their interests to hinder their adoption. This may go some way to explain why demand side management programmes implemented by utilities in a liberalised electricity market have had such limited success, despite the strong case for significant cost savings at the user level.

The survey also highlights how CFL purchasing behaviour is not a simple calculus about the most cost effective means to light a home. A significant number of respondents viewed the aesthetics of CFLs unappealing with 68% and 66% of people citing 'optics' and 'an unpleasant light colour' as disadvantages to adoption. Considerations such as 'the shape of the bulb' or 'the colour of the light' are thus also major influences on the adoption of CFL technology. CFLs also take several seconds to reach full luminescence and fade by up to 30% in light intensity over their useful life.   While early CFL design seems to have prioritised function over form, solutions to these aesthetic problems are increasingly available. For example, new bulb shapes with frosted glass and light fittings which obscure the shape of the CFL bulb and filter its light to a more aesthetically appealing hue are becoming increasingly available although these solutions still suffer from their own path dependent problems with many long-lived light fitting investments not easily suited to the new technology.

Another significant impediment to greater CFL adoption was concern over the need to specially recycle them due to their mercury content, with 65% referring to the higher environmental impact of recycling as a disadvantage. A typical CFL may contain up to 5mg of mercury per bulb as a vapour inside the bulb with the most 'ecofriendly' ones around 1mg. While this is not a risk at the individual level if released, when accumulated in landfill or combusted in waste disposal systems it can lead to local health concerns. Mercury poisoning has also emerged as an issue of concern for workers enaged in the production of CFLs in some lightly regulated Chinese factories. Many people do not know what to do with their used CFLs and some are not aware of the need to specially recycle them. Under the industry's Lightcycle programme involving Germany's nine lamp producers (Osram, Philips, Havells Sylvania, GE, Radium, Auralight, Navra, BLV and Heraeus) 90% of all fluorescent lamps are reported to be recycled at the industrial level but only 10% at the household level. This is likely to remain an issue of concern due to the low payoff for collecting used bulbs, positioned alongside the overall tiny proportion of mercury releases into the biosphere when put alongside other sources, such as coal power generation. However, it is likely to remain a concern for many consumers.

These non-price factors warn against reducing the decision to buy a CFL down to matters of price alone and explaining away consumers' choice to buy the more expensive option as simply 'irrational'. As mentioned earlier, individuals pursue a plurality of values which repeatedly can come into conflict and which may not be easily expressed in a common value – such as price. A consumer will weigh up matters relating to their personal aesthetic taste, motivation to address environmental issues as well as the function of light and unit cost when deciding to adopt CFLs. Suchnon-price dimensions of purchasing behaviour go some way to explain the behaviour of light-bulb 'hamsters' and understanding aesthetic rather than simply the functional or monetary dimensions of decision-making may help inform policy makers in the setting of new lamp technical standards to help reduce consumer lock-in.

4.5 Conclusion: beyond freedom versus the state

As discussed in the first part of this paper, the role of non-market-based instruments has been neglected in the mainstream standard welfare analysis of energy and climate policy, where the focus of research has concentrated on issues of 'optimality', 'least-cost mitigation' and mechanisms for carbon pricing. Regulation has been given a bad name, generally labelled as a 'blunt' instrument, lacking dynamic incentives. This paper seeks to challenge this perspective by urging policy makers to consider looking beyond the blinkers of equilibrium analysis to a more evolutionary approach which brings into focus the normative political formation of market institutions themselves, as opposed to taking such institutions for granted.

In this area, research on behavioural anomalies has been influential focusing on those issues especially important when people make decisions under risk and uncertainty. This research program has gained momentum because of the implications it may have for understanding the nature and scope of individual rights and responsibilities in liberal democracies. The premise is that this deeper understanding into our behavioural biases may help policy makers design more effective solutions to societal problems and move beyond idealistic notions of 'freedom-versus-the-state'.

This paper has sought to explore these issues through the contested issues around the diffusion of energy efficient lighting. CFL diffusion was selected owing to the relative accessibility and transparency of the decision-making process and institutional forces at play. It is also a widely understood issue that brings the role of government in framing individual decision-making around energy and climate change into the everyday lives of people.

For over a decade in Germany up until 2005 the level of CFL diffusion was stable and low. This was despite CFLs possessing significant advantages over incandescent lighting and the presence of numerous information and incentive-based initiatives. The major turning point in the diffusion of CFLs and the collapse of sales of incandescent lamps corresponds with a surge in public interest in CFLs off the back of the announcement and expectation of regulatory ban on incandescent lamps.

Providing a regulatory lead period is likely to have helped reduce the costs of switching to the new system of technology and behaviour by allowing supply chains to develop and by providing a clear signal to the market of the direction of technological change. While there were some demand side management schemes in place, It should be noted that this diffusion was achieved without artificially increasing the price of traditional lamps relative to CFLs or by taxing traditional bulbs which would be the usual *a priori* prescription of the standard welfare approach to encourage diffusion. If the European Commission's estimate that it would take a ten-fold increase in the price of traditional lamps is taken as a reference, the avoidance of these costs is substantial.

This study contributes to a broader research agenda reviewed by Clark and Urwin (2009) in economic geography generally and by Tietenberg (2010) in the energy efficiency and climate change literature to draw more strongly on behavioural insights in the policy process, for example as articulated by Kruger and Funder (2004). There is a rich vein of potential research in this area investigating comparative cases of electric lamp diffusion where countries have adopted regulatory bans, and where they have not as we move through this period of technological transition in the lighting market. It would be particularly interesting to evaluated the comparative effects of active government decision-making in this area (for example at the EU level) with non-decision making (although the number of countries without a ban in place is rapidly diminishing).

The implications of behavioural studies which empirically reveal the lack of take up of cost effective energy efficiency investments sit awkwardly with the notion of individual self-mastery which underpins much of the approach to economic and social regulation in liberal democratic states. These studies have provided a strong case for more structured or authoritarian government policy – and have set the scene for the debate between 'liberty-versus-the-state' which characterises so much of environmental policy making.

One solution to this dualism is to reframe this debate by re-injecting a sense of the evolution of political institutions that make up the market. If regulation is seen as a learning process, played out as part of the democratic process, with open and transparent collective decision making processes, then it is argued that regulation need not be viewed as a compromise to individual freedom, but rather a recognition that as human we have evolved a range of institutions to support collective action to achieve social goals – in this case reducing greenhouse gas emissions. Public policy is replete with instances where individuals have chosen increased structure over laissez-faire in recognition of the broader social benefits of collective action – support for the welfare state, public health care and public infrastructure being the most obvious cases in point – not to mention the regulation of consumer 'public bads' such as smoking, alcohol or sexual exploitation. These regulations are aimed at supporting public goods which are, in essence, the building blocks of a cohesive and productive society.

In our example, if people have decided to try to reduce greenhouse gas emissions and voted for politicians with a mandate “to take action on climate change” then there seems to be a fairly clear role for the state to provide greater structure around the decision to buy light bulbs, which offer such obvious economic and environmental benefits. This should still hold despite observing the seemingly paradoxical actions of consumers who still want to purchase incandescent bulbs or even complain about the inferior light quality of CFLs. What is important in this case is the presence and strength of the political and social norm around climate change and the need to improve energy efficiency which legitimises the collective decision-making process. To counter Rousseau’s critique, this is not so much “forcing man to be free”, but recognising that individuals over time have evolved collective decision-making institutions to reconcile situations involving conflicting individual values and where our desired or stated intentions may differ from our behaviour and actions.

This paper has also sought to show is that the political process itself is an important way in which society learns about and adapts its institutional structure. For example, public deliberation in Europe following the announcement of a ban on CFLs in Australia can be seen as having had a significant impact on diffusion in advance of the announcement and implementation of the EU’s own ban. Support for the formation of such social learning is vital because if the shift to a low carbon economy is to truly take place, it will not be because of the implementation of an emissions trading scheme, or even regulatory bans on specific technologies, but because the foundation of social norms on the issue have shifted - people’s attitudes towards the environment and their sense of responsibility regarding greenhouse gas pollution.

Chapter 5 The making of a market: the case for carbon dioxide emissions trading

5.1 Why create a market for pollution?

At first glance, people concerned about the environment might greet the idea to use markets to *protect* nature with a degree of scepticism. After all, was it not markets and the economic system that created our environmental woes, polluting waterways, the atmosphere, driving deforestation and overexploitation of the oceans and species decline in the first place?

Somewhat understandably then, when they first hear economists speaking of ‘unleashing’ market forces to cut carbon emissions, it can illicit conflicting emotions. How can these economic forces, which were so destructive, be transformed into environmental champions?

To understand how the forces of the economy play out on the environment and the relatively new role of carbon markets, it is useful to go back to first principles and define what exactly we mean by terms as ‘the economy’ and ‘the market.’

Much more than the acts of buying and selling, markets are the interrelated systems of human interaction by which we organize our lives and the things we value. Together, these systems constitute the economy. Stemming from the ancient Greek ‘oikos’ and ‘nomos’ literally meaning ‘house’ and ‘law’ respectively, eco-nomics at its most elemental, is the study of the forces that govern the human world.

Today, we can say modern economics is concerned with the nature and governance of the social systems that make up our world. Having placed economics in this context we can more clearly see that far from being exclusively about how money is made, economics can be more accurately described as being concerned with what humans value and how society organizes and apportions this value given limited time, money and other resources.

Amartya Sen for example, has focused his research on the capabilities and freedoms of individuals to live a life they have reason to value, rather than narrowly on the bundles of goods and services they consume (Sen, 1999). In the climate change context, we can think of 'a stable climate' as one of the key sources of value for individuals and society alongside quality of life factors such as access to education, healthcare, a rewarding job, time with the family - and money which, of course, has a significant bearing on the opportunities we have.

This means in addition to the economics of the various commodities, the things we buy and sell, interest rates, housing, unemployment and the measurement of gross domestic product, there is also the economics of environment, happiness and elements of behaviour extending to encapsulate this broader sense *value*.

Saying this, in order to compare different options to support informed decision making – say between a pristine river catchment and increased agricultural production and employment – economics does attempt to quantify this broader sense of value in monetary terms and, for some, this can raise ethical objections.

For example, Steven Kelman (1981) asks the question: Is it ethical to put a price on the environment and to use incentive programs to solve environmental problems ? His argument is that by placing a monetary value on the environment we are undermining its intrinsic value and transforming it from being a sanctified preserve to a marketable commodity. It is argued that the use of economic incentives changes our attitudes towards the environment and cheapens traditional values by legitimising polluting activities by allowing those who can afford it to continue polluting while the poor are disadvantaged. Kelman argues regulatory controls are more desirable as they send a powerful moral signal that the polluting activity is socially wrong and through them the state can better handle the equity dimensions around the use of the environment (Kelman, 1981).

Economist Nicholas Stern states 'if we do not act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever (Stern, 2007). If a wider range of risks and impacts are taken into account, the estimates of damage could rise to 20% of GDP or more.' 'In contrast the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year.' Stern argues how the use of emission trading will allow these emissions reductions to occur in the most cost-effective way, potentially solving problems such as deforestation and providing much needed financial support to developing countries for projects to increase (clean) energy production and offer more sustainable income sources than (often illegal) deforestation.

It is how this broad concept of value is translated into everyday decisions that is the focus of economics, and with respects to the subject of this book – emissions trading – how the value we place on preventing catastrophic climate change is translated into low-carbon lifestyles, technologies and infrastructure.

Even with this broader appreciation for markets and economics it is easy to see that even though many people are worried about the risk of climate change and value a stable climate - individuals, companies and governments are still not taking action to reduce harmful emissions. What has gone wrong?

5.2 Market failure

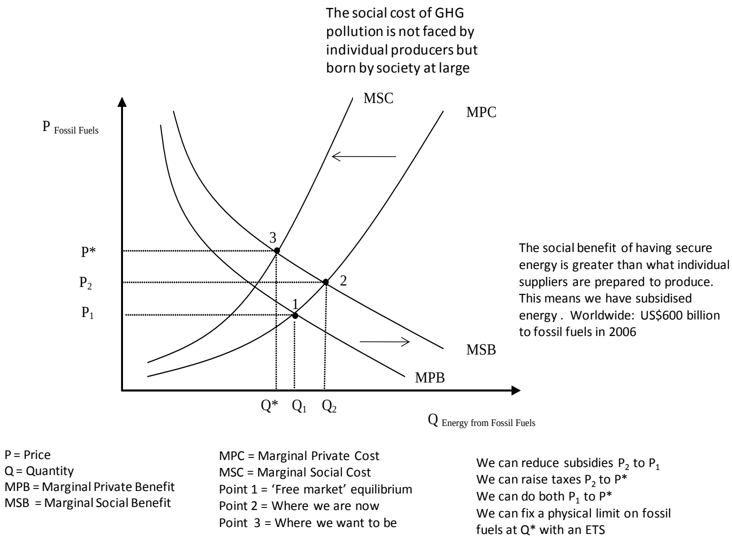
When society – whether at a local, national, regional or global community level- values something more than the sum of the amount that the individual or company value it, economists call this an *externality* (i.e. the value is external to the decisions made by the individual agent). These can be positive, say in the case of education or research and development, or negative such as in the case of greenhouse gas pollution.

In the case of the positive externality, society demands more of the good or service in question that will be provided naturally by market interactions. However, in the case of the negative externality society demands less of the goods or services produced (in our case high-carbon energy form fossil fuels, or products from land which has been subject to tropical deforestation) than what will be naturally be provided by the market.

These externalities can therefore be described as leading to *market failure*. Failure to adequately protect the environment, failure to support education or R&D, and failure to supply adequate health care - all being good examples of (bad) market failures.

Diagrammatically the negative externality associated with climate change and fossil fuel energy production is shown in Figure 5.1 by the deviation of the marginal private cost curve (MPC) from the marginal social cost curve (MSC). However, energy production also has a positive externality associated with it due to the large public benefit of having continuous, uninterrupted energy supplies that requires producers to maintain a surplus capacity above what they would as normal profit maximizers. Thus in addition, a marginal social benefit curve (MSB) lies above the marginal private benefit curve (MPB) of energy production (Helm, 2007) [5].

Figure 5.1 The Externalities of Energy Production from Fossil Fuels



This theory of externalities helps explain the evolution of energy provision. Historically, governments have subsidized energy production to ensure that a stable supply is guaranteed. This has shifted the 'free market' equilibrium from 1 to 2 in the above figure. For example, the Global Subsidies Initiative has estimated that the size of global energy for fossil fuels could be in the order of USD $600 billion per annum in 2006 and subsidies in the power sector estimated to exceed USD $200 billion per annum in 2003 (Doornbosch and Knight, 2008).

Now that society has become aware of the climate change problem associated with the burning of fossil fuels (the MSC moves outwards with time as our understanding of the higher the costs of climate change increases) the socially desirable level of production moves from Q_2 to Q*. Note that moving to this point requires imposing a higher price on fossil fuels *and/or* lowering the existing subsidies used in the first place to ensure stable and secure energy supply (Myres and Kent, 2001).

Note that the socially desirable, or optimal, level of pollution is positive. This means that society is prepared, in this case, to tolerate some pollution in exchange for the benefits of the energy provided. However, this need not be the case. The optimal level of pollution would be zero when the MSC curve was above all points on the MSB curve. This would become the case in the event that costs of climate change become larger and more immediate than currently understood.

5.3 Market Failure, Policy Choice and Socio-economic Organization

How society chooses to deal with market failures shapes, not just the environmental quality, level of innovation or life expectancy in a country, but because of the pervasiveness of the market as broadly defined as our mode of social and economic organization, the politics of a country. It is for this reason – for good or bad - that regulatory approaches can become closely tied in with political ideology.

If we believe Nicholas Stern's assertion that climate change represents the biggest market failure in human history , we must also be mindful of the changes to socio-economic organization climate change has the potential to precipitate through new regulatory environments.

Until the late 1950s opinion was divided as to how to most effectively deal with the regulation of externalities, such as industrial pollution. At the time, in the post World War Two environment, the dominant view of policy makers was that pollution should be controlled by a series of legal regulations such as the special zoning of polluting activities, quantitative limits on the physical volumes able to be disposed into rivers and the atmosphere, technology standards and so on. This involved public sector working closely with polluters, to establish how much pollution could be emitted by individual firms and the industry as a whole, setting standards for technologies, and setting up monitoring and enforcement agencies.

An alternative view was put forward by the economists of the time (see Baumol, 1972), influenced predominantly by Alfred Marshall's neoclassical programme emanating from Cambridge University, particularly the contributions to the standard welfare approach to economics of Arthur Pigou (1932). This programme of research and teaching suggested that a better way of regulation would be to impose a per unit tax on the polluting activity.

Economists who subscribed to this approach argued that the outcomes of the traditional regulatory or what they termed a 'command-and-control' approach, could be achieved at a lower cost to society and with a smaller government bureaucracy through a tax. Taxes, they argued would also provide incentives to continuously improve environmental performance as firms were always looking to minimize costs if they could, whereas there was no reason for a firm to exceed the pollution abatement beyond what was expected by the standard.

This tax could be set at the marginal external damage (the difference between the MPC and MSC curves in Figure 5.1) caused by the pollution at the optimal (Q*) level of pollution. This would therefore cause polluters to *internalize* the externality by imposing extra costs on production (for example putting a price on CO_2 emissions and reducing the incentive to generate energy from fossil fuels or develop land important for carbon sequestration). Faced with higher costs, the polluting firm produces less ($Q_1 \rightarrow Q^*$).

Officials in the public service, who perhaps saw these proposals as a direct threat to their jobs (and they were: economists also generally modelled the public service as trying to maximising their budgets, rather than social welfare, in the same way the private firm seeks to maximize profits), responded that the information burden to achieve the optimal tax rate for a given pollution level was unrealistic and would require just as many resources to do properly as using the traditional regulatory command and control approach.

The result of this debate was an acrimonious standoff, with market-based mechanisms such as taxes remaining unpopular. This situation persisted until Ronald Coase (1960), from the University of Chicago, launched an attack on the Standard Welfare Economics of Pigou and reframed pollution control as a problem of poorly defined property rights. In arguing his case, Coase applied basic logic to synthetic or imaginary examples of people and firms to show that if factors of production are thought of as rights, it becomes easier to understand that the right to do something that has a harmful effect (such as the creation of smoke, noise, smell, etc.) is also a factor of production…. The cost of exercising a right (of using a factor of production) is always the loss that is suffered elsewhere in consequence of the exercise of that right – the inability to cross land, to park a car, to build a house, to enjoy a view, to have peace and quiet or to breathe clean air.

Government regulation of the environment had in many cases already created a set of defacto property rights by controlling how much and where pollution was allowed to occur. Therefore, it was already established that once a certain standard of water or air quality was breached the offending individuals or firms (or the government) could be accountable to the legal system that would enforce the pollution control with fines or injunctions.

Coase took a step further to argue that this regulatory system could be improved by making these rights more transparent (by allocating pollution rights to individual firms) and transferable (allowing them to trade in these rights). In this model the role of government involved setting the appropriate standard for protection, allocating the initial rights and then stepping back to let the market decide over time, where and how the pollution rights would be used between different firms. Critically, Coase showed that this would allow property rights to flow to their highest-value use.

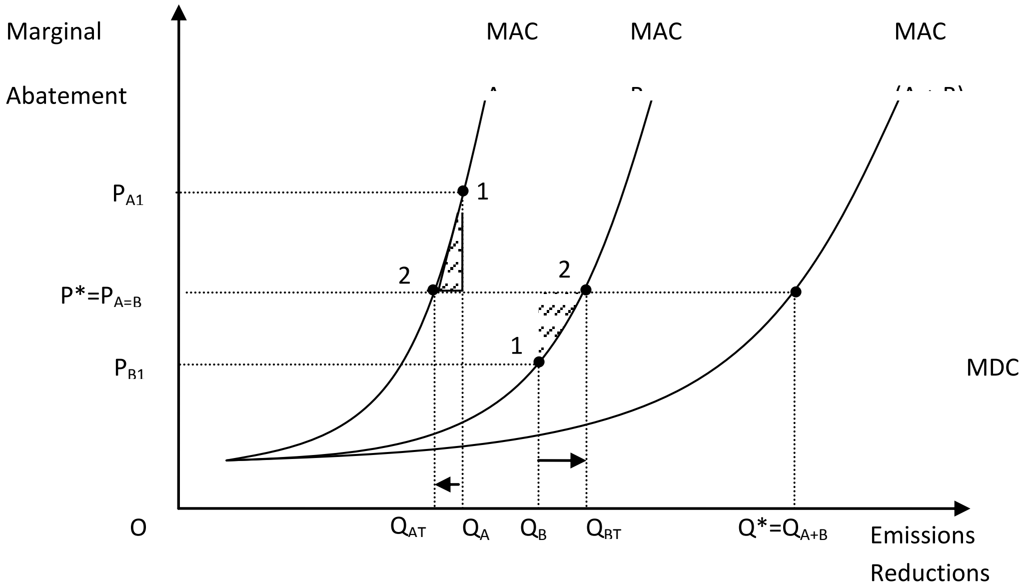
For example, a new firm that wants to enter the market to produce the commodity that generates the pollution needs to obtain the required 'pollution rights' in order for it to operate. Assuming the market for emissions rights is already fully allocated, the new entrant will need to buy these rights off an existing firm. To do this it must offer the existing firm a price high enough to entice it to sell its pollution rights. The vendor of pollution rights must reduce its production, increase efficiency or leave the market entirely. In order to offer a price high enough to induce a sale, the new entrant must be more profitable than the existing firm. The end result, in theory, is that across the regulated sector emissions rights will go to those who are able to pay the most for them. Therefore only the highest-value users will continue operating.

While this is a very powerful result, we shall see in the following chapters it also raises equity concerns around the ability to pay for rights, especially if pollution rights are being traded across countries with vastly different economic means.

Furthermore, in addition to encouraging pollution to move towards the highest value (albeit polluting) activities emissions trading also promotes ‘least cost’ emissions control. By this we mean that the trading of emissions rights encourages the firms, countries or sectors with the lowest costs of abatement to do most of the pollution control. In theory, the firms, countries or sectors with higher abatement costs utilize the emissions market to buy this cheaper abatement up until the point where the marginal costs of abatement are equal across all firms, sectors and countries.

A good example of this principle at work can be found in the operation of the Clean Development mechanism of the Kyoto Protocol. This allows cheap emissions credits to be bought from projects in countries such as China and Brazil and imported to countries where the costs of abatement are higher, such as the European Union and Japan. To see how this works, consider Figure 5.2 below.

**Figure 5.2	The Economic Benefits of Emissions Trading**



The costs of abatement at each additional unit of pollution control in each firm, sector or country 'A' (from now denoted as firm A) is described by the MAC_A curve and the same for firm B. As the MAC_B curve lies beneath the MAC_A curve the costs of abatement are lower for firm B. Suppose the combined total of emissions reductions required are described by Q* which is the sum of the allowed emissions of each firm set by the regulator (the emissions cap).

Simply allocating pollution rights by regulating emissions at Q* with no trading, would result in each firm (country) abating pollution at point 1 on their respective MAC curves (this would be their level of pollution at the start of the scheme minus some adjustment to reduce emissions to a required standard). Observe it costs more for firm A to control pollution at this point - with each additional unit of abatement costing P_{A1} - whereas firm B abates much more at a lower price of P_{B1}.

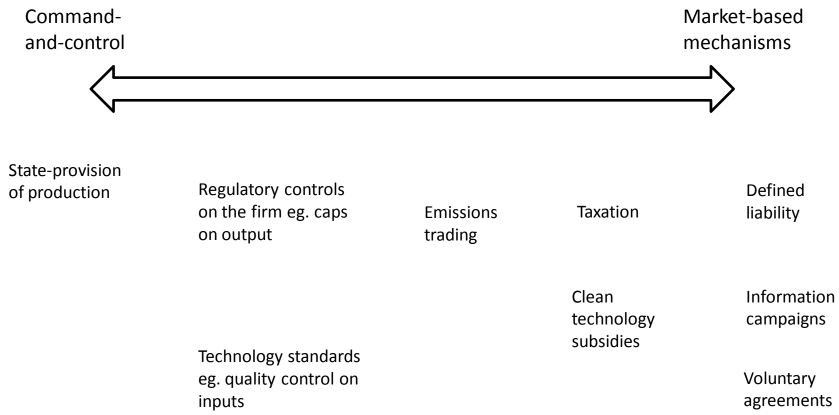
To 'unleash the power of markets,' or move towards the Coasian solution, let us now consider the introduction of emissions trading. Firm B realizes that it can carry out extra abatement beyond what is strictly required by it at a cheaper than it costs firm A to do abatement itself. It pays for firm A to increase its emissions (decrease abatement) from Q_A to Q_{AT} and buy permits from firm B which increases its abatement from Q_B to Q_{BT}. Q* remains the same.

Firm A will decrease its emissions abatement from Q_B to Q_{BT} up until the point that it costs the same to buy rights off Firm B or do the abatement itself. This will occur when the marginal abatement costs for firms A and B are equalized at P*. The benefit to society is that emissions reductions are carried out in a *least cost* manner, by the most efficient polluter. Graphically, this economic benefit to society is represented by the shaded segments of the figure. At Q_{BT} and Q_{AT} neither firm has any incentive to trade and the model is in equilibrium. It should be noted that this result requires rational, profit maximising decision-making by firms (countries) and perfect information and. a well functioning market. For simplicity, the model has been restricted to two agents, however, the same logic can be applied to a model with many agents. Indeed the potential gains from emissions trading increases, the more firms and countries are involved.

5.4 Emissions Trading in Context

Above we saw how Coase applied his property rights theory to '*The Problem of Social Cost*' or externalities, to offer an alternative logic to policy makers and economists who were locked in an argument between two ends of what can be described as an ideological or policy spectrum with 'command-and-control' one end and market-based approaches such as taxation on the other.

Figure 5.3 A Spectrum of Policy Instruments



Source: author

In the Figure above, command-and-control policy instruments are characterized as having the state or government in control of the key decisions relating to production of goods and services and pollution abatement. Alternatively, at the market-based end of the spectrum, these decisions are taken by individuals and firms. For these reasons, market-based mechanisms are traditionally supported by the champions of free-markets or libertarians, whereas command-and-control approaches are favoured by those who see a large state or more socialist government, as being the best form of social and economic organisation.

It is important to keep these institutional and political considerations in mind when evaluating policy instruments as, in practise, different policies will be more or less effective depending on the context in which they are applied. For example, as pointed out in Stern regulation may be more effective in countries with a culture of using command-and-control methods, or where there are political or administrative problems with raising taxes or with tax collection (Stern, 2007). Policies that work in one sector such as stationary energy, maybe less appropriate for others, such as transportation or agriculture.

In addition, any decision to implement a new policy instrument should be taken in the context of policies already in place that impact on the problem. For example, it is more efficient to first scrap existing subsidies which encourage fossil fuel use than to implement a new tax or an emissions trading scheme and it is necessary to be mindful of the geopolitics of energy security regarding sovereign autonomy.

Contingent on these broader geographical, cultural and political contextual considerations, policy instruments may vary in their environmental effectiveness, distributional impact, cost effectiveness in achieving emissions reductions and in their institutional feasibility. As a rule of thumb, these four considerations are useful starting point for evaluating policy.

With these caveats in mind, let us now consider the advantages and disadvantages of the main policy instruments for CO_2 emissions control, which are summarized in Table 5.1.

Table 5.1 *The Relative Strengths and Weakness of Regulatory Standards, Emissions Trading Schemes and Taxation*

	Regulatory Standards	Emissions Trading Schemes		Taxation
Principle	The state sets mandatory rules or imposes technology standards	**Cap and Trade** The firm receives a quota of emissions. To comply it either reduces its emissions or buys additional quota from another company directly.	**Baseline and credit** No cap on overall emissions. A baseline is established and emissions credits or allowances are earned once participants reduce emissions under the baseline	The producer pays a fee proportional to its emissions of pollutants
Example of Main Application	Emissions standards for car manufacturers. Standard on NOx emissions from boilers.	Kyoto Protocol (C&T+B&C) EUETS (EU) (C&T) REGGI (USA) (C&T) NSWETS (Australia) (B&C) Voluntary Carbon Market (B&C)		Fuel taxes Registration fees for cars based on engine size Proposed tariffs on high-carbon goods
Strengths	Simple. Can have low transaction costs. Very appropriate where there are high damages from pollution e.g. nuclear meltdown. Transparent. Easy to implement. Can send a powerful moral signal. Does not involve operating through behavioural response to price signals	Dynamically efficient, by encouraging innovation and investment in new abatement technologies Emissions cap provides an attractive political signal. Cap focuses on achieving a specific quantity of abatement Auctioning permits under cap and trade can raise revenue for government and produce a 'double dividend'. Cap and trade achieves least-cost abatement between firms. If MAC uncertain better than tax if MD is steep. Engages the banking and finance sector in abatement innovation. Can be used as a tool to combat global inequity. Carbon pricing is hidden behind CO_2 cap increasing political acceptability.		Dynamically efficient, by encouraging innovation and investment in new abatement technologies Creates a flow of revenue for government which can be used to lower other taxes (the 'double dividend'). Less open to political lobbying. Keeps investment in low-carbon solutions local. If MAC is uncertain better than ETS if MD is flat. Sets a clear carbon price that investors in infrastructure can use to plan with greater certainty.
Weaknesses	Not dynamically efficient - provides little incentive to improve beyond the standard. Can dampen technological innovation. Abatement is unlike to be achieved in a least cost manner. Low transaction costs	Open to political gaming (e.g. limited auctioning and preference to incumbent firms vis new entrants) Information requirements initially high to set cap for each firm. Resources for abatement can be dispersed geographically. Can introduce uncertainty over price, therefore undermines long-term investment planning High transaction costs.		Politically very difficult to bring in as adverse equity effects on poor citizens very transparent. Difficult to control the quantity of pollution with a price instrument under uncertainty. Behaviour is not always sensitive to price signals Low transaction costs if integrated into existing tax systems

Within economics there is a vigorous debate around the question 'to tax or to trade?' (Hepburn, 2006) That is, should governments be aiming to impose a carbon price through taxes on fossil fuels such as oil and coal? or through setting emissions quotas on firms and countries and then allowing trading à la Coase? In each case the policy objective is to establish a carbon price sufficient to shift the economy away from greenhouse gas producing activity, but one operates through the price mechanism and the other through the quantity mechanism.

William Nordhaus represents the canonical perspective of economic theory applying the insights from Martin Weitzman that under different types of uncertainty price instruments (taxes) should be preferred over quantity instruments (quotas and emissions trading) and visa versa (Weitzman, 1974 and Nordhaus, 2007). This follows a simple and powerful logic.

Using a pure price instrument, such as taxation, while achieving certainty on what the price of carbon will be (in theory optimality at P*) the policy maker is unsure exactly what the final quantity of emissions will be. The carbon price is set and the quantity of pollution emerges through the market. It may take several years and changes in taxes to achieve the optimal tax rate (P*) and the desired level of emissions at Q*. However, what it does guarantee is what the cost of pollution abatement will be – thus providing certainty to polluters to plan investment.

Alternatively, by using a quantity instrument, the policy maker provides certainty around the level of pollution that will be emitted (Q*) and allows the price of carbon to emerge in the market. However, this can mean that the polluting industry faces greater uncertainty around the costs of abatement than under the tax.

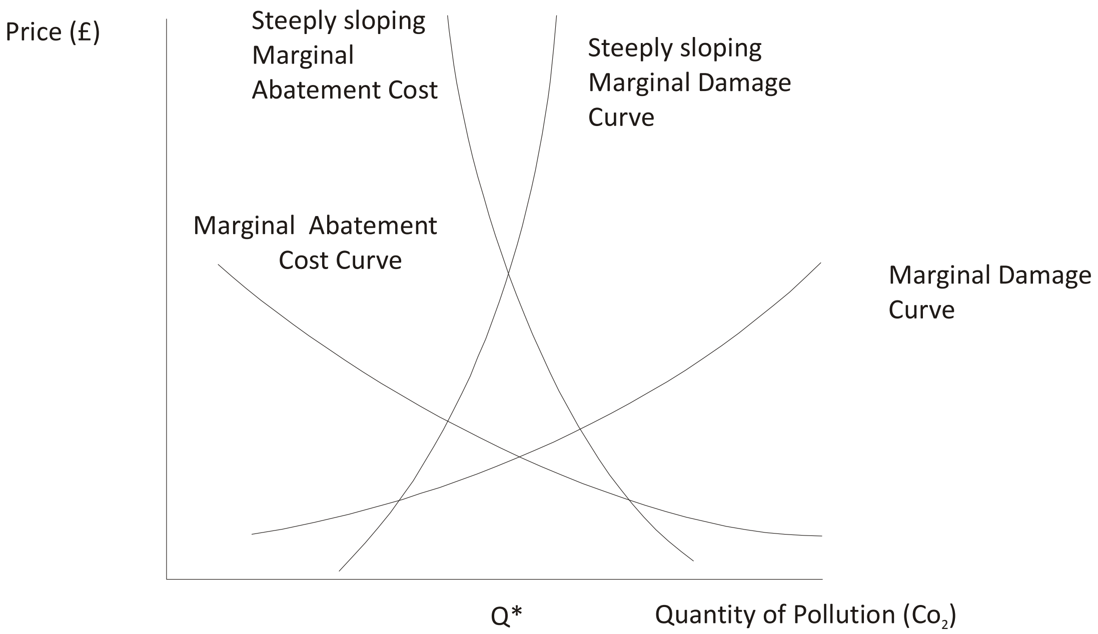
Whether taxes or trading is to be preferred in this simple model depends on the policy priority of the regulator and the relative costs of the damage from pollution and cost of abatement in the event of uncertainty in the position of the marginal damage curve (See Figure 5.4).

If the marginal damage costs are high (steeply sloping) - that is if not hitting the emissions target results in catastrophic events (such as melting of the Greenland ice sheet, or release of methane from the permafrost, leading to a positive feedback cycle which rapidly accelerates global warming) then clearly ensuring that Q* is achieved is highly desirable – the policy maker should use a quantity instrument.

If on the other hand, if the damage costs are low (ie a flat curve) and the marginal abatement costs are high – for example, it may be extremely expensive to decommission long-lived, high-carbon energy infrastructure and expensive to scale up renewable energy - then it would be preferable to set the carbon price to allow people and industry flexibility around how much abatement needs to be achieved.

Under these circumstances, the choice of instrument depends on the view that the policy maker takes on the costs of abatement versus the risk of a catastrophic event occurring. If they are very worried about the risk of a climate catastrophe (steep MDC curve) they should use a quota and emissions trading, if they are more worried about the costs of mitigation – such as higher fuel prices, inflationary pressures, higher long-run interest rates, slower economic growth, higher unemployment and so on, then the use of taxes would, in theory, be preferred.

Figure 5.4 Balancing pollution and abatement costs under uncertainty



5.5 Discount rates and policy choice

This highlights one reason why the somewhat esoteric debate around discount rates is so important. As most of the costs from dangerous climate change occur 20 years and more into the future, but the cost of mitigation are incurred in the short term - how we account for these far off costs in *today's* terms is critical to our view on the slope of the marginal damage curve. Within economics, this is done through discounting.

Discount rates are implicit in dozens of decisions we make every day, though most people do not usually think about it in these terms. The reason why most people discount is due to the simple reason that humans are impatient by nature and generally speaking we value things more, the sooner we can get them. This form of discounting is known as pure time discounting.

An additional reason why we discount the future is because we assume we will be better off in the future combined with the general belief that an extra pound is generally worth less the better off you are.

On a practical level, this is reflected by interest rates. One pound invested today would accumulate to £(1 + *r*) in year 2 if the interest rate was *r* per cent. Where *r* is typically expressed as a decimal point, e.g. 6% would be 0.06, 10% is 0.10 and so on.

Turning this logic around, we can ask, 'How much is £1 in year 2 worth to us today in year 1?' The answer is that it is worth £1/(1 + r) for the reason that this is the amount you would have to invest in year 1 to obtain £1 in year two.

For example, using a relatively high discount rate of say six per cent or more (approximately what is used for long-term commercial decision-making) would mean that the policy maker perceives the marginal damage function today as quite flat as the costs of climate change occurring in the future would be worth a lot less in today's terms, therefore according to the logic above, taxes should be preferred.

Using a low or declining discount rate over time (such as used in the *Stern Review*) of say four per cent or less would mean the policy maker would weight the long-term costs of climate change more relative to the short-term costs of mitigation, and (according to theory) should lean towards a cap and trade scheme.

It is an implicit argument of the *Stern Review* that it is appropriate for governments to use lower discount rates than in the private sector as they must make decisions both in the public interest and because they govern for future generations just as much as they do for current citizens. This is an argument based on an ethics or philosophy of Rawlsian equivalence –

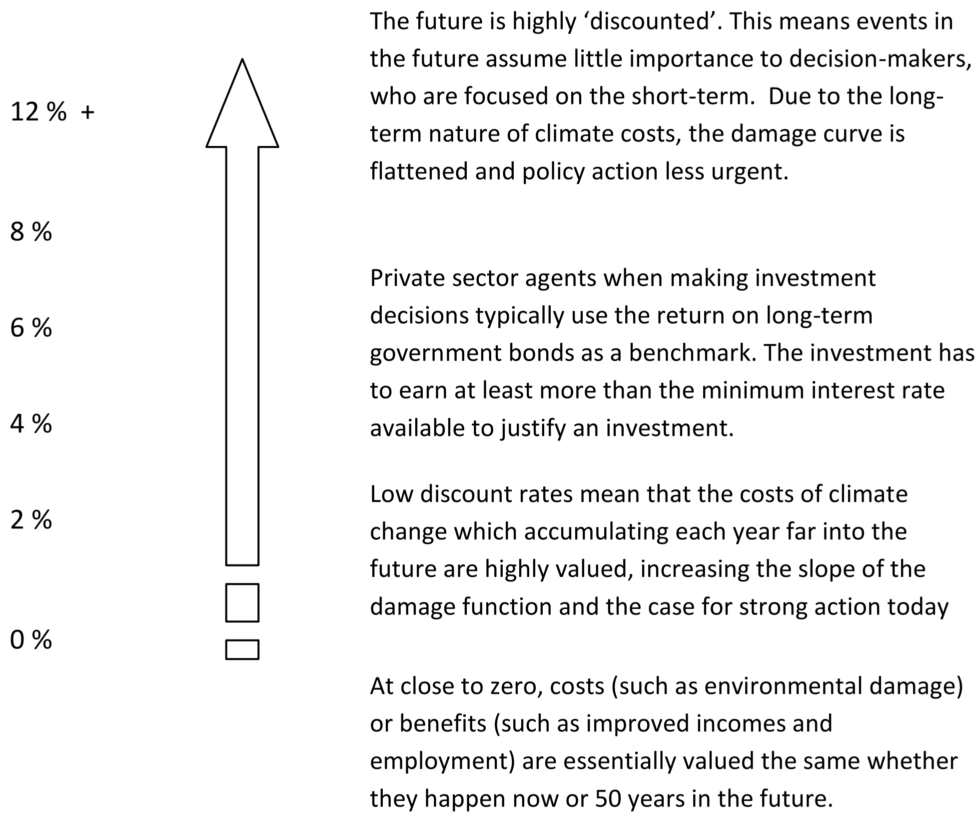
that is political leaders should make decisions on the basis that when they die they would come back re-incarnated as a random member of any section of society. In contrast to this view, the private sector is generally assumed to be focused on the interests of current shareholders and must weigh investments against opportunity cost of capital (the interest rate).

The *Stern Review* attracted considerable criticism for adopting a low discount rate and somewhat less criticism for favouring emissions trading over taxation. At the centre of the controversy was that the *Review* only discounted due to the assumption that future generations will be better off and the chance (about 1 in a thousand each year) that we will be extinct as a society due to meteor strike or some other catastrophe. On the matter of pure time preference (see Box 5.2) the *Review* assumed a discount rate of zero. That is that the 'government' should hold no bias between the welfare of current and future citizens on the basis that society as a whole is impatient. It is for this reason that Stern is frequently characterized as taking a stronger ethical stance than other economic studies such as those by Nordhaus, who favours higher discount rates and also taxation over emissions trading.

Indeed, if the policy maker takes a very low discount rate (assumes marginal damage from CO_2 is very high) and is concerned about whether the price signal will be able to change behaviour in time then it may become efficient to impose regulatory standards or bans on high-carbon technologies. For example, in the UK the idea of a ban on new coal power plants is being debated and world-wide, fuel efficiency standards are already in place for car manufacturers.

Such policies have the advantage of not working at all through the slow process of changing behaviour through the price system. However, if not carefully designed such standards could result in high electricity prices or disruptions to power if new generating capacity was not able to be brought on at a price consumers were willing to pay for. A further disadvantage of such strong regulatory action is that it could act as a disincentive on investment in energy supply leading to shortages or high prices for consumers.

Figure 5.5 Discount Rates and Decision Making



5.6 Theory and practice and the case for 'silver buckshot'

In Figure 5.1 above, the simple case of a negative pollution externality was presented in the context of energy production, which we also noted has important positive production externalities. Theoretically we created a framework for looking at the costs and benefits of alternative policy approaches, placing emissions trading in the context of alternative policies such as taxation and regulatory bans standards.

In practice, climate change is a far more complicated externality involving multiple sectors and jurisdictions each with their own economic, cultural and political realities and histories. For example, while it does not matter where CO_2 is emitted when assessing a firm or nation's contribution to global warming, the impacts in terms of storms, floods and droughts *are* distributed differently. Low-lying areas are most at risk from sea level rise (eg Bangladesh, Denmark and various small island states) and temperatures will rise most pronounced in the Arctic and Antarctic regions, which may in the long-run actually be positive for some (Russians in Siberia) but negative for other reasons (for wildlife such as polar bears). This means the slope of the MDC curve varies across geographic regions.

Perversely, the wealthier states most responsible for the historical stock of greenhouse gasses are the ones most able to adapt through sea defences, new technologies for growing drought resistant crops and so on, where poorer states will have trouble to access adaptation capital and technologies exacerbating damage costs in those regions.

There are also many, many more externalities at play, in addition to the negative pollution externality and those around energy security. For instance one of the most important is due to oil supply being set by the collusive behaviour of the Organisation of Petroleum Exporting Countries known as OPEC. This leads to tighter supply and higher prices than would otherwise be the case and makes it difficult to assess how 'the market' will respond to higher carbon prices. It is also interesting to note that this oligopolistic behaviour by OPEC reduces supply (Q) and pushes up prices, in a manner similar to a carbon tax (Tietenberg, 2004).

On the one hand, OPEC may decide to increase production and cut prices in response to higher carbon prices in order to maintain market share and slow technological change away from fossil fuels thus negating the net change in the price of fuel at the pump and any change in emissions.

Alternatively, OPEC may tighten supply pushing up prices even further to maintain profits and creating political and economic instability in the face of extraordinarily high fuel costs and hoping that democratically elected governments will loose their appetite for imposing higher carbon prices.

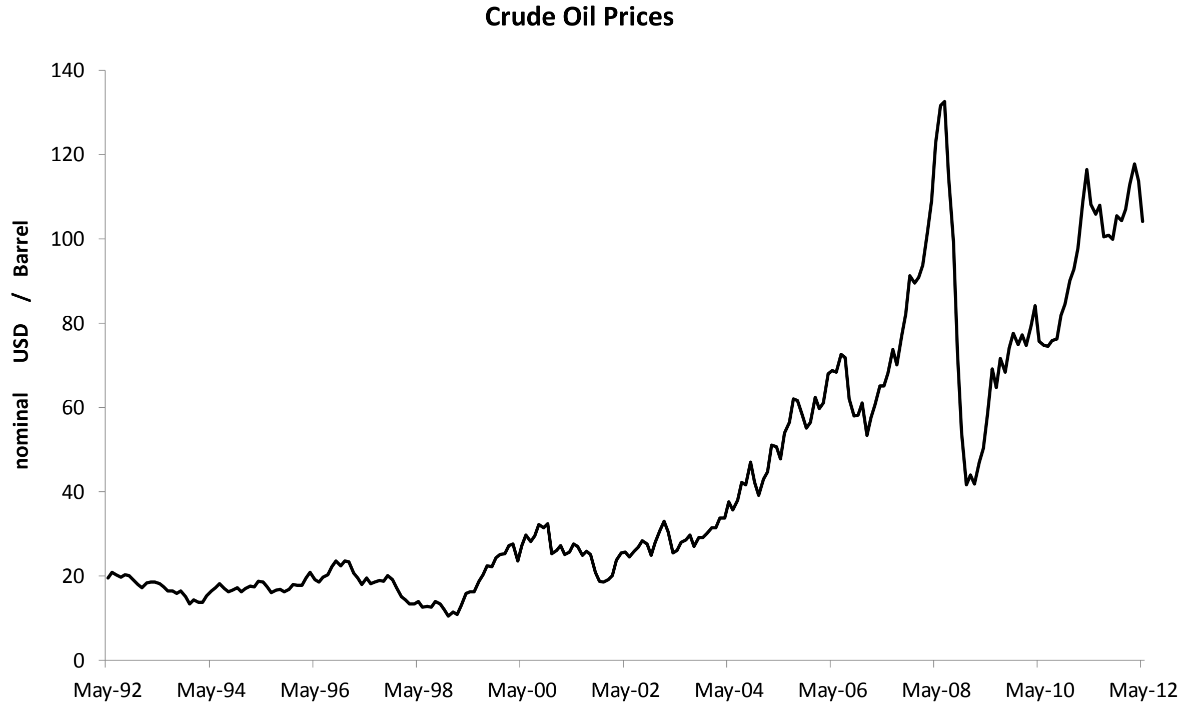
Note the outcome of this struggle between OPEC and the oil consuming nations (mainly the OECD states) largely comes down to who gets the economic rents from higher fuel prices – the OECD taxpayer in the carbon pricing scenario, or the OPEC member states in the higher price and collusion scenario. In each case the implicit carbon price could be the same, but the distribution of income from higher fuel prices drastically different.

Table 5.2 shows us that every $20 (USD) increase in the price of a barrel of oil has the same impact on producer prices as a $50 increase in carbon price.

The presence of these and other market failures and barriers to change means that while carbon pricing is necessary it is unlikely to be sufficient to effectively reduce emissions.

These practical problems have prompted Steve Rayner at the James Martin 21st Century School at Oxford University to argue that there is no silver bullet solution to carbon policy and that what is needed in practice is 'silver buckshot'. Such an approach would integrate the different carbon pricing strategies with industry policy, research and development in

Figure 5.6 Oil prices over time



Source: World Bank composite index (dated Brent, WTI, Dubai Fatech)

Table 5.2 Oil prices and the Carbon Price Equivalent

Oil Price ($/barrel)	Carbon Price ($/tonne CO_2)
20	50
40	100
60	150
80	200
100	250
120	300
140	350
160	400

Source: *Stern* (2007:287) assuming a proportionate gas price increase to oil price increase clean technologies through to technological demonstration experiments and early market support with targeted subsidies.

By integrating active *industry policy*, this approach attempts to address concerns that households and firms, especially in the short term, do not always respond to price signals. Reasons for this include system complexity and lack of information about low carbon technologies, the long-term nature of energy investments, difficulty financing projects with large upfront costs and the slow pace of cultural change that is required to underpin a low carbon economy. These problems result in what is called path dependency, that is once a particular technology or process (such as energy from fossil fuels) is entrenched it takes a concerted effort beyond just sending price signals to shift the system, for example to a world based on renewables.

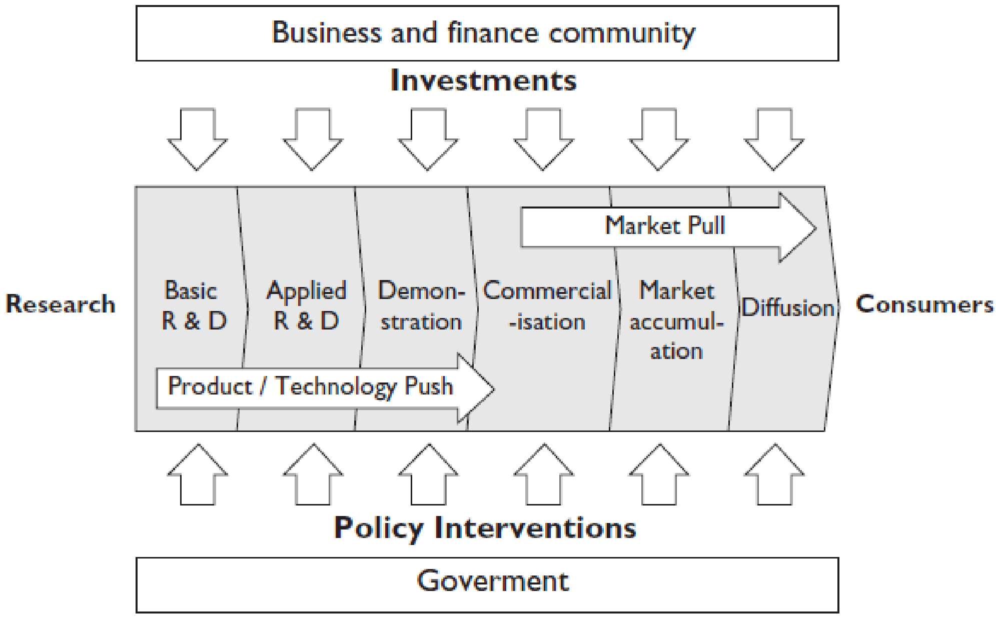
According to Brian Arthur, small past decisions can lead to path dependency or the notion that technologies become 'locked-in' even though better alternatives exist, simply because once investments are made it makes similar, supportive investments more attractive. There are five main forces that Arthur identifies as driving this process of 'increasing returns to adoption' (Arthur, 1994).

Firstly, learning by doing suggests the more often a technology is used the more it is developed and improved (Rosenberg, 1982). For example, the use of petroleum-based fuels in the internal combustion engines of cars has led to large improvements in performance of those engines and fuels, compared to the competing technologies of electric-battery or hydrogen motors. Secondly, network externalities mean that often technologies are advantaged by the number of adopters (Katz and Shapiro, 1985). For example, the vast number of petrol cars limits the diffusion possibility of battery-electric or bio-fuel cars due to the lack of alternative refuelling infrastructure in the case of the former, and the ability of the engine to handle ethanol or bio-diesel in the later. Thirdly, economies of scale mean the more a technology is used, the lower its cost. Electricity production is one of the classic examples of natural monopoly where the average costs of a large power plant fall with the amount of electricity produced making them competitive, but only at very large outputs (and levels of market concentration). Fourthly, increasing returns in information mean that often the more a technology is adopted, the more it enjoys the advantage of being better known and understood. This means that the risk of adopting a new technology falls as it becomes more widespread. Finally, technological interrelatedness suggests that as technologies become diffused, other sub-technologies and products become part of its infrastructure and help bring down its costs (Frankel, 1955). For example, petroleum-based technologies have a huge infrastructure of refineries, distribution systems, filling stations, car manufacturers and so on that rely on them, further underpinned by an education system that trains engineers, geologists and chemists in the required skills for the industry in addition to political organisations that have grown in order to secure the legislative and subsidy frameworks that support the industry.

However, proponents of market-based solutions to climate change may argue that the industry policy elements of the ‘silver buckshot’ approach constitute ‘picking winners’ as the government may be put into a position of having to choose one technology over another. For example, the decision around significant new investment in nuclear energy is one such case. While a high carbon price helps the economics of nuclear energy, without substantial additional state support such as an efficient and supportive planning and approval process and the state insurance or subsidization of nuclear waste disposal, it would be very difficult for nuclear investments to take place.

Michael Grubb (2004) outlines a useful framework to consider these competing schools of thought on climate policy (illustrated in Figure 5.7 below).

Figure 5.7 Main steps in the innovation chain



Source: Grubb, 2004

Here technological change is mapped as a series of 'steps in the innovation chain'. Accelerating this process for low-carbon technologies requires not only well designed policies and investments on the supply-side (technology-push) but also on the demand side (technology-pull) policies. For technology-push the focus is on research and development programmes and demonstration projects of new technology, while for technology-pull policies are mainly through the use of economic incentives such as carbon pricing (Doornbosch and Knight, 2008).

The alternative to 'picking winners' is to set the carbon price high and let 'the market' 'choose' the winners, rather than politicians. In theory, this choice emerges out of a competition between new clean technologies and fossil fuels, as the costs of new mitigation techniques comes down due to learning and carbon prices rise penalising the old fossil fuel systems. It is argued that such market approaches help avoid the danger of political decisions being captured by vested interests through lobbying.

When considering the nexus between 'picking winners' (technology-push) and letting solutions to CO_2 mitigation emerge through the price signal (technology pull) there is a trade-off between the danger of political capture (and a bad decision) on the one hand and the time it takes for the price signal to work its effect on the other due to path dependency and behavioural reasons. In practice, where the line is drawn in the innovation process will come down to each country's perspective of the role of the state in organising economic activity and the policy tools and institutions available to it, such as public finance.

In an economy riddled with market failures, and already subject to various (and competing) policy interventions and political rent seeking, the choice of policy approach – 'to tax or to trade' or regulate in some other manner is in practice perhaps best described as one of guiding principle than of strict practice. Nevertheless, as in politics, such principles can form a useful basis to signal a general approach in the face of complexity and uncertainty.

5.7 The essential elements of an Emissions Trading Scheme

There are two basic types of emissions trading scheme: cap and trade and baseline and trade schemes.

Cap and trade sets out a system where the government defines a new set of property rights to use the atmosphere base on an emissions limit or cap. Then, after the distribution of the allowances between actors involved in the scheme, it allows trade in these allowances so that actors can choose to conduct abatement or by additional allowances. Finally at particular times, actors covered by the scheme are required to surrender the allowances that that correspond to their level of emissions – this may be above or below what they originally were allocated depending on the costs of CO_2 abatement they are faced with. The European Emissions Trading Scheme, and Sulphur Dioxide Trading Schemes in the United States, are examples of a cap and trade scheme.

The baseline and credit schemes involve establishing a baseline level of emissions for a sector (such as proposed plans for deforestation) or a project or company (e.g. the Clean Development Mechanism or the NSW Emissions Trading Scheme). Under this scheme no overall emissions cap is set, however actors are encouraged to reduce their emissions below this baseline (usually defined as the business as usual scenario) to generate emissions credits which can then be traded – although some base line and credit schemes have no, or limited trading. This approach is the basis for 'White Certificate' schemes that governments are using to encourage energy-efficiency measures such as those in Connecticut, USA (George et al., 2006), Flanders (D'haeseleer et al., 2007), the UK (DEFRA, 2007a), France (Monjon, 2006) and Italy (Pavan, 2005).

5.8 Cap and trade schemes

As a first step, the establishment of a cap and trade emissions trading scheme involves the definition of a cap on emissions in a specific area. The definition of the scope is based on several parameters including geographical coverage, temporal range and the gases covered. This is usually referred to as the scheme's coverage.

The carbon price, or price of emissions permits in an emissions trading scheme, is shaped by the forces of demand and supply. On the supply-side, the legislator sets the desired level of pollution (the cap) ex ante – that is before the emissions occur, at the fixed amount Q*. This cap is generally made to a carbon reduction target for that sector.

Demand is driven by the polluters who must operate within the proportion of the cap that has been allocated to them. As each unit of pollution from their business must be offset by an equivalent emissions right, as soon as they exceed the amount they have initially been allocated, they have to enter the market to buy emissions permits thus creating demand for permits.

Demand for allowances will depend on the severity of the cap but also on the level of actual emissions from involved agents. If the reduction target is small, demand for emissions rights will be weak. Similarly, if the involved agents (states or companies) are able to significantly reduce their emissions, to perhaps within their cap, then demand for permits on the ETS will also be week and prices will remain low to moderate. This can occur either due to the employment of mitigation technologies, such improving energy efficiency, or due to a fall in demand for the firms actual output (as in the case of the economic recession of the former communist bloc countries following the collapse of communism and transition towards market economies in the 1990s and early 2000s).

The monitoring and reporting of emissions is the next critical element. The precise achievement of the environmental target is known only after the calculation of actual emissions at the end of the commitment period. Therefore, the definition of clear rules and standardized methods for calculating emissions are a prerequisite for the credibility of any emissions trading system.

Emissions are fungible, therefore it is important that these measurement methods are reliable and consistent so that a tonne of carbon dioxide means the same thing between different agents, potentially across different sectors and from different countries. For example, in the United States, industry is required to use continuous measurement equipment to monitor flu gasses to account for CO_2 to a high degree of accuracy.

Reliable registries are also needed to ensure that emissions and corresponding emissions rights (allowances) can be traced. Registries ensure the booking of transactions of emissions rights. They are similar to a general ledger where all accounting transactions are posted.

In existing schemes, such transfers of ownership take place in real time. This means that registries do not account for future transactions (futures or forward), only spot transactions can be registered. Registries only provide an inventory of traded quantities; therefore they do not contain any information on agreed prices. Their function is to ensure traceability of the allowances and thereby guarantee the environmental integrity of the system. At the end of the accounting period reconciliation between actual emissions and emissions rights held by the participants is performed using the data booked in the registry.

Finally, in order to ensure environmental integrity of the system regarding the cap, the regulator must set sanctions to penalize agents who can not offset their emissions by an equivalent number of allowances. A system of fines encourages polluting entities not to emit more than the number of allowances they hold. For instance, under the first emission trading scheme, the US sulphur dioxide market, the government established a penalty scheme in case of shortage of allowances: if a company did not have enough allowances to cover its emissions at the annual reconciliation, it was liable to pay a fine of $2,000 per uncovered tonne.

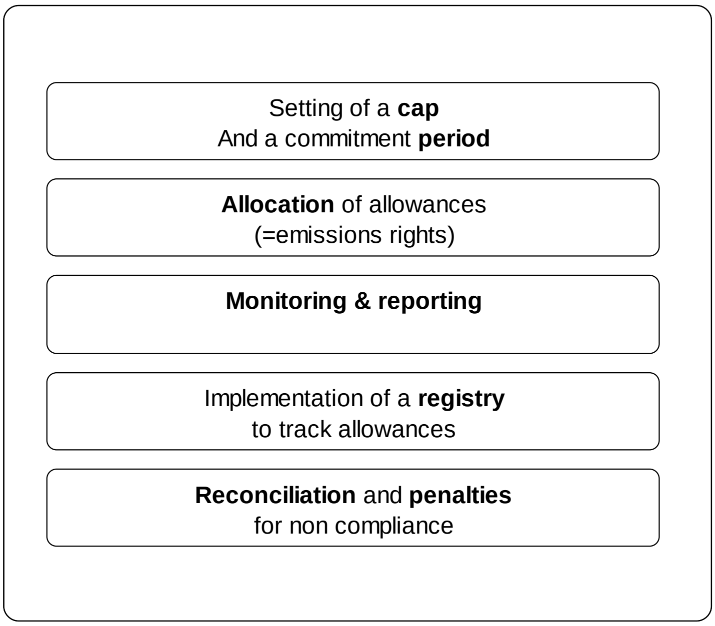
However, fines alone are not always enough to ensure environmental integrity. Take for example the case where there is a substantial over demand for permits due to an unusually cold and long winter which meant more energy was used to heat homes, than the regulators might have expected when they set the cap. The price of emissions permits in these circumstances may rise so high that the polluter may choose to pay the fine, rather than attempt to buy emissions permits.

To avoid this pitfall, governments may institute that the payment of a penalty not release the agent from the obligation to reduce emissions. Therefore the entity in default must also redeem the rights missing during periods of subsequent compliance. This approach was chosen under the EU Emission Trading Scheme.

5.9 Setting the cap and commitment period

As discussed above, the setting of the cap (establishing Q*) is the foundation of any emissions trading scheme. The cap establishes the level of scarcity of emissions allowances and therefore the supply-side of setting the carbon price in the regulated sectors. To provide environmental integrity, the cap should be set consistently with national, regional or multilateral emissions targets and be clearly below 'business as usual' (BAU) emissions. In practice this process is complicated due to uncertainty around what future emissions will be (Grubb and Neuhoff, 2006).

Figure 5.8 Constitutive elements of a cap-and-trade emissions trading scheme



An important element of setting the cap and emissions right scarcity is the establishment of rules around the use of emissions credits generated from areas outside the regulated emissions market, such as through the Clean Development Mechanism (CDM). By allowing these outside emissions credits to be imported into the scheme the policy maker allows emissions to rise above the cap, within the geographical area which is regulated.

In practice the use of such flexible mechanisms is controlled in order to ensure that investment in domestic emissions reductions are made rather than the purchase of emissions credits from outside the regulated system. In theory, provided the purchased credits represent real emissions reductions, there is no reason why such restrictions should be imposed as it limits one of the most beneficial aspects of emissions trading – that emissions reductions occur where it is least cost to obtain them.

The commitment period is the temporal aspect of the cap. It set out over what time period emissions reductions at the company level must be obtained. If the benefits of emissions trading are to be realized the system must balance predictability in its shape and rules, with flexibility to take advantage of changing circumstances. As will be discussed later in the Chapter, a long commitment period, with banking and borrowing of emissions credits between periods, can provide greater certainty for investors and reduce policy risk (Helm, et al. 2005).

5.10 Allocation methods

The creation of a new market for greenhouse gasses requires property rights to be identified and made transferable where previously there were none. In practice this amounts to establishing 'rights' to use the atmosphere. This allocation process should not be confused with the buying and selling of these rights within an emissions trading scheme and the resultant price for emission credits which rises and falls once the system has been established.

There are two main allocation approaches involving either selling these rights to the atmosphere or giving them away. A hybrid system can also be used which incorporates a combination of the two. There is a vigorous debate around this allocation process and at its core lies an assumption about who initially should own the property right to the environment – the polluter, or the public at large (ie the taxpayer and government).

Under ideal theoretical conditions of perfect information and competition and in a static analysis each allocation method should be equally efficient as the agents involved face the same marginal costs of abatement (set through the market price of emissions credits). In practice, where there are firms entering and exiting a market full of market failures and externalities, selling permits (usually by auction) presents significant efficiency advantages although on the other hand giving permits away for free increases the acceptance of the scheme. To understand this, let us first examine the case of 'free-allocation.

Free-allocation involves giving pollution rights away free of charge by some predefined rule such as 'grandfathering'. This simply means that the property rights to the environment are allocated on the basis of *prior use*. This allocation method is usually argued strongly for by polluters as it recognises their implicit right to use the environment as they always have, albeit now under the constraint of a cap.

By sheltering industry from the full potential costs of implementing the emissions trading scheme, free allocation seeks to avoid the problem of stranded assets, that is investments made at a time when emissions of greenhouse gases were regarded as harmless and which lose value today following the introduction of an emissions market. For example, an investment in a coal power plant will become less profitable following the implementation of a CO_2 emission trading scheme).

Alternatively, if the government elects to sell permits to industry it assumes that polluters had no prior *right* to the environment and that the atmosphere is a commons effectively owned by all citizens. Under this approach agents covered by the scheme face an upfront cost with participation as they have to bid for the right to use the atmosphere. Once they have this right it is recognised an asset and can be sold on if the firm decides to stop operating.

The value of these permits can be substantial, so their free allocation can be represented as a considerable 'windfall' to the firm (Sijm, et al., 2006).

Free allocations, based on rules such as grandfathering, also raise dynamic competitiveness concerns by implicitly favouring incumbent firms at the expense of new firms wishing to enter the market, who may not receive a free allocation but have to 'buy in'. If there are no reserves for new entrants and all allowances have been granted to existing businesses, newcomers are penalized by having to buy all their allowances on the market.

For example, the United Kingdom's peak industry Group, the Confederation of British Industry (CBI) argues that any plan to auction permits under the European Emissions Trading Scheme must take into account the competitiveness pressures that auctioning brings to bear on vulnerable sectors. They warn that energy intensive sectors including aluminium and steel production face a significant risk. Risk is defined as the nexus between international trade exposure and the impact of energy price increases on the final product. Firms which are unable to pass on costs due to competition from firms in non-EUETS countries face declining profitability and market share. This then can lead to carbon leakage – the propensity for CO_2 pollution to merely shift from the regulated to a non-regulated country. The result is the regulated country looses its polluting industry (and the economic activity it produces) but there is no environmental gain, or even worse emissions increase as emissions may be even less regulated than they were before. As a result of this, the CBI argues for 'free allocation' and will only support the full auctioning of permits if an international agreement can be achieved that sets similar standards for all major competitors of energy intensive British and EU industry.

Free-allocation may be less of an issue when capital markets work perfectly and take the opportunity costs of emissions into account when assessing the value of existing firms. This is because when an inefficient firm receives sufficient allowances to cover its existing emissions, it should be economically advantageous to close or scale down operations and sell surplus emission rights to an efficient new entrant (Bosquet, 2000). However, in practice this mechanism does not work perfectly, so states set aside a small quantity of unallocated rights for new entrants under free allocation systems.

In addition free allocation rules may have the danger of encouraging a 'use it or loose it' mentality among firms and discourage the closure of old or inefficient firms which are kept operational to secure valuable permits.

Auctioning also avoids the difficulty of defining rules for the sharing of available allowances between states or industries. In other words, no allocation rule needs to be defined. In a free allocation process, the allocation is a political process, and therefore is influenced by various forms of lobbying and can be very laborious (Joskow and Schmalensee, 1998). This also often results in over-allocation.

Finally, auctioning raises funds that can be used for other purposes, for example to address market imperfections in the labour market. Many environmental economists have advanced the hypothesis of a double dividend associated with environmental taxes or levies. The first dividend is an improvement in the quality of the environment. The second is the positive effect on employment and gross domestic product (GDP) resulting from the reduction of other more distorting taxes such as labour taxes (which penalise the incentive to work) thanks to the new funds collected through environmental taxation.

Some of the desirable features of free allocation include:

- *Allocative efficiency* – a well designed auction system channels permits to those that value them the most, which allows resources to flow to their highest value use.
- *Efficient price discovery* – important price information is provided by the interaction of bidders at an auction. This facilitates price discovery, which has a major role in stimulating behavioural change. For example, the revealing of each emitter's willingness to pay for the right to pollute by helps entities manage their emissions obligations and make investment decisions more clearly than if permits are provided via free allocation.
- *Auction revenue* – the sale of permits at auction generates revenue which can be used by the government for difference purposes.

It should be noted at that as the secondary emission market matures the benefits from the first two advantages diminishes.

Bosquet analyzed practical experiences and studies on the double dividend (Bosquet, 2000). His conclusion is rather mixed. In the short or medium term, benefits are significant in reducing pollution, but weak in terms of job creation. The fundraising aspect is an argument often advanced against auctioning because by creating a transfer of private funds to the state, auctioning tends to harm the competitiveness and profitability of businesses, compared to those outside the emissions trading scheme. In general, environmentalists argue that funds collected should be used for environmental protection while companies consider that funds should be used to compensate businesses, including through research and development support. In both cases, Bosquet found that such requests from pressure groups (green NGOs or industrial lobbies) prevent the realization of a double dividend.

An alternative method that can be integrated with free allocation or auctioning is benchmarking. If regulators decide to reward emissions reduction before the beginning of the scheme, governments can consider allocating emissions based on energy efficiency or a similar indicator. Such an allocation method uses a comparison of environmental performance across time.

While benchmarking is effective for the allocation of allowances to sectors producing well-defined products (for example mega watt hours of electricity per tonne of steel or cement) benchmarking is more complicated for sectors with differentiated products (for example, defining a CO2 benchmark for car manufacturers is less straightforward given the wide variety of models). When considering allocations between nations, a benchmark could be per capita emissions in the country (an option favoured by some developing countries), or emissions released per unit of gross domestic product.

Governments can also allocate allowances based on projections of future emissions in order to avoid excessive restrictions on expanding industries. However, such an approach requires a considerable amount of information which is often confidential. In practice, industries will tend to overestimate their forecasts for fear of not receiving sufficient allowances. Such an approach can lead to over allocation, as has been the case during the first phase of the EU ETS (Ellerman and Buchner, 2007).

Another option might be to allocate more allowances to industries that are more vulnerable to international competition. Companies that have to compete with other corporations not involved in an emissions trading system are more vulnerable because they cannot pass on the allowances costs to their customers. This has been claimed for steel, cement and chemicals industries, although analysis in the UK indicates that auctioning EU ETS permits would only affect companies producing less than 1% of GDP (Carbon Trust, 2008). In the case of the power industry, the price of allowances can easily be reflected in the price of electricity (at least in a fully liberalized market), since electricity is not transported in large amounts over very long distances.

In practice, governments sometimes develop a hybrid allocation method. Today with the development of emissions trading platforms, access to allowances is open and prices are publicly available. Indeed, auctioning can be open to all and interest groups (e.g. environmental or health promotion NGOs) may be able to buy allowances in order to further reduce the emissions cap to reflect their members interests. The extent to which auctioning is allowed will have a significant bearing on the perceived strength of the emissions trading scheme in question. While 'free allocation' offers scope to provide a subsidy to carbon intensive industry, therefore increasing acceptance of carbon reduction proposals (relative to say a carbon tax), such a subsidy should be carefully evaluated in terms of other competitiveness measures that might be taken such as border tariff adjustments.

5.11 Management of price volatility

A system such as an emissions trading scheme that sets a limit on quantities is less able to deliver certainty on prices. A cap-and-trade system can therefore lead to significant price variability. Such volatility potentially poses a significant threat to industries and economies in a carbon-constrained world. There are however various mechanisms to control volatility. The common characteristic of the different mechanisms presented here is that they reduce the potential price range for allowances over the course of the commitment period.

The first option is to allow banking of allowances for future use. This allows governments to encourage companies to further reduce their emissions today by allowing them to establish a reserve of allowances for the future. This can limit price volatility between trading periods and smooth prices (Amundsen et al. 2006).

Another, at this stage theoretical approach, would be to allow agents to borrow allowances from future periods (Mavrakis and Konidari, 2003). This would help limit the volatility in the short term but could lead to shocks between periods. In addition, borrowing would tend to allow increased short-term emissions that would be detrimental to climate change abatement.

Setting price floors and or ceilings is another method that could be also used. These would aim to provide a mechanism of safety valves to reduce the risk for investments in emission reductions (Jacoby and Ellerman, 2004). The price floor would insure the regulator against the emissions market collapsing due to either an over allocation of permits or a fall in demand for permits. The price ceiling, would insure industry against extremely high costs of abatement, however this would need to be weighed against the loss in environmental integrity that adding additional permits to the system would induce.

A minimum price can guarantee a minimum level of profitability for investments in emissions reduction technologies. If a project avoids the release of 10 tons CO_2-e and costs £100, then setting a minimum price at £10 would help guarantee a safe investment. However, because this requires the regulator to buy emission rights this mechanism would be expensive for the regulator if the equilibrium price of allowances stabilized below the minimum price.

Despite this drawback, in practice such hybrid systems involving a combination of instruments based on quantity and price are quite popular. For instance, most mandated green certificates markets, that is, markets which have been established to support electricity from renewable energy include both price controls and quantity targets.

A second method used to limit price volatility is to link cap-and-trade schemes to baseline and credits projects outside the capped system. With baseline and credits project, an investor can generate additional emission credits by investing in emission reductions in other sectors or areas. These credits can then be used for compliance purposes in a cap-and-trade scheme. Emissions savings need to be defined relative to a counterfactual (a baseline without the investment, e.g. business as usual (BAU)). For instance, if it is too expensive for a British company to reduce its emissions, it can decide to invest in emissions reduction a country (for instance China) where investment can avoid emissions more cost effectively. The emission saving achieved through this investment (i.e. the difference between emissions after investment and emissions under the BAU scenario), after monitoring by an accredited external auditor, gives the right for emissions credits. These emissions credits are fungible with the allowances in the cap and trade scheme and therefore allow additional emissions.

Finally, in order to avoid fluctuations in a market, a government can link its system to another scheme. The linking mechanism is a way to improve market liquidity by increasing its size and the number of involved parties. In practice linking emissions markets is complex because of varying definitions. Some countries may have more severe monitoring and reporting guidelines, higher penalties for non-compliance and so on. Linking with a less reliable system can harm the effectiveness and credibility of a scheme and actually increase volatility so should be approached with caution.

5.12 Baseline and Credit Schemes

Baseline and credit schemes also rely on the creation of tradable permits. However, under these schemes no cap is set on overall emissions. Rather, a baseline is established and emissions credits or allowances are earned once actors involved in the scheme reduce emissions under this baseline. This baseline could be set at a project level (as in the case of the CDM), at a firm level (as in the case of the NSW Emissions Trading Scheme) or at the sectoral level or at the national level.

An environmentally stronger variant on this is where the baseline is also be used to provide emitters with a level of entitlement to emit. If actual emissions are below this entitlement then the actor has allowances it can sell. However, if emissions exceed the entitlement, then allowances must be purchased to account for emissions above their baseline.

There are several ways base lines can be set, depending on the policy objective, and desired environmental effectiveness of the scheme (Garnaut, 2008). For example, options include:

- setting the baseline as emissions in a particular year,
- average emissions per unit of production based on installed technology in a base year,
- average emissions per unit of production based on best practice technology, or
- any combination of these or other approaches.

5.12.1 Reduced Emissions from Deforestation in Developing Countries

Land use change in the tropics accounts for around 20 per cent of global emissions and represents the largest source of developing country emissions being the second largest source of emissions world wide after fossil fuel use.

However, in spite of the 'Australia clause' which allows developed countries to claim credits for slowing land clearing, 'avoiding deforestation' is excluded as a way for developing countries to generate emissions credits under the Kyoto Protocol, although afforestation and reforestation are eligible for credit generation.

This exclusion has led to the formation of the Coalition of Rainforest Nations and separately for Brazil to launch what has become know as the Reduced Emissions from Deforestation in Developing Countries (REDD) proposals.

The basis of these proposals centre around variants on baseline and credit forms of emissions trading, and have also been termed 'sectoral CDM' as opposed to the project based

The structure of the proposed baseline and credit schemes is illustrated in the figures below in the case of nations where the forest carbon stock has stabilized, is deteriorating and is improving. In each case, the establishment of the baseline would require the determination of some historical average of emission supported by satellite imagery and forest carbon flux ground truthing studies.

Figure 5.9.1 Static Baseline

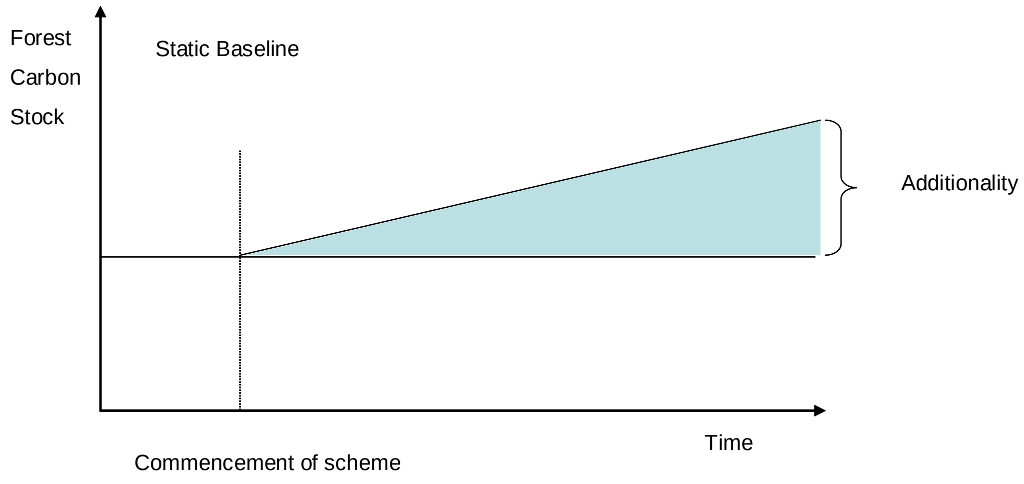


Figure 5.9.2 Deteriorating Baseline

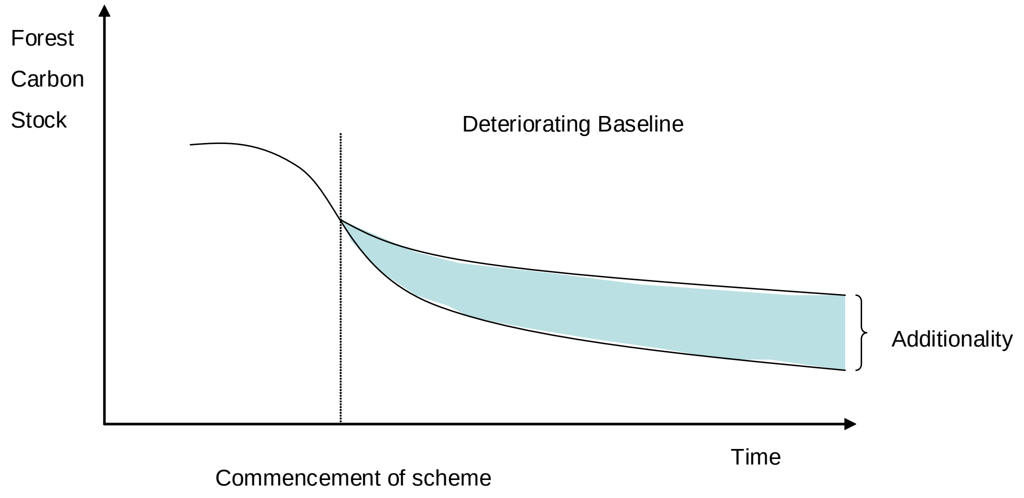
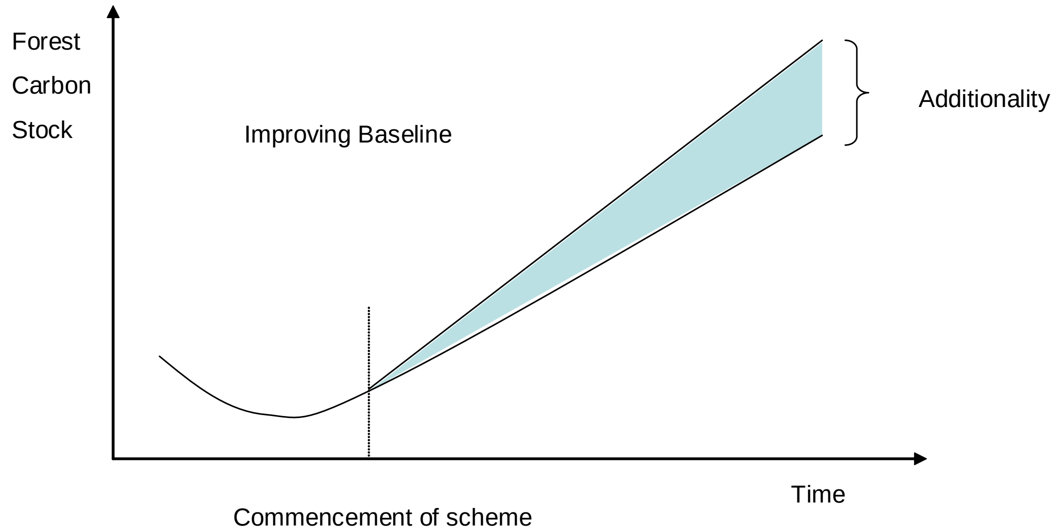


Figure 5.9.3 Improving Baseline



Such baseline and credit schemes can be use as a 'no regrets' climate policy, where once countries participate they are only exposed to the positive incentive side of achieving and exceeding the baseline. Emissions credits are generated according to the amount of addtionality achieved and can be sold into other carbon markets such as the EUETS.

However, some developing countries are cautious about such programs as once established the baseline can easily be transformed into a binding target and penalties imposed for non-compliance. Furthermore, some environmental groups worry that emissions reductions from deforestation would flood the carbon market with cheap credits (Fearnside, 2001). From an economic standpoint, it is beneficial to have emissions trading schemes with as broad a scope as practically possible, as this allows emissions to occur where it is cheapest for them to happen. Including the REDD proposals would have the further advantage of allowing nations to set stronger carbon targets and emission caps as part of emission trading design.

5.13 Conclusion

This Chapter has introduced the fundamental elements behind the theory and practice of emissions trading in the context of other policies to address climate change. While conceptually it can be useful to debate the pros and cons of emissions trading vis à vis other policies the reality of an economy riddled with market failure and the diversity of economic and political systems make it impossible to conclude that there is any one silver bullet policy mechanism to climate change. Instead, a 'silver buckshot' approach – which incorporates emissions trading, may offer the best and fastest solution to manage CO_2 reduction.

As concern and understanding of the damage costs of climate change escalate, and the costs of CO_2 mitigation fall, emissions trading becomes increasingly attractive from a theoretical perspective. This is because it can provide greater certainty around the physical quantity of emissions to be reduced as well as providing the economic incentive to allow pollution to only focus on the highest value sectors and to minimize the cost of abatement by fostering continuous innovation in low carbon technology.

Emissions trading schemes also tend to be more politically more attractive than other policies such as taxation, which make it harder to cushion the competitiveness impact of implementing a carbon constraint and can illicit rapid opposition such as in the case of 'increasing prices at the pump' for petrol. However, here there is still a gap that needs to be bridged between the theoretical benefits that emissions trading offers and its practical implementation – for instance sectors such as transport and emissions from deforestation have been left outside the scope of most emissions trading schemes.

Despite the practical challenges of implementing a new market system for the control of complex pollutants such as greenhouse gasses, emissions trading schemes offer a powerful and efficient logic for policy makers, organisations and individuals of all political persuasions. Emissions trading simultaneously satisfy the statist view of taking a tight regulatory approach while allowing for the application of incentive arrangements that provide for continuous innovation, favoured by market libertarians. It is perhaps this Coasian logic which bridges the old conceptual debate around how to manage environmental problems which best explains the growing popularity of emissions trading.

Chapter 6 The political economy of greenhouse gas mitigation in Australia

6.1 Introduction

An official act of the City of Copenhagen for the two week duration of the 15th Conference of Parties to the United Nations Framework Convention on Climate Change (COP15) in December 2009 was to the rename the city 'Hopenhagen'. During this period, over 190 nations, including one of the largest ever gatherings of national leaders, focused on the Danish capital to negotiate a successor agreement to the 1997 Kyoto Protocol.

Under 'Kyoto' developed nations had committed to take the first steps to avert 'dangerous climate change' by limiting their anthropogenic greenhouse gas emissions to 5.2 per cent of 1990 levels on average over the period 2008-2012. It also established the Clean Development Mechanism to fund carbon mitigation in developing nations, which were not required to adopt 'binding targets'. However, despite becoming a powerful international symbol of scientific and political cooperation on climate change, emissions under Kyoto in developed nations have continued to rise much along a 'business-as-usual' path (Barrett, 2009:62). In addition, the environmental integrity of its 'flexibility mechanisms' which allow these unmet targets to be covered by reductions in other nations have been called into question (Brohé et al., 2009: 94, 236, 271).

A key challenge therefore in the newly named city of Hopenhagen was the need to move beyond symbolic gestures and agree a treaty with 'meaningful' targets and timetables which provided a funding mechanism for the low-carbon economic development of poorer countries. However, the outcomes of the meeting were left ambiguous as the details for a final post-Kyoto accord were deferred to be agreed during 2010. Two factors behind this were the need of the United States to pass climate and energy legislation before making 'legal' as opposed to purely 'political' commitments and the intransigence of the Chinese negotiators to agree to outside authentication of their emissions data. These two issues are symptoms of the main argument of our paper: how the Kyoto negotiations, emissions trading schemes and carbon targets have created a veil behind which inaction on climate change can be hidden. Seen through this lens, the COP15 result reflects the difficulty in reconciling the symbolism of past agreements and institutional arrangements with the reality of environmental outcomes and renewed drive for effective policies.

That climate change is a global issue of great importance is now widely acknowledged (Stern, 2007). The award of the 2007 Nobel Peace Prize to the Intergovernmental Panel on Climate Change (IPCC) and to Al Gore perhaps demonstrates this best. The Third Assessment Report of the IPCC (2001) firmly established climate change as a political issue on the global agenda. The Fourth Assessment Report, released in November 2007 (IPCC, 2007: 3), suggested it was 'very likely' that human activities have contributed significantly to the observed temperature increase in the recent half century (i.e. an assessed probability in the interval 90-99%). Lord Nicholas Stern has highlighted (in Brohé et al., 2009) that should emissions continue on their current trajectory to 750 parts per million CO_2 equivalent in the atmosphere by 2100, there would be a 50 per cent chance that average global temperatures will rise by 5° Celsius. The last time the world was 5°C warmer 30 million years ago, forests covered the planet from pole to pole and sea levels were around 50 metres higher relative to today. The implications of such pressure on the world's physical geography over the next 100 years on geopolitical stability are severe, with one of the first likely climate catastrophes being a sudden melting of the Greenland ice cap, with the result that sea levels would rise between 4 and 8 metres. With most of the world's cities, even entire countries, under threat of inundation it is not surprising that nation-states have signed up to international targets and timetables to reduce emissions under the 1997 Kyoto Protocol. What is surprising, given the scale and scope of potential consequences, is the degree to which emissions seem to continue to rise and the persistence of barriers to imposing new legislation to curb them.

This paper investigates the way the Kyoto process has framed the politics and policies of greenhouse gas mitigation in Australia. Kyoto has exhorted a powerful international norm on political discourse, but it also seems to have created a framework that has not necessarily encouraged domestic emissions cuts. We have termed factors behind this observation the 'Veil of Kyoto'. This is not to say that targets and timetables are damaging per se, or are not important to policy implementation at the nation-state level. Indeed, such aspirational goals (especially if viewed as credible) are vital to capture the imagination of the nations, individuals and entrepreneurs that will drive the low-carbon transformation of society. Rather, our argument is that such Kyoto-style agreements must not be seen as ends in themselves and focus must stay on actual emission trends and measures to improve environmental performance at the level of nation-state.

Much recent work on climate change in human geography has focused on its boundary-making (Bakker, 1999; Shmueli, 1999), cultural (Dalby, 1996; Kartin, 2000; Feitelson, 2002; Dalby, 2003; Boykoff, 2007, 2008), and military (Toset, Gleditsch et al., 2000; Jasparro and Taylor, 2008) dimensions and the spatiality of carbon governance (While, et al. 2009). A special issue of *Political Geography* was devoted to the theme of climate change and conflict (Nordås and Gleditsch, 2007). Global environmental negotiations have also attracted the attention of political geographers, providing an important laboratory for understanding both the social construction of abstract issues (Dalby 1996), as well as the possibilities and limits of national action (Taylor 1999) and global structures of governance, especially the United Nations (Caflisch 1996; Dalby 1996; Momtaz 1996).

Somewhat paradoxically for a sub-discipline traditionally concerned with nation-state actors, the role of the state in climate change has been strangely underplayed on the political geography (and political ecology, its sub-disciplinary bed-fellow where the environment is concerned) research agenda. There are, of course, notable exceptions to this in existing literature. They include: Bailey and Rupp's (2005) and Bailey's (2007a) comparative studies of climate policy in the UK and Germany; Kerr's (2007) work on the efficacy of national climate programmes; and Bailey's (2007b) investigation into the 'scalar politics of EU emissions trading'. However, few studies have explored the multiple framings of climate change (particularly from a risk perspective), and fewer still have unpacked what 'national interest' actually means and how it is played out in the climate change context.

Outside of political geography, there has been considerable analysis of Australia's self interest as a global player on the Kyoto stage (for example, Hamilton 2001; Lowe 2004; Macdonald 2005), some analysis of its poorly targeted, ineffective abatement policies (Pollard 2003; ANAO 2004; Lyster 2004), and an exploration of non-ratification and domestic climate policies (Crowley 2007).

To set our work apart from existing literature, we instead focus on both the political geography and the structural situatedness of climate change in Australia, making an assessment of nation-state policy the cornerstone of our argument. In an editorial in *Political Geography*, Paul Robbins (2003) called for the space to be created within political geography for "an *everyday political ecology of the state*" (as well as "an *ethnographic exploration of institutions in nature*", in political ecology) as "the analytical and practical benefits of such a convergence are too attractive for critical scholarship to ignore" (pg. 644). By investigating the influence of 'Kyoto' on the politics and policy of climate change at the nation-state level in Australia, our work attempts to go some way towards meeting this geographical exigency.

This paper is organised as follows. In the next section we describe the politics and structure of climate change discourse in Australia and argue how the veil of Kyoto has masked actual environmental performance and shaped Australia's centre-piece environmental legislation, the Carbon Pollution Reduction Scheme (CPRS). Significantly, in August and December 2009, the CPRS legislation was rejected by the Australian senate creating the potential for an early election based around the climate change issue, possibly sometime early in 2010.

In conclusion we summarise the key contributors to the veil of Kyoto in Australia and draw out what our analysis might mean in the wider discourse on climate change and directions for further research elsewhere. If treated sceptically, the Copenhagen outcomes could be interpreted to reinforce our key point: that 'political' commitments seem to be eclipsing 'legal' frameworks while emissions continue to rise. However, more optimistically, the COP15 result could be seen as exposing the inherent difficulties of a Kyoto-style process driven through obtaining agreement among over 190 states through the international UN system. This can be contrasted with a more bottom-up approach of coordination through the UN system which reflects the legislative action taken by the most significant nation-states. This focus on nation-state legislation is what we argue must form the foundation of any meaningful international agreement on climate change.

We interpret the politics of greenhouse gas mitigation in Australia in terms that Beck (1995, 2005) describes as a risk society ill prepared to deal with contemporary hazards and as a culturally embedded symbol of climate change in the world's driest inhabited continent. These hazards are translated to the public through media coverage and political debate around a number of high profile events. These events, beginning with the 'Stern Review' (released on 30 October 2006), came together to create a sense of scientific consensus on human-induced climate change and, as a result, Australian public opinion polls began shifting in favour of 'taking action' against global warming. This combination of factors was also important in shaping Japan's decision to ratify the Kyoto Protocol: Tiberghien and Schreus (2007: 71) argue that "... media discourse, public opinion, and bureaucratic actions, helped to build the Kyoto Protocol into a symbol of Japan's new policy identity ... *embedded symbolism* [emphasis added] constrained the ability of anti-Kyoto forces to get their concerns onto the political agenda ... The rallying effect of Kyoto essentially trumped the decision in favour of ratification".

In Australia, climate change became an election issue in 2007, although its relative significance to other issues is beyond our scope here. Suffice to say that there were a number of issues that came together to compound the difficulties of the ruling Liberal/National coalition government.

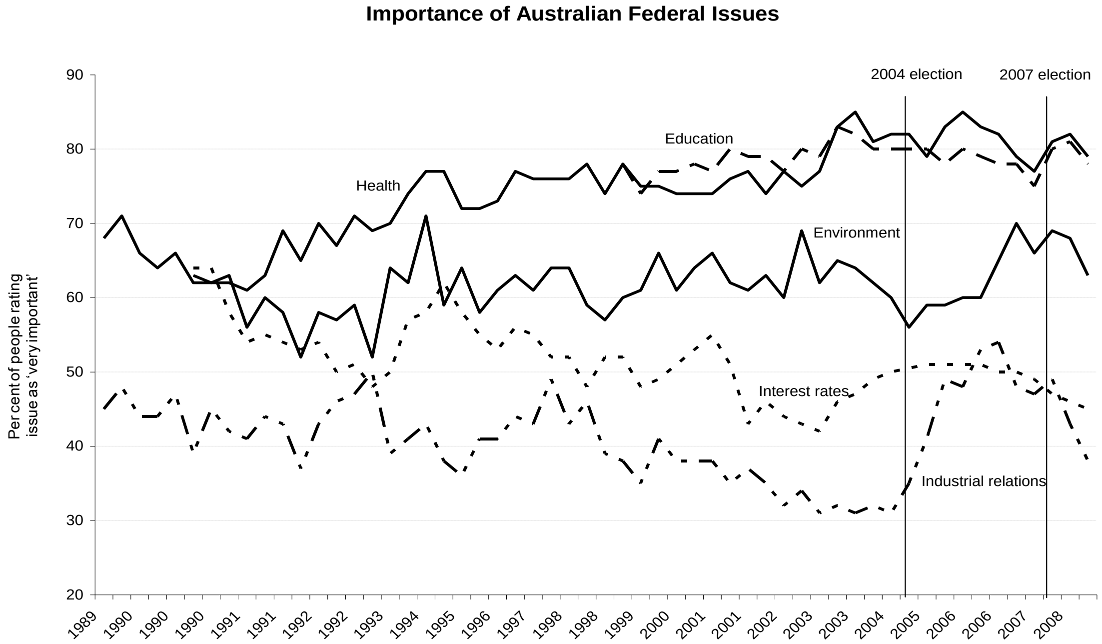
6.2 The Veil of Kyoto

The November 2007 Australian Federal Election heralded a dramatic shift in Australia's climate policy. Held just weeks before the United Nations Climate Change Conference in Bali (otherwise known as the 'Thirteenth Conference of Parties' or COP13), the newly elected Labor Party ousted the incumbent Liberal/National Coalition and, at the earliest possible occasion, on 3 December, 2007 ratified the Kyoto Protocol as their first act of parliament. The announcement, which was greeted with sustained applause from the assembled dignitaries and members of the press, suggested that the global politics of climate change appeared to have turned a corner, the US was isolated and a new, more inclusive agreement seemed possible (Christoff 2008). At the same time, the new Labor Government sought to fast-track the institutionalisation of a formal CO_2 market by bringing forward the implementation date for a national emissions trading scheme from 2012 to 2010 and committing Australia to a long-term target of a 60 percent reduction in emissions relative to 1990 by 2050.

The data in Figure 6.1 suggest climate change was amongst the factors that became important to voters in the 2007 election. While health and education were of higher importance in voters' minds, the politics of these issues were relatively stable or even declining between 2004 and 2007. In contrast, 'the environment', which can be reasonably considered as a proxy for climate change given the public discourse over this time, rose around 13 points to 70, along with the other main policy issue of the campaign -- industrial relations -- which rose around 25 points to just over 50.

Exit poll data for the Australian Climate Institute (2007b) reinforces the impression that climate change was an important factor. Their report states that "for those [voters] who made up their mind [which party to vote for] during the campaign, climate change was more important than for those who made up their mind earlier in the campaign" (pg. 2), and that voters who "switched to Labor from the Coalition rated climate change as an influence on their vote more highly than the rest of the population" (pg. 3).

Figure 6.1: The Evolution of the Importance of Federal Issues in Australia, 1989 - 2008



Source: Authors, based on Newspoll (2009a)

Prior to November 2007, climate policy in Australia had followed a course closely aligned with the United States. Both countries refused to sign the Kyoto Protocol or introduce a formal cap on domestic emissions, leaving the way open for state-based emissions trading markets to develop in an ad-hoc manner and voluntary emissions markets to emerge in response to growing public concern. At the core of the position adopted by the Liberal/National Government was the belief that even though Australia was on track to achieve its Kyoto Target of 108% of 1990 emissions during the period 2008-2012 it did not wish to ratify the protocol until the meaningful participation of major developing countries, in particular China and India, was achieved. This policy was supported by a number of domestic measures such as a Mandatory Renewable Energy Target (introduced on 1 April 2001) and the Ozone Protection and Synthetic Greenhouse Gas Management Act (introduced 5 December 2003) which encouraged renewable energy and controlled hydrofluorocarbons respectively. The Government also implemented the Greenhouse Challenge programme, which aimed to maximise participation by promoting voluntary action among polluting businesses. At the same time internationally, Australia focused its efforts on establishing the Asia-Pacific Partnership on Clean Development and Climate which set out a framework for clean technology transfer between Australia, the US, China, India, Japan, Canada and the Philippines (see www.asiapacificpartnership.org/). The International Forest Carbon Initiative was another initiative which sought to use Australia's expertise in the area to build capacity in developing countries to account for and trade in carbon credits sourced from changes in land use (see www.climatechange.gov.au/international/publications/fs-ifci.html).

In addition to Australia's 108 per cent target (relative to 1990 emissions), at Kyoto in 1997 the then-Environment Minister, Senator Robert Hill, had negotiated the inclusion of emissions from land clearing (deforestation) in the base year (1990). This became known as 'the Australia clause'. As can be seen in Figures 6.2 and 6.3, this clause is critical for Australia's ability to meet its 108% target. Since 1990, emissions from land clearing have declined sharply due to a combination of new federal and state regulatory native vegetation controls, such as the Environment Protection and Biodiversity Act (2003) and various state-based native vegetation controls.

It is also important to note that the accounting rules for the Kyoto Protocol only include anthropogenic emissions. The *National Inventory Report*, which is compiled under the broader rules of the UNFCCC (as opposed to the Kyoto Protocol accounting rules) shows the overall Australian emissions have risen by 82 per cent over the period from 1990 to 2007 as a result of a "temporary" jump in emissions from grasslands and croplands due to widespread drought conditions (Department of Climate Change, 2009a). Under current Kyoto accounting rules, these 'non-anthroprogenic' emissions are not included towards mitigation targets. This is a position Australia is keen to maintain (Wong, 2009).

Thus, despite being an actual source of emissions in 2007 relative to 1990, land use and change under Kyoto actually constitutes the only substantial emissions reductions over the 16 years to 2006, falling by 54 per cent. All other major categories of emissions have risen strongly in Australia since 1990 with stationary energy emissions rising the fastest by almost 50% (Department of Climate Change, 2009b). Yet despite this highly contingent sectoral emissions profile, the Government repeatedly stated (and continues to under Labor) that it is 'on track' to meet its Kyoto target. It is this use 'Kyoto' to hide underlying emission trends is what we have termed part of the 'veil' of Kyoto.

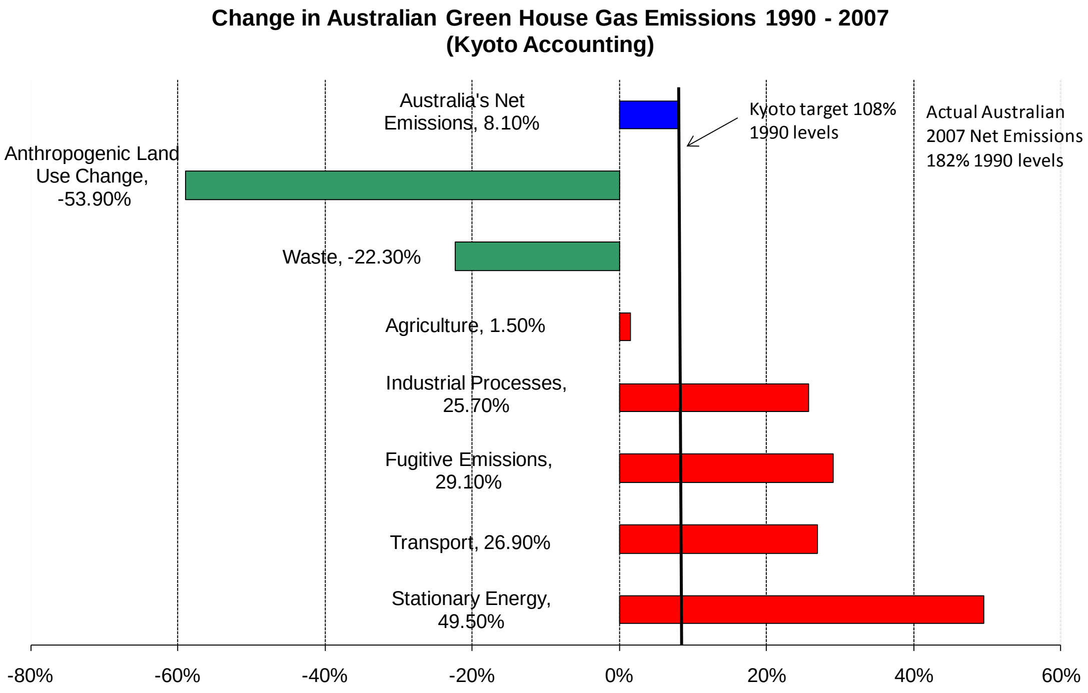
In the post-11 September 2001 diplomatic environment, this allowed Australia, during the 2002-2003 national debate on emissions trading and Kyoto ratification, to position itself firmly alongside its US ally. When criticised by the Europeans Australia could rebut that the EU was in no position to criticise given that Australia would meet its Kyoto target and most European states would not. It is worth noting that in addition to a strong personal relationship between Prime Minister Howard and President Bush, Australia was, at the same time, negotiating a long desired Free Trade Agreement with the United States which was finally agreed and brought into effect in 2004 (at a critical time for domestic and international climate policy development). Thus, while it is difficult to point to any one causal factor explaining the Government's decision not to ratify the Kyoto Protocol, especially given that Kyoto was unlikely to impose any immediate additional cost on the economy (Australia was expected stay within its Kyoto target of 108% of emissions), these factors can go some way to understanding the optics of the decision-making process (for a critical examination of the role of the fossil fuel industry in lobbying on the Kyoto Protocol, see Pearse 2007 and Hamilton 2001).

From the Howard Government's perspective, the decision to ratify or not ratify the Kyoto Protocol seems to have largely been regarded as a symbolic one. However, over the year leading up to the 2007 election (see Figure 6.4), a combination of international criticism and domestic pressure made this very symbolism the weakness in their credibility on the issue and an important point of political differentiation with Labor.

In October 2006 the British Government released the *Stern Review on the Economics of Climate Change*. In many ways the report was as much intended as a political and diplomatic staging post to launch a vigorous international public-relations campaign as it was a serious attempt at the most comprehensive and rigorous economic analysis of climate change to date. By making explicit his approach to the ethics of discounting, Stern arrived at a benefit-cost calculus which gave economic support to strong early action on climate change, favouring emissions trading over carbon taxation. Stern also attempted to reframe climate change as an opportunity for business and a boost for the economy, rather than the standard attitude that control of emissions would cost jobs and prevent economic growth.

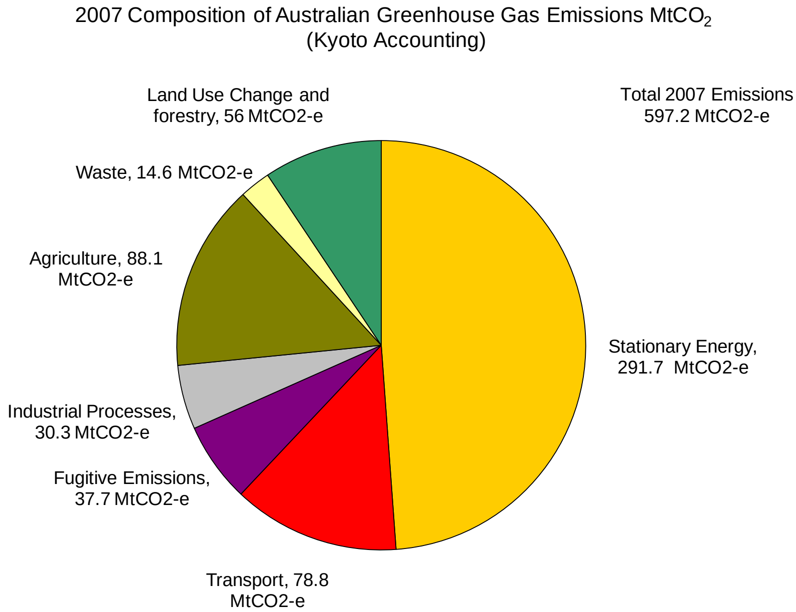
In March 2007, amid much media interest, Nicholas Stern visited Australia to present his report to both John Howard and Kevin Rudd. As a visiting academic, he was in a less constrained position than British officials to criticise the Government position of not ratifying Kyoto:

Figure 6.2: Percentage Change in Emissions, 1990 – 2007



Source: Authors based on Department of Climate Change (2009a, 2009b)

Figure 6.3: Composition of Australian Greenhouse Gas Emissions, 2007



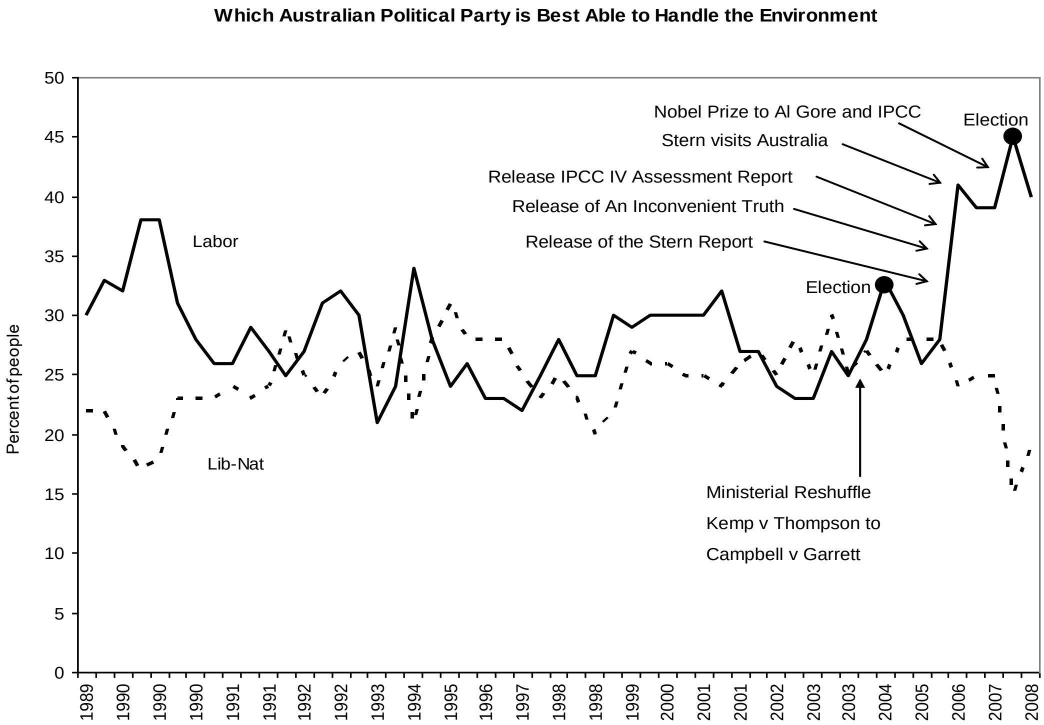
Source: Department of Climate Change (2009b)

> More and more countries round the world are prepared to move on the basis of their own responsibilities and their judgement of their own responsibilities in the light that others are also moving. That gains momentum and if some countries peel off then that momentum is seriously damaged. (ABC, 2007)

Moreover, at the same time parts of Australia were caught in the longest, most severe drought on record. In 2006, the late-winter to mid-spring rainfalls failed. While the average rainfall South Australia was the lowest since 1900, across Victoria and the Murray-Darling Basin the season was the second driest since 1900. Although New South Wales' rainfall was boosted by above normal falls along the north coast of the state, the state average rainfall for the season was the third driest since 1900. The nationwide drought had been picked up on by voters -- fuelled by media coverage -- as an 'everyday' impact of human-induced climate change. In effect, drought had acted as a surrogate for climate change: it assisted Kevin Rudd to position himself as leading the party that was most in touch with contemporary issues and best equipped to deal the complexities of modern life. Howard on the other hand preferred to address the drought through the lens of federal-state relations on water policy.

On February 2, 2007 the United Nations Intergovernmental Panel on Climate Change (IPCC) handed down its Fourth Assessment Report (IPCC, 2007) in Paris. This coincided with the first sitting week of the year in the Federal Parliament and provided yet further impetus to the growing momentum on the climate change issue.

Figure 6.4 Labor benefits from increased international pressure on Climate Change



Source: Authors, based on Newspoll (2009b)

Kevin Rudd, then-Leader of the Opposition, used the opportunity afforded by the first sitting day of Parliament to call a 'Matter of Public Importance' on the challenges of climate change and water scarcity. In his address to Parliament he made clear his plans to frame the Federal Election around sound economic management based around opposition to the government's industrial relations policy *and* climate change:

> This year we will see a battle for ideas for the nation's future... The battle ground on which we are going to engage this fight is one which centres around our [the Labor Party's] two sets of values regarding the way we want to shape this country's future. …we have to build long-term prosperity without throwing a fair go out the back door

> and we have to build long-term prosperity and take action on climate change and water (Australian Parliamentary Hansard, 2007:49).

Quoting directly from the IPCC Report he went on to criticise what he characterised as the Government's overly sceptical approach to the issue:

> The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report leading to very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming... Going to the footnote, what is 'very high confidence' defined as? 'Very high confidence' means: at least a 9 out of 10 chance of being correct (ibid: 51).

Then-Environment Minister Malcolm Turnbull responded by repeating the Government's long-held position that the Kyoto Protocol was not the best instrument to address the problem. Turnbull also commented that in the climate change debate room must be given to sceptics:

> The response to climate change is a complex one. It requires an open mind, and it requires practical measures. What the opposition is giving us now is some kind of cramped political theology. Nobody is allowed to doubt. Sceptics are to be banned. Anybody with an open mind is to be banned (ibid:19).

> We all recognise that ratifying the Kyoto protocol by itself will not result in Australia emitting any less greenhouse gases because we are already on track to meet our Kyoto target. It will not have, in and of itself, any effect on the greenhouse gases in the atmosphere (ibid: 52).

The other major element in the intensifying international campaign for greater cooperation on climate change came with the release of Al Gore's movie documentary *An Inconvenient Truth* late in 2006. This film was a world-wide phenomenon leading to a Nobel Peace Prize for Gore in conjunction with the IPCC. In addition to the film running for the year leading up to the election, the Nobel Prize came just one month before the November 2007 election again elevating the issue and damaging the Government for its perceived scepticism at a crucial time. In Australia the film had a significant impact on public perceptions. Data indicated that half of the people who saw the film said it changed their mind on the issue, with 54, 74, 87 and 91 per cent for the age groups under 25, 25-39, 40-55 and 55+ respectively, said it would change their habits (Nielsen-OUCE, 2007).

Figure 6. 4 shows how these various events had the effect of creating a perception of scientific consensus around the belief that climate change is human-induced and the perception that a tangible solution was to be found in the symbol of the Kyoto Protocol. In this sense, we can see how successive pronouncements by John Howard attempted to portray himself as a 'climate change realist' and the Opposition as 'hysterical', whereas the Opposition framed their position as 'serious' and the Government 'untrustworthy' (Olsson and Paglia 2008). This suggests a process of labelling - an essential element in the politics of 'risk society' (Beck 2005).

In recognition of the serious electoral threat climate change was posing to the Government, in January 2007 Howard appointed the Liberal Party's rising star Malcolm Turnbull to shore up the environment portfolio. Indeed, it can be argued that a structural shift in the Liberal-National Party's ability to command the environmental high ground (2002 to 2004) over the Labor opposition can be traced to Ministerial changes with a break seeming to occur just before the 2004 election. On the other side of politics Labor appointed high-profile Peter Garrett - an environmental lighting brand famously opposed to nuclear energy and former lead singer of rock band 'Midnight Oil'.

In addition, in December 2006 Howard established a group to report to him on a new Australian Emissions Trading Scheme. The Emissions Task Group (ETG) had very particular terms of reference, designed to ensure the position of the resources sector was maintained:

"Australia enjoys major competitive advantages through the possession of large reserves of fossil fuels and uranium. In assessing Australia's further contribution to reducing greenhouse gas emissions, these advantages must be preserved.

Against this background the Task Group will be asked to advise on the nature and design of a workable global emissions trading system in which Australia would be able to participate" (Howard, 2007).

What is notable is Howard's explicit reference to supporting the fossil fuel sector in a policy process designed to reduce carbon emissions. This highlights the geographical embeddedness of fossil fuels in Australia. Linking the issue of uranium mining to climate change was particularly controversial as Australia currently has no nuclear power plants aside from one small nuclear reactor at Lucas Heights in Sydney, used for research and the creation of medical isotopes. This may have been an attempt to frame climate change around the decision to 'go nuclear' and drive a wedge between environmentalists.

In May 2007, the ETG handed down its report and the Government announced that it would move to implement an emissions trading scheme in 2012. This was in contrast to Labor's policy to bring one in by 2010. As can be seen in Figure 6.4, public opinion continued to run against the Coaltion. The situation was so clear that the Coalition was facing an electoral landslide against it, that carefully placed rumours of a Cabinet revolt to 'sign Kyoto' led by Malcolm Turnbull were leaked to the nation's leading pro-business newspaper, the *Financial Times* around one month before the election in October 2007.

However, Howard was determined not to give in to pressure on the issue. A combination of public feeling on climate change, anxieties over industrial relations, and a sense of a need for change in leadership translated into a landslide defeat of the Government with the Prime Minister losing his own traditionally safe seat of Bennalong, only the second time in history a sitting Prime Minister had lost their seat.

As a classic problem of social coordination around how to manage a global public good, international norm building is fundamental if nations are to put aside short term national interest for the longer term gains that cooperation on CO_2 mitigation offers. This relies on solving the problem of collective action and the ascension of the 'free rider' problem at the nation-state level. The 2007 Australian election suggests (at least in the context of a liberal democratic state) that this is possible - through the weight of international and moral pressure and without recourse to trade restrictions or other punitive measures. However, it also showed a triumph of symbolism over pragmatic responses as voting Australian's were able to feel good about 'taking action' by 'signing Kyoto' – a decision which does not bring about any reductions in Australia's emissions from the business as usual. Ratification of the Kyoto Protocol has not seemed to have helped Australia gain control of its own rapidly rising emissions, and at worse, may have distracted voters from how this can be done - legislation aimed at root-and-branch reform of Australia's energy sector. In the following section we evaluate post-election policy developments focusing on Australia's centre-piece environmental legislation, the CPRS.

6.3 Post-2007 policy development

In early 2008 the government fulfilled an election commitment by announcing that a national-level cap and trade scheme called the 'Carbon Pollution Reduction Scheme' (CPRS) would be implemented to commence operation on 1 July, 2010. However, as the practical challenges of implementation became more apparent, the CPRS start date was delayed a year, while simultaneously lifting the government's maximum limit for its 2020 Kyoto-style target from 15 to 25 per cent. This focusing of public attention on targets and timetables while delaying implementation of national legislation to control pollution is another layer consistent with the Veil of Kyoto.

Following the 2007 election, the Labor government requires an extra seven votes to pass legislation in the senate. The Greens oppose the CPRS bill as they believe it should aim to cut emissions by 40 per cent by 2020 (rather than the 5 per cent proposed) and it was first rejected by the senate in August 2009. The Liberal-National coalition, was led for most of 2008 and 2009 by Malcolm Turnbull switched to supporting the signing of Kyoto, but retained a more conservative stance on the CPRS bill. The argued that it would be preferable to wait until a clear signal is given at Cophenhagen and also that greater structural adjustment assistance be given to polluters. Despite these qualifications however, towards the end of 2009 under Mr Turnbull it was looking lively that the CPRS bill was to pass in the senate on its second passage.

In the lead-up to Copenhagen the situation was intensified by the second vote on the CPRS legislation in the Australian senate. The issue prompted a challenge to Turnbull's leadership of the opposition led by Tony Abbott who argued against passing the CPRS legislation. Mr Abbott was supported by senate leader Nick Minchin who controversially had dismissed climate change as an extreme left plot to "deindustrialise the Western world" after the collapse of communism (The Economist, 5 December 2009). Winning the contest by only one vote, Mr Abbott took control of the opposition, and the CPRS legislation was voted down for the second time. It has also left the opposition with a gap in its policy agenda and the need to articulate a coherent response to a major issue of public concern.

Now ejected for a second time after a period of three months has elapsed, a 'trigger' will be given to the government to call an early 'double dissolution' election. This is significant as such an event is the only occasion when the entire senate faces the electorate, as opposed to the usual practice of half-senate elections. It would also be significant as the election would be focused around the debate on the climate change bill. After the 'trigger' is given, such an election can be called any time at the Prime Minister's discretion.

According to Newspoll in *The Australian* newspaper, at the time of the August 2009 senate rejection of the bill, Labor led the opposition by 57 points to 43 with Rudd ahead of Turnbull in personal approval ratings of 65 to 17 percentage points. At the time of the second rejection of the bill the government was leading the opposition on a two-party-preferred-basis by 56 to 44 per cent. This suggests an early election based around climate change in early 2010 is quite possible and would likely further extend Labor's lead over the coalition.

The CPRS was designed to replace, or at least complement, a number of other policies that had been instituted at the state and federal level. These included: the Greenhouse

Challenge, launched in 1995 in order to encourage the abatement of greenhouse gas emissions through voluntary standards; the Generator Efficiency Standards, introduced in 2001 with the objective to increase efficiency in fossil-fuelled electricity generation; and the Mandatory Renewable Energy Target (MRET) which required electricity wholesalers to buy at least 2% or 9,500GWh of electricity from renewable sources. On coming into power, Labor promised to increase the MRET target to 20% or 45,000 GWh of electricity production to be purchased from renewable sources by 2020. Legislation to put this target into effect passed in the senate in August 2009.

The most significant attempt to slow emissions has been taken at the state level by the New South Wales Greenhouse Gas Reduction Scheme (NGAS) (IPRT, 2008). NGAS is a baseline-and-credit emissions trading scheme which uses emissions intensity rules to regulate the stationary energy sector. However, while it has had some success at encouraging the development of the carbon offsetting sector, its use of emissions intensity rules mean that carbon emissions have actually increased in its covered sectors casting yet another veil over the issue of rising emissions (Passey et al., 2008).

The government also intends on establishing an Australian Carbon Trust, modelled on the UK's Carbon Trust, to help households invest in energy efficiency (Department of Climate Change, 2009c). While these policies are all important, it is the CPRS which forms the keystone of the government's strategy to reduce emissions and therefore is the focus of our paper.

In December 2008, the government released its White Paper (2008) outlining how the CPRS was to operate. This included what sectors of the economy it would cover, the emission thresholds for participation, what businesses would be forced to comply, and the rules regarding the accounting, trade and generation of greenhouse gas emission permits. Notably, however, at this time the government took no decision on the actual cap to be set under the CPRS[6], signalling that it would be announced just months before the start of the scheme on 1 July, 2010. During public consultation on the bills in April 2009, and after pressure from business groups in the midst of global recession, the government subsequently decided to delay the CPRS by one year to commence on 1 July, 2011. However, the proposed announcement of the CPRS cap is still intended to occur in the months prior to 1 July, 2010 according the Department of Climate Change (2009d).

The CPRS cap will be influenced by the Government's medium term national target. This was set in the December 2008 White Paper as a minimum of a 5 per cent reduction of national emissions by 2020 relative to 2000. In absolute terms, this amounts to a reduction of 27.6 $MtCO_2$-e from the 2000 base-year value of 552.8 MtCO2-e[7]. The choice of 2000 as a base year rather than 1990 is a notable departure from the Kyoto Protocol. However, bringing the baseline forward does not in Australia's case undermine the environmental integrity of the scheme. Once, emissions reductions from land clearing are factored in, emissions in 2000 were 552.8$MtCO_2$-e, almost identical to 1990 emissions of 552.6$MtCO_2$-e. However, excluding land clearing it represents a weaker baseline. In the 2008 White Paper, the government also signalled that in the event of a "global agreement under which all major economies commit to substantially restrain emissions…" it was willing to adopt up to a 15 per cent target, or an absolute reduction of up to 82.9 $MtCO_2$-e.

[6] The CPRS cap, which is to cover around 70-80 per cent of Australian emissions, is distinct from the national cap which was set in the White Paper to be at least a 5 per cent cut relative to 2000 emissions with the possibility of a cut of up to 15 per cent, the upper limit of which has been recently lifted to 25 per cent.
[7] Mega tonnes of carbon dioxide equivalent is used as not all greenhouse gasses are CO_2 (eg methane, nitrous oxide, HCF gasses) but can be expressed in terms of their CO_2 equivalent.

A series of indicative national emission pathways were set out in the White Paper for the first commitment period of the CPRS. While the CPRS will only cover approximately 75 per cent of national emissions, these pathways give a good indication of the expected stringency of the cap:

- 109 per cent of 2000 levels (602.6 MtCO2-e) for 2010-11;
- 108 per cent of 2000 levels (597.0 MtCO2-e) for 2011-12; and
- 107 per cent of 2000 levels (591.1 MtCO2-e) for 2012-13.

Thus the CPRS did not impose any greater obligations, in terms of national emissions, than would have been required under the Kyoto Protocol (108 per cent of 1990 levels). Indeed, in its originally proposed first year commencing on 1 July 2010 it was to actually allow *more* pollution that was intended under Kyoto.

In May 2009, the government announced "in response to extensive consultation with environmental advocates...," and "international developments since December 2008 [that] have improved prospects for such an agreement," that it had increased the maximum national target cut to 25 per cent relative to 2000 (Department of Climate Change, 2009c). However, until the parameters of what a "global agreement under which all major economies commit to substantially restrain emissions..." are laid out, there remains significant uncertainty around what stringency the CPRS cap will impose on emissions and following the lack of progress at COP15 this statement now would seem optimistic at best, or a misjudgement of the international political realities to exploit the political benefit of being perceived to strengthen Australia's target.

A transitional Electricity Sector Adjustment Scheme has been established to cross-subsidise carbon-intensive business (such as coal-power stations) using around $3.9 billion of revenue from CPRS permit sales, based on an initial carbon price of around A$25 per tonne (White Paper, 2008). Such mechanisms, while they can play an important role in the transition away from long-lived, high-cost infrastructure (Compston and Bailey, 2009), need to be carefully managed so that they do not merely increase the profitability of heavy polluters in the short term and undermine domestic emission reductions implied by targets.

Even with a weak cap, Australia's rapidly growing emissions trends suggest demand for carbon permits will be strong. This is because while caps may be modest, emissions are still likely to grow rapidly beyond them. This can be illustrated by looking at the stationary energy sector which comprises around half of total Australian emissions (Figure 6.3) and where emissions have risen by almost 50 per cent over the Kyoto period (Figure 6.2) and continue to rise as result of new build coal generation. For example, in 2007 (the most recent year of data) Australia's emissions from stationary energy were 291.7 $MtCO_2$ and growing at a rate of around 2.5 to 3 per cent on average, or approximately 5 $MtCO_2$, each year. To put these figures in perspective, the 445MW Tarong North power plant in Queensland produces 3.1 $MtCO_2$ each year (Passey, et al. 2008: 3011). This growth implies that there will be healthy demand for emissions permits from electricity generators, especially if they continue to build new coal-fired plants.

Significantly, the government also revised its initial CPRS exposure draft, which placed a limits on the volume of carbon permit imports (as does the EUETS), to a position of no limits on international trade in carbon permits. This means carbon polluters in Australia will be able to source an unlimited supply of emission permits on international markets meaning they can continue to pollute domestically, but offset these emissions with international permits. Disturbingly, there is evidence to suggest that many of these international permits may not be ‘additional’ - that is that they do not represent actual emissions reductions and would have occurred anyway (Wara, 2007). This propensity of the Kyoto mechanisms to slow investment in low carbon technologies at the nation-state level is another contributor to the Veil of Kyoto.

The disjuncture between the CPRS policy and the discourse is a result of several factors, not least the influence of the resource sector on the economy and the health of the public finances. This issue is strikingly illustrated in the observation that (according to Kyoto’s accounting rules) Australia has the highest per capita CO_2 emissions in the developed world (Brohé et al., 2009:7). The Australian economy is closely tied to semi- or un- processed (but energy intensive in terms of extraction and/or processing) resource exports to the Asian economies. The Reserve Bank of Australia (2008) reported that in 2007 46.5% of Australia’s total exports were primary resources to Asia, of which coal and metal ores and minerals accounted for 26.7% and other resources 19.9%. Similarly, Australia's wealth of cost-effectively obtainable coal and natural gas creates economic obstacles to a significant transition to alternative energy supplies, especially where the alternative generation technologies have yet to be developed on a large scale in Australia. This means that in addition to relying on coal for its own energy generation, Australia is the world’s largest coal exporter with around $A26 billion of exports each year, most of which fuels China’s rapid development (and emissions).

Kyoto’s accounting rules dictate that emissions are attributed to where they are produced rather than where they are consumed, which leads to an overstating of the emissions attributable to export dependent countries like China and understating them to importing countries such as America (Helm, 2009:19). For Australia, this means that exports of coal and other carbon intensive resources to China do not figure in its greenhouse accounting, even as the Australian government excises revenues from those exports and the Australian consumer benefits from the import of manufactured goods using that high carbon energy. Thus Kyoto's accounting understate Australia's true carbon emissions contribution both as a consumer of Chinese imports (thus driving energy demand from production in China) and as a supplier of the coal to fuel that energy demand. This is the final element to what we have called the Veil of Kyoto.

6.4 Conclusion

In this paper we explored how the Kyoto Protocol has framed the politics of greenhouse gas mitigation in Australia. While we find it has exhorted a powerful international symbolic norm around climate change, its success at encouraging environmentally effective policy has been limited. Indeed, while the Rudd government and most Australians seem to have embraced 'Kyoto' with good intentions as a powerful symbol of 'the everyday' relating to action on climate change, the power of this symbolism has veiled the structural drivers of Australian emissions in several ways.

Firstly is the common perception that Australia is 'on target' to meet its Kyoto obligations, and hence 'doing a reasonable job' at reducing its emissions. When we look at structural emissions growth in the last 17 years we reveal that emissions have increased by around 50 per cent in the stationary energy sector. If one looks behind the Kyoto accounting rules to actual (including non-anthropogenic) emissions we see that rather than an increase of 108 per cent relative to 1990 levels (under Kyoto), Australia's emissions in 2007 were 182 per cent of 1990 levels.

A second feature of the 'Veil of Kyoto' has been its focusing of attention on targets and timetables. In Australia, the strengthening of 2020 targets has been used by the government at the same time as delaying the implementation of the CPRS legislation. Another factor is that the efficacy of these targets may be tempered by the use of $AUD3.9 billion in 'structural adjustment' payments to high carbon industry.

The open-ended availability of international carbon offsets may also mean Australian polluters will be able to defer domestic mitigation investment and continue to increase their emissions. Furthermore, Kyoto accounting rules allow Australia to cloak its role as the world's largest coal exporter to the world's largest emitter, China, even as it earns billions of dollars in export revenues and acts as a driver for Chinese emissions by being a consumer of her imported goods.

These factors have combined to form the 'Veil of Kyoto': a powerful political symbol of the everyday which has transcended science and the physical state of actual Australian emissions. This has left Prime Minister Rudd in something of a 'climate trap'. As the inconsistencies between symbolism and policy become reconciled, Rudd faces the risk of alienating Labor from groups which favour strong action on climate change and those more worried about short-term prosperity being damaged by mitigation policies. This difficult balancing act is currently being played out in dramatic fashion by the Australian senate's second rejection of the CPRS legislation and the potential for this to trigger an early 'double dissolution' election in 2010. With Rudd and Labor far ahead in the opinion polls, this may be part of a larger Labor strategy to flush out opposition stances on climate change and destabilise the Liberal opposition leadership. By gambling on building increased political support on the climate issue in this way, Rudd may be seeking to outmanoeuvre the opposition and resources sector in order to pass through a more ambitious CPRS bill than would have been possible by negotiating the original bill through the senate.

We wish to emphasise that by suggesting ‘Kyoto’ has created a veil over the politics of greenhouse gas mitigation in Australia we do not to argue against targets and timetables, emissions trading, or strong action through international treaties. Rather, our analysis suggests a warning against placing too great a focus on the symbolic nature of political commitments while ignoring the structural drivers of emissions and the implementation on environmentally effective policies and measures at the nation-state level.

An alternative approach which is being pursued in many OECD countries in parallel, or as an alternative (in the case of the United States), is to see climate change through the lens of ‘Green Growth’ or ‘New Green Deal’ policies (e.g. OECD, 2012). This positions climate change as an investment challenge which is closely related to the process of creative destruction described by Schumpeter (1975[1942]) and built upon in the fields of evolutionary economic geography and innovation studies, which place technological change as the focus of analysis (Nelson and Winter, 1982; Simon, 1955, 1957; Arthur, 1988; David 1993; Martin, 2010; Geels and Kemp, 2006). This puts the focus squarely on the enabling framework necessary to catalyse private-sector investment in the transition to a low-carbon energy sector. Rather than appealing to the institutionalisation of a political symbol as the focus of policy, this approach looks to highlight the positive role of innovation to achieve both environmental and economic objectives along with a series of pragmatic set of policy conditions on energy efficiency, carbon pricing and innovation (OECD, 2012:12). The Veil of

Kyoto as evidenced in Australia may also be a useful analytical metaphor to consider the actions of other states. For example, for Russia, with 17 per cent of global emissions, ratifying Kyoto may have only ever a symbolic bargaining chip to be played in its bid for membership of the World Trade Organisation (Henry and Sundstrom 2007) and to help improve her international image (Gref 2004). More recently, it has been suggested that Russia has moved from a state of 'symbolic gesturing' to one of "dangerous indifference" as the Kremlin perceives that Russia "might actually benefit from climate change" (Mabey, 2008) (see also Wilson, 2008). In the case of the United States, President Obama has embraced the idea of national-level emissions trading to be brought in by 2012 and, in the lead-up to Copenhagen, announced a national emissions reduction target of 17 per cent below 2005 levels by 2020. However, when put alongside the European target of 20 per cent below 1990 levels by 2020, the American target reduces to a 3 per cent cut below 1990 levels. In response to the American move, China also announced a target aimed at a 40 to 45 per cent decrease in emissions intensity per unit of GDP by 2020. However, with GDP growing at around 8 per cent a year, this means Chinese emissions can still rise strongly. These examples suggest the elements of the Veil of Kyoto could be a powerful force to obscure actual emissions after Kyoto expires in 2012.

Another important shift was signalled in the August 2009 Japanese election, where climate change featured prominently in the debate. With the election of the Democratic Party, Japanese national targets were strengthened to a 25 per cent cut by 2020 relative to 1990 levels, up from an 8 per cent cut as proposed under the former governing Liberal Democratic Party. However, at the same time the new government promised the immediate lowering of fuel taxes and road charges for drivers, policies likely to stimulate emissions. This again raises the spectre of climate symbolism trumping climate policy.

Although there are common strands in the framing of climate change risk and policy between nations, equally important are these differences. Furthermore, how these are manifested and interweave in international discussions has important geopolitical implications relevant not just to greenhouse gas mitigation policy but also to energy security and the regulation of world trade.

Given the critical importance of the nation-state in mitigating greenhouse gas emissions we hope that this paper begins to respond to Robbins' (2003) call for political geography to pay to "an everyday political ecology of the state […] as the analytical and practical benefits of such a convergence are too attractive for critical scholarship to ignore" (Robbins 2003: 664). If framed through the metaphor of the Veil of Kyoto, the difficulty of securing meaningful action at COP15 in Copenhagen can be seen as stemming from the problems inherent in reconciling the momentum behind the symbolism and institutional arrangements of Kyoto with the reality of deteriorating environmental outcomes and renewed drive for effective policies. While the delay to conclude a successor agreement to Kyoto in 2009 may be disappointing for some, it may also offer hope that a renewed focus is being placed on the implementation of legislative measures by nation-states as the basis of a new international agreement. This might be the basis for 'meaningful' action.

Chapter 7 The political economy of Green House Gas pollution in Russia

7.1 Introduction

Depending on the measure taken, Russia is either the world's third or fourth largest polluter of greenhouse gasses (GHG), emitting around 2,000 $MtCO_2$-e in 2008, or around 5% of global annual emissions. This compares with China and the United States, which contribute around 20% of annual emissions each, and puts Russia on a similar par as India and Japan. Germany follows next, with around 2.5% of annual global emissions. Clearly, Russia is a key player in the global effort to reduce the risk of dangerous climate change, a position all the more striking given a fall in Russian emissions of around 51% between 1990 and 2008. Over this period energy emissions fell 32% with the collapse of economic output in the 1990s associated with the dissolution of the Soviet Union and subsequent attempt to transition to a market economy. With 22% of the world's forested area, Russia is also home to the world's largest forest estate. Accordingly, land use and land use change feature strongly in Russia's emissions profile. Between 1990 and 2008, emissions from this category decreased by 559% moving from being a source to a net sink. Furthermore, with around 36% of electricity generation sourced from zero carbon sources, such as hydroelectricity and nuclear power, Russia has achieved an unparalleled decarbonisation of its economy over the last two decades, albeit for reasons far removed from climate policy.

Russia's 'achievement', however, has been underplayed on the international stage for several reasons. Most notably, the Russian case seems problematic to the logic of ecological modernisation – that cutting emissions is compatible economic growth (see for example Stern, 2006). Russia's radical decarbonisation came about as a result of an economic collapse which left millions unemployed and caused a massive deterioration in living standards. In practice, the so-called 'shock therapy' involved with the implementation of market reforms in the early 1990s exposed the centrally-planned public system to what has been called a chaotic process of economic 'disorganisation'. As the Soviet demand and supply networks broke down, a new predatory business oligarchy rose in its place. This period was characterised by widespread corruption and asset stripping as formerly state-run industry was privatised. Eventually, Vladimir Putin (after becoming President in 2000) used the security apparatus to reassert order based around the power of the state and today Russian officials estimate that around 60% of GDP is produced by state-controlled companies (Clover, 2010). This stabilisation resulted in a return to economic growth but not a commensurate increase in emissions, suggesting the Russian economy had 'decoupled' from GHG emissions.

A second potential reason for the lack of acclaim for Russia's GHG reduction achievements can be seen by considering Russia in the context of what has been called the 'Veil of the Kyoto' - the GHG accounting rules of the Kyoto Protocol (Howarth and Foxall, 2010). While Russia is a major exporter of oil and gas (the tax revenues from which have underpinned the Russian recovery), the vast bulk of emissions associated with these exports are attributed to the countries in which they are burnt, mainly in Europe and China. This means that Russia's CO_2 profile remains contained despite a dominance of fossil fuels in the economy.

Finally, and strangely from a climate policy perspective, the Kremlin has not highlighted its climate 'achievements' as vigorously as one might expect, instead emphasising the possibility of economic growth (and emissions) surging past the Soviet high-water mark in international discussions. For instance, at the 2009 climate talks in Copenhagen attention focused on Russia's commitment to a 15-25% reduction on 1990 GHG emissions by 2020, a commitment widely criticised as inadequate by the environmental community. Such attention overlooked the fact that Russian emissions are already below these levels and that such a target would be considered ambitious in most other industrialised nations.

These contradictions and lack of a positive ecological modernisation narrative perhaps go some way to explain why the case of Russia seems to have been underplayed in the academic and popular literature. When Russia is talked about (see for example, Afionis and Chatzopoulos, 2010; Tipton 2008; Henry and Sundstrom, 2007; Korppoo and Ikeda, 2006; Buchner and Dall'Olio, 2005; Golub and Strukova, 2004; and Müller, 2004), it is generally in the context of its role in the UNFCCC negotiations, particularly the ratification process of the Kyoto Protocol, or as part of macroeconomic modelling studies of emissions investigating relationships between carbon prices, emissions and GDP. Given the importance of political factors in shaping the Russian economic system, where the rule of law does not support a 'market system' in any western sense of the term, it seems that case study explorations of the historical, institutional and political context offer a sound basis for developing an understanding Russian climate policy and GHG outcomes.

In this chapter we set out to develop such a case study of Russia informed by strategic policy network theory where relationships between actors in the system evolve as a function of 'resource' interdependencies. These resources can be either physical or political but in either case to be relevant they must be able to be controlled, desired and to be transferable between those in the network (for example, EU recognition of Russian 'market economy status' as a step towards ascension to the World Trade Organisation for support of the Kyoto Protocol). In this context each member wants something from one or more of the other network members and is prepared to exchange something of their own to get it. For climate change policy, Compston (2009) has distinguished ten typical tradable resources, such as legislative amendments, formal approval, access to information, recourse to the courts, investment, political support, patronage and cash. While some elements of this nomenclature are more relevant than others for Russia, it serves as a useful framing logic to understand our case and hopefully allows some comparison of our results with similar studies (Compston and Bailey, 2008; forthcoming). This work supports a research agenda identified by Paul Robbins (2003) for a "political ecology of the state", in this case assessing the multiple framings of climate change at the level of a nation-state in pursuit of the 'national interest'.

This chapter is set out as follows. We begin by describing the structure of greenhouse gas emissions in Russia during the Yeltsin 'decarbonisation years' between 1990 and 1998 and then the 'recovery years' of 1999 to 2008 under President Putin. Noting the importance of land use and land use change for Russian emissions and global climate governance, this section highlights one of the key economic and political questions facing Russia: that is, whether the state revenues from levies on oil and gas exports are embedding the fossil fuel sector ever deeper into Russia's institutional matrix of business and politics, or, alternatively, whether these revenues are supporting a managed transition away from an over reliance on extractive industries. While this is a difficult issue to assess, it is one which will significantly determine the sustainability of Russia's economic recovery as well as influencing the power-politics of the 2012 Presidential elections. Next, we describe the role of climate change in post-Soviet politics, drawing attention to the nature of the competing political factions within the Kremlin and layers of governance which are likely to have a significant influence on policy development and implementation in Russia. This framing is useful as it helps identify the lines of power which can drive policies to reduce emissions, following either the interests of the *siloviki* (military-security agencies), technocrats (for example, Gazprom) or more market oriented 'liberal' forces. In the final section, we identify four broadly themed areas of reform to promote low carbon development, which aim to support Russia's strategic domestic and international interests. These are: economic modernisation, innovation and energy efficiency; emissions trading and the Kyoto Protocol (with a special focus on the nexus with World Trade Organisation membership); the development of gas exports to Europe and the potential to support a Chinese 'dash-for-gas'; and, public and official awareness of climate change issues in Russia and the potential to securitize the climate agenda to align with the interests of the *siloviki*.

Due to space constraints, this chapter does not attempt to be comprehensive in its coverage of all the climate relevant issues facing Russia. More could be written on the important issue of the management of the vast Russian forest estate and the geo-physical impacts of a changing landscape for global climate systems. We have also not delved too deeply into the potential for new investment in nuclear and renewable energy systems, the expansion of which are stated priorities for the President (both energy systems have ambitious targets articulated for them). Nevertheless, this chapter hopes to have captured the main dimensions of GHG mitigation and climate change policies in Russia along with the distillation of a program of measures to support the pursuit of Russia's economic and political priorities.

7.2 The structure of Russian greenhouse gas emissions

Over the past 20 years, Russia has undergone a profound transformation from a planned to a more market-oriented economy. This transition induced a painful social and technological transition and a radical decoupling of the economy from carbon intensive growth towards less polluting activities -- at least from a Kyoto accounting perspective (Figure 7.1). The economic and social cost of this transition has been high. Between 1989 and 2002, Russia's population fell from 147, 022 million people to 145, 164 million. At the same time, Gross Domestic Product (GDP) contracted by 39%, unemployment increased by 39% and a staggering 23.8% of the population dropped below the $2 a day poverty line between 1990 and 1999 (World Bank, 2004).

It is generally accepted that Russia's output collapse (and the accompanying fall in emissions) resulted from the disruption of the planned economy caused by the disintegration of the highly centralised Soviet system (Blanchard and Kremer, 1997; Djankov and Murrell, 2002; Eilat, Sachs and Zinnes, 2001; and Brown and Earle, 2006). Government planers in the state bureaucracy set the production, prices and delivery timetable for goods and industrial activities which were dispersed and specialised across the different republics. A nonmonetary inter-enterprise transaction system supported this production structure (Commander and Mumssen, 1998). Virtually every component of this system was owned and controlled by the state and private sector activities were left to a significant informal sector (i.e., the black market).

During the Soviet period, some western analysts suggested that the Soviet environmental policy process could be thought of in terms of a 'state corporatist' model, which had evolved since Stalin's time. Just as pluralist systems in market democracies take into account different groups in the policy making process, under a state corporatist model a plurality of groups impact on decisions, however the different branches of the state have a much greater role, as opposed to individuals, private firms and NGOs. Much like in a liberal capitalist system, where ideas spread through the media and market, under a state corporatist model the dissemination of ideas and solutions to problems must flow through the party-state structure. Analogous to a market-oriented system, it is not the system per se but the quality of governance underpinning it which determines whether the environment is valued and protected or not[8].

According to the neoclassical economic logic which provided theoretical support for the transition to a market economy, the central planning system was held to be operating incredibly inefficiently. Under market reforms, price controls were relaxed, state corporations privatised, a tax system introduced, fiscal and monetary policy tightened and flexibility introduced to the exchange rate. According to the theory, these reforms should have led to a more efficient allocation of resources and the *expansion*, not the *contraction* of output. In hindsight the neoclassical view proved to be naive as Russian market institutions were far too immature to support western-style market relationships. It was often the case that large former public firms had or knew of only one supplier of key components of the production process and only had one or two buyers of their output. Once the central planner withdrew and breaks in this supply chain occurred, trade between Russia and the former Soviet Republics collapsed. Instead of production, to earn income the new owners begun to sell off (cannibalise) their machines, firms began to lose crucial workers, and their capacity to adapt to the changing environment. This process of

[8] For a critical discussion of the respective modes of environmental governance under capitalist and communist systems, see Pearce and Turner (1990).

disorganisation facilitated a new (often armed) elite oligarchy to rise in the place of the central planner and resulted in a severe weakening of predictability and application of the rule of the law (Blanchard et al., 1997).

The Organisation for Economic Cooperation and Development (OECD, 1999) emphasises a more positive narrative instead focusing attention on the decoupling of GDP and pollution. It has been observed that the structure of planned economies tends to differ from market economies in the former's emphasis of heavy over light industry, and industry over services (for a review see Ickes and Ofer, 2005). As suggested by Table 7.1, the transition to a market-based system shifted demand away from heavy industry, defence, infrastructure investment and public consumption towards private consumption, which is governed by consumer instead of the planner's choice and is less polluting (carbon intense). The OECD suggests that the collapse of the centrally planned system in the early 1990s and liberalisation of the economy was a once-off event which exposed Soviet industry to price signals and competition from overseas. As formerly state-run enterprises struggled to find their place in this new order, many firms were forced to close and others (eventually) emerged to take their place[9]. It is argued that this process lead to greater efficiency across the economy and thus lower carbon intensity.

The *disorganisation* thesis runs somewhat counter to OECD's narrative as the correlation between market reform and pollution reduction does not necessarily imply causation. Other important factors which effect both output and pollution are likely to have had an effect such as the erosion of the rule of the law which has been a feature of the post Soviet system as well as the mothballing of industrial capacity. In this case the decline in pollution

[9] This period of transition has naturally been a focus for much research. For example, Berkowitz and De Jong (2003), Popov (2001), and Hanson (2000).

(and domestic output) does not reflect an increase in efficiency (and increasing imports) so much as the institutional dysfunction of new economic system.

In the context of climate change, this period is important as the Soviet economic collapse and apparent decoupling of subsequent growth in former Soviet Republics from carbon emissions is perhaps the most significant decarbonisation event in history.

Since 1999, under the new leadership of Vladimir Putin (initially as Prime Minster, then as President, and now Prime Minister again), the Russian economy began to grow at an annual rate of around 6% to 7%. Over this period, carbon emissions seem to have decoupled from GDP growth. However, the fossil fuel industry has provided much of the economic foundation for this renaissance. In 2009, Russia was the world's largest producer of natural gas (20.9% of world production), the second largest producer of crude oil (12.3% of world production) and the world's sixth largest producer of coal (IEA 2009). State revenues levied from these industries are providing much of resources to cross-subsidise other areas of Russia's recovering economy. Whether this process is embedding the fossil fuel sector deeper into Russia's institutional matrix of business and politics, or alternatively is part of a managed transition away from an over reliance on extractive industry, is a contested issue. The risk is that over reliance on the fossil fuel sector exposes economic development (and the political stability rising prosperity buys) to the vagaries of world fossil fuel prices, subject to boom and bust and far removed from the Kremlin's ability to control.

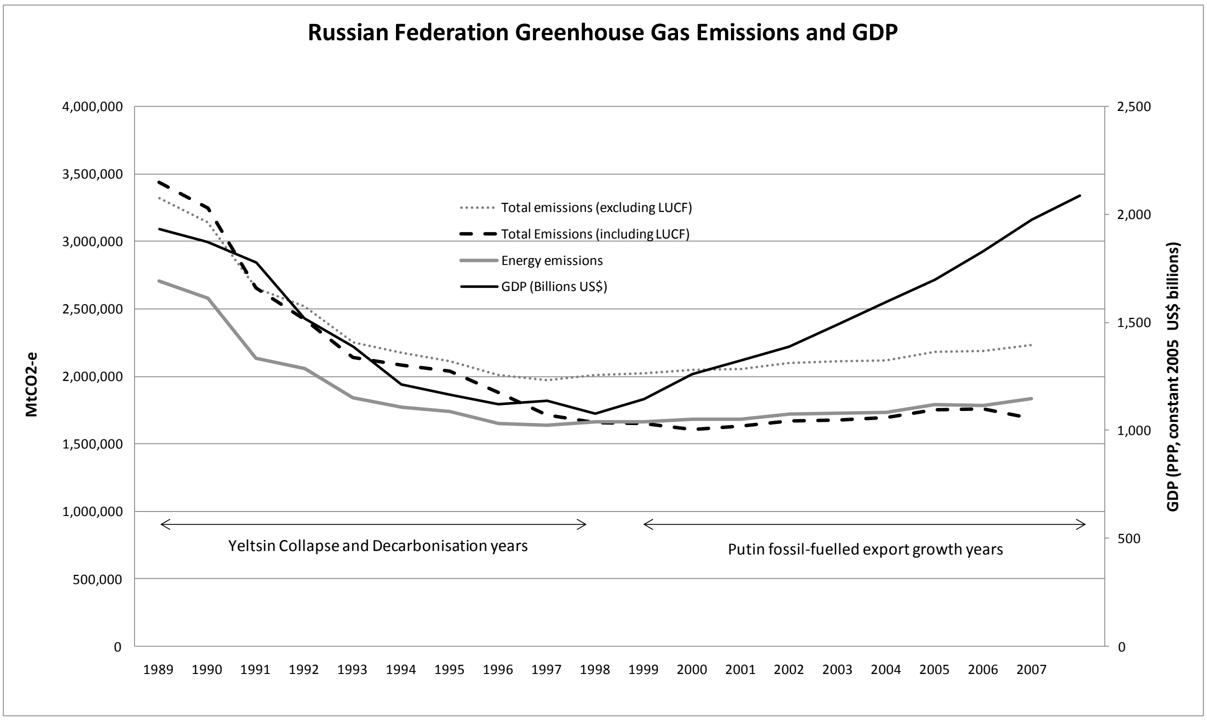
Indeed, in Yaroslavl in September 2010, President Medvedev argued, "Just because energy prices have risen and we have had a burst of growth, people get comfortable, but it may not last. There is no alternative but to change the source of our growth."

Table 7.1: Changes in the industrial structure of employment in Russia: 1990-2001 (%)

Sector of the economy	1990	2001	% Change
Agriculture and forestry	13.8	12.7	-8.1
Manufacturing	30.3	22.7	-25.1
Construction	12	7.8	-35.4
Transportation and communications	7.7	7.7	0.6
Trade and catering	7.8	15.4	98
Housing and personal services	4.3	5	17.3
Health, sport and social security	5.6	7	25
Education, science, culture	13.8	12.7	-8.1
Public administration, banking and other services	5.3	9	68.9

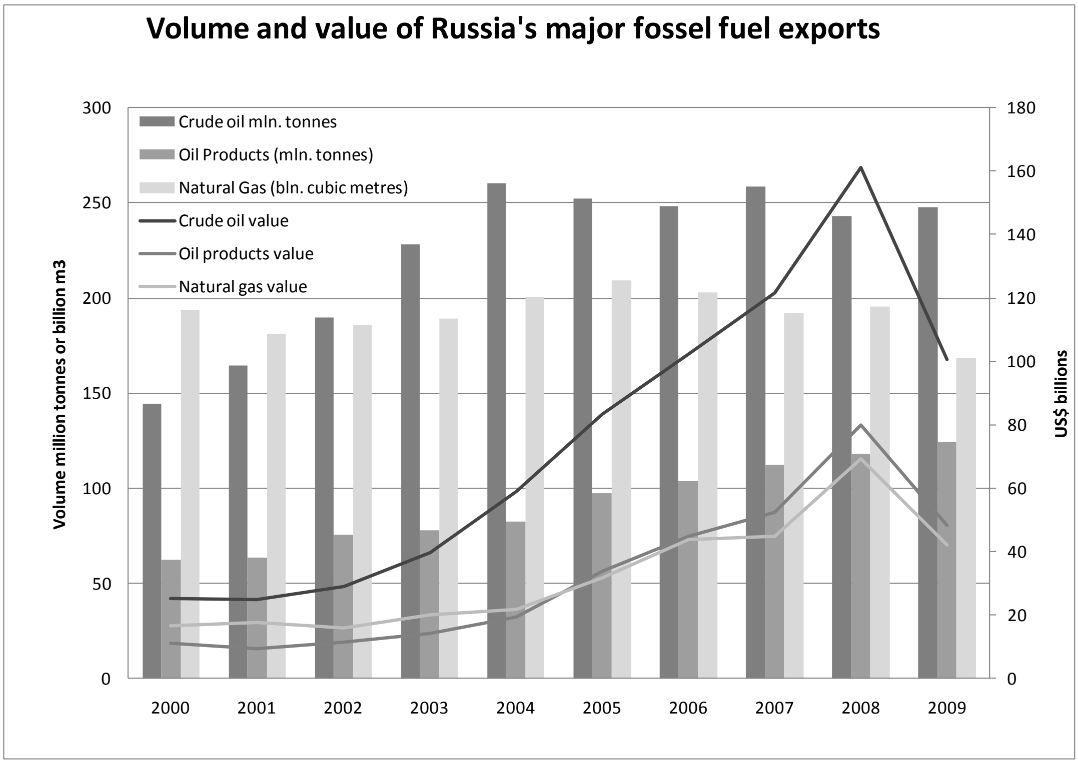
(Source: Ikes and Offer, 2006)

Figure 7.1 The decoupling of Russian GDP from carbon emissions



Source: UNFCC, World Bank online data bases

Figure 7.2 The importance of oil and gas exports to Russian economic recovery



Source: Central Bank of Russia, online data base

While Russia has almost doubled the volume of its export of fossil fuel products, the physical quantity of gas exported has actually declined over the last 10 years. This is despite the near trebling of the value of gas exports over this period and reflects in part the failure of Russian utilities to bring on line supplies from major new gas fields, decreasing production from existing fields and the requirement to meet domestic supply obligations. These observations act as a caution against the common perception often expressed in European media that Europe is becoming increasingly reliant on a surging Russian gas export industry. While prices have risen, volumes have not, and it is Russia's production of oil which most firmly positions it as a world energy superpower.

Russia is listed in the Annex B of the Kyoto Protocol, which sets binding targets for developed nations. Russia's target is that emissions of the six "Kyoto Gasses" should not exceed five times their combined 1990 levels during the period 2008-2012. In annual terms, this means that Russia's emissions should not exceed, on average, their 1990 level, or 3,048 MtCO2-e, each year over the period 2008-2012.

However, it is important to note that the emissions from fossil fuel exports are not included in Russia's emissions profile. Rather, emissions are attributed to the country in which the fuel is consumed. Indeed, one of the most important drivers of the European Emissions Trading Scheme (EUETS) was the fear that the Kyoto Protocol was not going to enter into force. As the EUETS set the stage for increasing prices for fossil fuels in European markets (and lower demand), it is also likely that it was in the interests of Russian energy exporters to support the much less onerous provisions of the Kyoto Protocol than see a stronger EUETS.

The vast bulk of Russian emissions are from stationary energy production used for public electricity and heating (see Figure 7.3). Between 1990 and 2008, which was the last year of official data, total emissions had fallen by around 51%, with energy and land use and land use change delivering the biggest emission declines of 874,272 and 655,848 $MtCO_2$-e respectively.

According to the International Energy Agency (2006), there were around 700 electricity plants in Russia in 2003 with a total generating capacity of 214 GW. Of this capacity, 37% was carbon free, with renewable (hydroelectric) power contributing 21%, and nuclear energy 16%. Fossil fuel powered thermal generation accounted for the remaining 63% of generation capacity, and of this gas dominated with 63% of generation, coal 27% and fuel oil around 10%. West of the Urals, gas dominates with about 80% of thermal generation, while east of the Urals over 80% of generation is coal based.

Stretching from the Baltic Sea to the Pacific Ocean, the territory of the Russian Federation covers one eighth of the world's land mass and includes around 20% of the world's forested area, the largest area for any one nation. Russia's terrestrial ecosystem ranges from tundra and boreal forests in the north to steppe grasslands and desserts in the south. Much of this stretches across cold, northern latitudes where the effects of global warming are expected to be strongest. Changes to the Russian permafrost, which cover more than 60% of land, are also likely to play a major role in global climate change. Permafrost is generally thought to be highly sensitive to global warming, although rates of thawing and carbon release are still uncertain (Dankers, et al., 2010). The frozen ground contains a layer of organic material which once thawed, decomposes and releases methane into the atmosphere. The changed conditions also increase the risk of peat fires, which may also have a significant impact on the release of CO_2 into the atmosphere through combustion. Forest management is an important element of greenhouse gas stabilisation as organic material in forests and under the ground act as a store of carbon which, if burnt, are released into the atmosphere. Young forests which are growing sequester carbon dioxide from the atmosphere into their biomasss, which explains the change in emissions from this category.

In the summer of 2010 Russian land use was brought into focus while Russia was gripped by its worst drought in over 30 years. In the month of July, Moscow registered 10 of the hottest days since records began 130 years ago. Tragically, the dry conditions combined with summer lightening storms and resulted in severe forest fires across large areas of western Russia[10]. There are many factors influencing the incidence of such fires, including changing forest management as well as the drier forest conditions accompanying warming temperatures (see Stocks et al., 1998)[11].

Accounting for land use change in Russia is characterised by high levels of uncertainty. Korppoo and Spencer (2009) state that satellite data is not used to calculate forest cover in Russia, but instead data is collected from around 7,500 district forest areas of an average size of 14,000 hectares, and around 1,700 forest areas and national parks of an average size of 600,000 hectares (about half the size of England), with an uncertainty level of about 17%. They also state that the Kremlin reports that 70% of Russia's forest is considered "managed"

[10] On 1 January 2007, President Vladimir Putin signed the Forest Code which eliminated the national fire service (inherited from the Soviet era) and placed the responsibility for defending forestlands on those who had the rights to use them, mainly paper mill owners and real estate developers. At the time, the Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences warned that "the first dry year after the liquidation of the system of forest protection would become a catastrophe [for Russia]".

[11] As of August 2010 it is too early to assess what, if any, impact this major catastrophe will have public attitudes towards climate change and any increased potential for greenhouse gas mitigation policies. It should also be noted that as only direct anthropogenic emissions are included in the calculation of emissions under Kyoto, the carbon released into the atmosphere from peat or forest fires are not included under Kyoto, although they may have been influenced by forest management practices.

which is likely to bring into the inventory some non-anthropogenic carbon changes, which are meant to be excluded from Kyoto's accounting of greenhouse gas emissions.

The significance of land use and land use change for Russia's natural and anthropogenic greenhouse gas emissions is important both in the accounting of Russia's annual emissions and also in driving potential positive carbon feedbacks, where mild global warming triggers further releases of natural stores of greenhouse gasses. For these reasons, Russian land use change and its climate dynamics justifies careful management and detailed study from the scientific community.

7.3 Climate change in post-Soviet politics

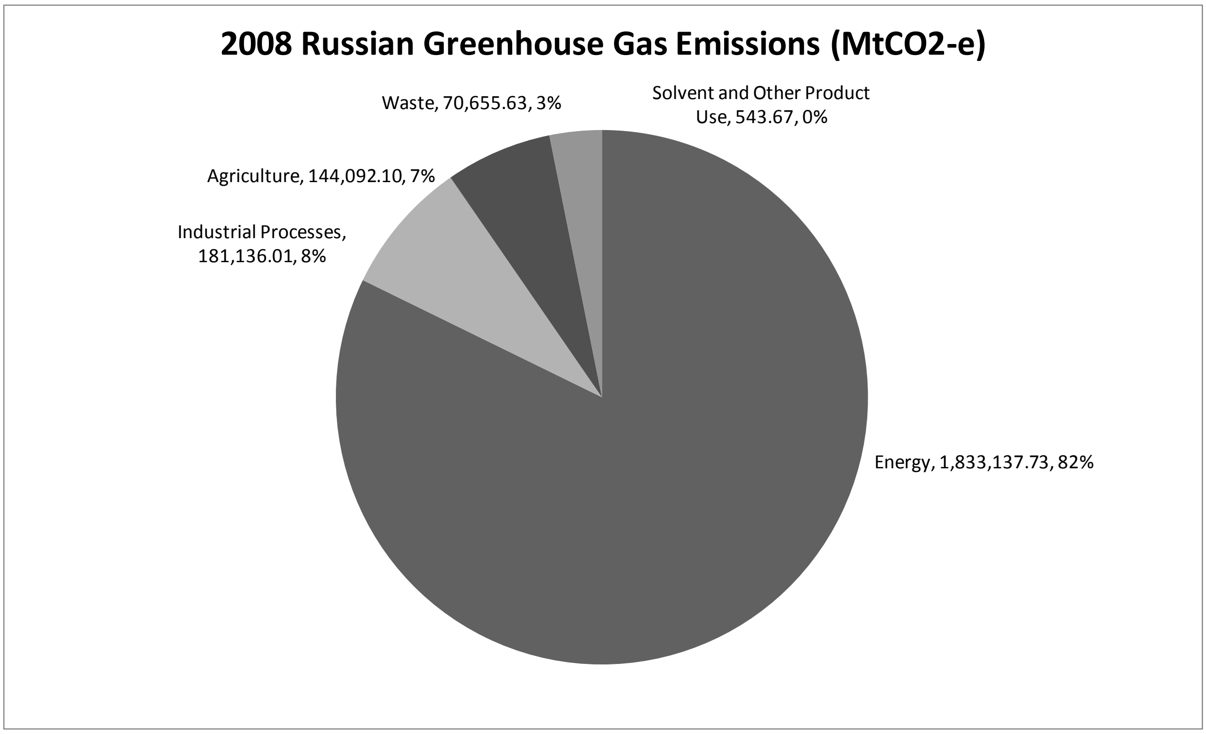
Since the end of the 1990s, political power in Russia has become increasingly concentrated within the Kremlin – Putin's so-called '*power vertikal*'. With so much power concentrated in the central government, it might be tempting to perceive that climate policy is dependent on a single powerful leader and the office of the President. This, however, would be an oversimplification of a system where factionalism, bureaucratic scuffles and personality clashes can have important bearing on policy. These internal frictions are exacerbated by the substantial possibilities of financial gain available to officials which has lead some analysts to suggest that the Kremlin factions are more important at determining policy than directives from the President.

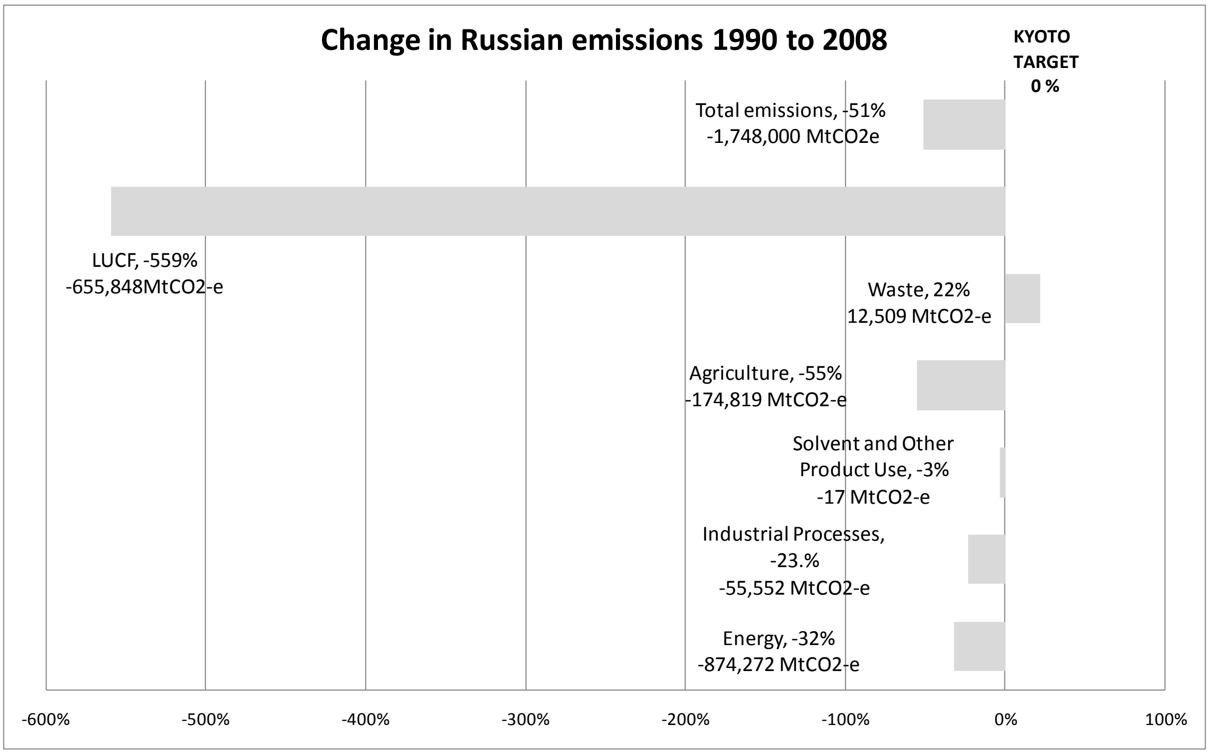
These factions are likely to number between 2 and 10 and are commonly characterised to be comprised of 3 main groups: the liberals, the technocrats and the *siloviki* (described in Bremmer and Charap, 2007). The liberals, led by the Minister for Finance and deputy Prime Minister, Alexi Kudrin, are defined by their shared approach to economic policy which, while significantly more interventionist than Western liberalism, is more market friendly than their Kremlin colleagues. The technocrats' central figure is current President and ex-Gazprom Chairman Dmitry Medvedev, with the group deriving its significant influence through control of the government gas monopoly. The *siloviki* are probably the most powerful and are broadly drawn together through their membership of the intelligence, legal and military sectors of government. Closely aligned with Prime Minister Putin, prominent members include Deputy Prime Minister Igor Sechin, former heads of the FSB Victor Ivanov and Nikolai Patrushev currently responsible for anti-narcotics and head of the Security Council of Russia, respectively. They are described as being drawn together through their shared belief in continued consolidation of political and economic power within a highly centralised state, supported by well financed security and defence structures; their belief in statism also supports the notion that Russia's mineral wealth belongs to the Russian people and they seek to limit foreign ownership and control of these resources; they pnromote the restoration of Russia's greatness on the world stage; and are finally said to be bound together by endorsing the 'nationalistic, xenophobic and sometimes anti-Semitic views' of the most conservative elements of the Russian Orthodox Church.

Eidman (2007) has described the political situation in Russia as "the power of bureaucratic oligarchy" in which "the traits of extreme right-wing dictatorship -- the dominance of state-monopoly capital in the economy, sivoliki structures in governance, clericalism and statism in ideology" were prominent. Shevtsova (2000, 32) has described Russia as a "superpresidential regime". These comments represent a common perception among many analysts that an autocratic system of "sovereign democracy" has come to dominate in Russia over more western notions of parliamentary democracy.

As Andonova (2008) explains, Russia's first post-Soviet leader, Boris Yeltsin, consolidated decision-making power in the hands of the Presidency with the 1993 Constitution. Yeltsin governed in close relationship with oligarchic economic elites (owners of newly privatised state enterprises) and a group of tight-knit advisors (Yeltsin's so-called 'inner circle'). While Russia's legislative body, the Federal Assembly or *Duma*, was established to impose checks and balances on the President, in practice it has been reduced down to what many regard as a mere 'lobbying body'. The President nominates the Prime Minister, can initiate legislation and, if necessary, dissolve the Assembly itself.

Figures 7.3 and 7.4 Structural change in Russian emissions, 1990 to 2008





UNFCCC, online database

The President also dominates foreign policy, with Article 80.3 of the Constitution setting out that international treaties can only be approved by the Federal Assembly after the President, Prime Minister or First Deputy Prime Minister proposes the document for ratification. After ratification, the President’s signature is still required for the treaty to enter into force.

Centralization of executive power continued under President Vladimir Putin, who took office in 2000. Putin, however, sought to distance himself from some of the legacies of his predecessor by strengthening the Russian state and restructuring relations with business. In doing so, he selectively prosecuted oligarchs who interfered with the political process, most notably Mikhail Khodorkovskii, owner of the Yukos oil company. Putin also increased the share of state ownership and management of energy and other natural resources and re-centred the role of security apparatus in Russian society. The authority of the federal bureaucracy was strengthened through reforms in the tax code, land code and the judiciary. Provincial governors were removed from the upper house of the Federal Assembly and in 2005 the direct election of governors was replaced by a system of presidential nominations, whereby governors are only confirmed by the vote of the legislatures in their provinces. With respect to civil society, there has been a trend towards increased control over the media and efforts to curb international funding and activities of NGOs.

With the constitution not allowing President Putin to run for another term, in March 2008 Dmitri Medvedev was elected President, although many outside observers suggest Putin remains the ultimate power. In his inauguration speech, Medvedev stated that: “I believe my most important aims will be to protect civil and economic freedoms ... We must fight for a true respect of the law and overcome legal nihilism, which seriously hampers modern development" (Medvedev 2008).

Despite this, there is still no 'law' in Russia in any western sense. This lack of the rule of law, combined with a lack of transparency, has blurred the line between the state and private sector, making it difficult to separate business from political imperatives and corruption from legitimate transaction costs. One illustration of this is the World Bank's World Governance Indicator's Project, which places Russia in the bottom half of its percentile rankings across all measures of governance such as effectiveness of government, rule of law and voice and accountability (World Bank 2009).

In 2009, Medvedev released a Climate Change Doctrine at the Copenhagen Climate Summit which signalled a significant shift in rhetoric and official acceptance of climate change[12]. While clear in its sentiments of accepting the basis for climate change adaptation and emissions reductions, the Doctrine highlights the challenges of low public awareness and the potential for conflicts of interests and corruption to work against emission control measures.

The Doctrine does not set out specific mitigation measures to be implemented, but instead is to be the conceptual foundation for a package of measures which are yet to be released. If such measures are announced and implemented it suggests Russia may have reached something of a turning point regarding climate policy which has been traditionally a weak priority within other policy areas such as energy and industrial policy, municipal heat supply, energy efficiency and forestry.

[12] The 'Climate Doctrine of the Russian Federation' was released on 17 December 2009 and is available in English at http://eng.kremlin.ru/text/docs/2009/12/223509.shtml and in Russian at http://www.kremlin.ru/acts/6365

7.4 Economic modernisation, innovation and energy efficiency

Perhaps the strongest lines of power for climate policy have been through the economic modernisation and innovation agenda and the drive to increase gas exports. A recent World Bank (2008) report found that Russia could save 45% of its total energy consumption through energy efficiency actions. This would require around US$320 billion in new investment but would result in energy cost savings of around US$80 billion a year yielding a four year payback period. Once the export earning potential of the released gas capacity is factored in, the potential benefits were estimated to rise to US$120 to US$150 billion each year. The report argues that these inefficiencies are a legacy of the old Soviet culture which prioritised large infrastructure spending. Indeed, in 2008 Russian citizens and companies benefited from one of the world's largest energy subsidies, estimated to cost the state about $US40 billion in lost revenues relative to 'market' prices. The idea is that if Russia achieves efficiency gains it can divert gas supplies away from its heavily subsidised domestic market to the more lucrative export market.

This potential 'energy reservoir' has been recognised at the highest levels with President Medvedev convening the Presidium meeting in Arkhangelsk in 2009 on "Improving the Energy Efficiency of the Russian Economy" where he urged the assembled governors:

> "We must improve energy saving in every area, but I would particularly like to single out the situation in the public utilities sector. All of the governors here today are well aware that energy is used in an atrociously inefficient way when it comes to heating and public utilities. Our buildings and our overall housing infrastructure are a kind of black hole that sucks in enormous amounts of energy resources."

In November 2009 the Duma passed an ambitious package of energy efficiency reforms covering appliances, lighting, housing, utilities, energy meters, contracting, financing and information. This replaces the 1996 law "On Saving Energy" which called for large improvements, but was mostly ignored.   Some measures in the recent 2009 bill include:

- On January 1, 2011, incandescent light bulbs will be banned in state and municipal buildings and all incandescent bulbs over 100W will be banned throughout Russia. On January 1, 2013 and January 1, 2014 all incandescent bulbs of 75W and 25W will be banned, respectively.
- Meters are to be installed to measure natural gas, electricity, heat and water in all buildings (excluding apartment buildings) by January 1, 2011. All apartment buildings are to have meters installed by 1 January, 2012.
- A state authority will develop efficiency standards for apartments which must be shown on the front of all new apartments.
- Energy efficiency labelling will be implemented on certain types of goods on principles agreed by the government.
- Mandatory energy audits will be required for energy companies, large energy consumers, and 'regulated activities'. Electricity planning can be more closely integrated with heat planning to achieve the efficiencies of combined heat and power. Initial audits are to occur by December 31, 2012 and then every 5 years.
- Energy saving investments are to be supported by tax credits and accelerated depreciation; and
- A national energy-saving information and education plan is to be initiated.

Success stories in this area abound and include Chelyabinsk *oblast'* (district) where more than 1,600 heat, electricity and water meters were installed in public buildings between 1997 and 2005. These meters allowed the *oblast'* to save 170 million rubles in this period, or 3% of its communal services expenses in 2005. In 2001-2002, Rostov *oblast'* spent 52 million rubles to install 893 heat meters, 355 water meters, 30 gas meters and 65 electricity meters in public buildings. Over this period, total energy consumption dropped by 20.7 per cent. The payback period of these meters averaged 2 to 4 years. These and other examples are listed on Russia's Centre for Energy Efficiency (CENEf) website[13].

The modernisation agenda was also a prominent idea behind one of Russia's biggest recent economic reforms, the sale in July 2008 of the state-owned Unified Energy System of Russia (RAO UES), Russia's dominant electricity generation, transmission and distribution company. The firm was split into 20 wholesale companies and marketed to foreign and Russian buyers, who acquired plants and networks, which had been underfunded since Soviet times and lagged foreign benchmarks regarding fuel rate, efficiency and operating time (Millhone, 2010). A related electricity infrastructure plan foresees new coal, hydroelectric and nuclear plants – with gas and oil developments being prioritised for export markets.

One legacy of communism is the view that energy provision is a basic human right which should be provided for free, or at least highly subsidised. Domestic tariffs have been set so low that suppliers have found it difficult to cover costs and make new investments. Increasing tariffs to facilitate greater energy conservation is currently considered an important part of the modernisation agenda. However, implementation may be difficult as

[13] http://www.cenef.ru/

consumers accustomed to free or cheap electricity react to being asked to pay higher prices, especially to foreign companies.

7.5 Climate change and Russia's effort to join the World Trade Organisation

The WTO oversees about 60 international legal agreements which provide the legal rules for international commerce. The WTO has 153 members covering about 97% of world trade and, while Russia is the largest nation not part of the WTO, it is at an advanced stage towards membership. Upon membership, WTO texts must be adopted by governments. They cover areas from agriculture to textiles and clothing, banking, telecommunications, industrial standards and product safety, food sanitation and intellectual property and more. Key principles are: that countries should not discriminate between nations or between their own and foreign products; the gradual lowering of trade barriers, such as tariffs and subsidies; and the promotion of transparency to support a stable and predictable business climate. The WTO also provides a neutral rules-based settlement process when trade disputes arise. Since World War II, these principles have supported the gradual liberalisation of world trade which many argue has helped promote economic growth and diminish political tension, especially between major economies.

It is often argued that the key to Russia's ratification of the Kyoto Protocol on 18 October 2004 lay in its ambition to join the WTO. Under WTO rules all existing members have the right to veto new applicants. For its support, the EU had initially demanded that Russia deregulate the natural gas industry and raise its heavily subsidized gas prices (Bretherton and Vogler, 2006, 19). In the negotiations held in May 2004 in Moscow, the EU won commitments from Russia to increase domestic prices by 2010 along with agreement to ratify the Kyoto Protocol, the liberalisation of Russia's banking and telecommunications sectors and the lowering of average Russian import tariffs from 18% to 8% (McLaughlin, 2004, 11). For Russia, EU recognition of Russia as a 'market economy' was an important step towards WTO membership and makes the country less vulnerable to anti-dumping cases.

Subsequently, at the Conference of Parties to the Convention on Climate Change in Italy in December 2003 President Putin confirmed that, "the EU has met us halfway in talks over the WTO and that cannot but positively affect our position on the Kyoto Protocol. We will speed up Russia's movement towards Kyoto Protocol ratification" (Kotov, 2004).

The EU has long sought to bring Russia into the WTO so that it would have a legal framework to deal with an often unpredictable trading partner. The EU is also likely to be interested in the deregulation of the Russian gas industry to reduce Moscow's ability to use gas supply as a political instrument. If EU energy firms can gain access to Russia's vast network of gas pipelines (for example through the application of competition policy) Europe will be able to source gas supplies from central Asia, shifting Russia's role towards that of being more a transport corridor and loosening the Kremlin's political grip on production.

The benefits of membership for Russia lie in access to new export markets, increased foreign investment and expertise to assist in modernising their economy. For instance, Gazprom would dearly like greater access to the (high) market price paying consumers in western Europe. To join, Russia needs to meet difficult institutional requirements ranging from agriculture to sanitary standards. However, such is the priority placed on attaining this goal by Russia that the Kremlin even transferred two of its islands in the Far East to China to ensure their support for their application (Buchner and Dall, 2005).

7.6 Emissions trading and the Kyoto Protocol

During the 2000s, Russia's position underwent an evolution from climate sceptic to being a central player in the climate regime. At the 1992 negotiations on the Climate Change Convention, the Russian delegation questioned theories of anthropogenic influence on the climate system and maintained that global warming would largely be to its benefit. After initially aligning itself with the members of the Organization of the Petroleum Exporting Countries (OPEC) in opposing any quantitative emission limits, Russia eventually sided with the US, Japan and Australia at the 1997 Third Conference of Parties (COP 3) in Kyoto in pressing for more lenient targets for industrialized states than the 15% reduction from 1990 levels proposed by the EU.

At Kyoto, Russia wielded considerable bargaining power. Representing 17.5% of 1990 emissions (as the former USSR), in the absence of the United States, Russian participation was essential for the regime to come into existence. Another source of Russia's bargaining leverage at Kyoto was its position as a mediator between the EU and the US. Together with the US, Russia was in favour of the unrestricted use of the flexible mechanisms such as emissions trading, since it expected to be a net seller of emission reduction allowances. In 2002, experts of climate policy estimated that Russia could economically benefit about $US10 billion annually from the protocol through emission trading, Joint Implementation (JI) projects and increased foreign investments (Andonova 2008).

In practice, however, Russia exercised its right of veto over new JI projects in Russia. As of December 2008, 31 such projects had been submitted to the Russian Government for approval, with all approvals withheld. Kudlai (2009) suggests that this was in order to secure some sort of strategic advantage by stockpiling emissions credits for future use in climate negotiations. In August 2010, Russia approved 15 JI projects, the first one of which was the construction of an energy efficient combined cycle gas turbine. This reticence to build domestic institutions to support the Kyoto Protocol's flexibility mechanisms is likely to have also impacted the Kremlin's ability to sell its surplus carbon credits (some 3 billion tonnes for the period 2008-2012) on international markets. Buyer countries such as Japan and those in the EU have instead purchased assigned amount units in countries such as the Ukraine, Latvia, Poland and the Czech Republic. For example, Japan has purchased 30 million, 1.5 million, four million and 40 million AAUs from each of these countries respectively under Green Investment Schemes where the sale revenues are used to fund low carbon projects.

In 2010 at COP 16 in Mexico, Russia sided with Japan signalling concerns about a second commitment period for the Kyoto Protocol. However, after strong pressure from developing countries it was agreed that a Kyoto Protocol working group 'aim' to complete its work 'as soon as possible' and 'in time to ensure that there is no gap between the first and second commitment periods' along with 'taking note' of Annex 1 countries' emission reduction targets. While developing countries may have preferred stronger language ('will' rather than 'aim') it is widely acknowledged that the multilateral process established at Kyoto is likely to be extended in some form beyond 2012. Owing to its stockpile of emissions credits, and flat emissions profile Russia would seem to be in a strong position to benefit from a successor to the Kyoto Protocol.

A less direct, but important benefit of Kyoto for Russia, is the pressure it may have took off more stringent environmental legislation within Europe. One of the most important drivers for the establishment of the European Emissions Trading Scheme (EUETS) was the fear that the Kyoto Protocol would not come into force. As the EUETS set the stage for increasing prices for fossil fuels in European market, it is likely that it was in the interests of Russian energy exporters to support the less onerous provisions of Kyoto than to see a stronger EUETS impose higher prices for fossil fuels and thus lower long run demand in Europe.

7.7 Gas exports to Europe and the potential to fuel a Chinese 'dash-for-gas'

In 2008 the value of Russian oil and gas exports peaked at around $US 300 billion before the global financial crisis led to a recession reducing energy consumption and fossil fuel prices (Figure 7.2). The World Bank's estimate of the gas 'reservoir' potentially available for export flowing from energy efficiency investments is $US 40 to 70 billion each year, suggesting an extra dividend from efficiency investments.

With natural gas electricity generation capable of emitting up to 70% less CO_2 than some inefficient coal power stations and with gas turbines being cheaper and more versatile than coal power stations, substitution from coal to gas electricity generation is an important path for reducing emissions. The European Union currently sources around 25% of its gas from Russia. However because of the highly subsidised domestic supply arrangements, European sales account for about 60% of gas revenue (Mitrova, 2009).

Lack of metering and the difficulty moving from the communist system of free or highly subsidised tariffs for electricity is a significant barrier to energy conservation. Dilute or split incentives mean that those with the know-how and ability to invest (electricity providers) in energy efficiency measures are not the same as those who benefit (consumers). However, if utilities are rewarded by government incentives linked to the increased gas capacity available for sale to export markets as a result of energy efficiency this problem may be mitigated.

The development of new gas fields is also an area of climate policy which can play to both Russia's strategic interests: strengthening its sphere of influence in neighbouring countries; securing new sources of government revenue; and facilitating clean(er) development in importing countries by encouraging a substitution away from coal power generation. A major risk to this strategy will be a perception among gas importing countries that the Russian state-owned gas company Gazprom will use its exports for political purposes, a fear supported by the dominance of Russian politicians on the company's board of directors.

Gazprom's activities account for about 10% of Russian GDP and it controls around 17% of world gas production. It possesses the world's largest gas distribution network with around 158, 200km of pipelines and has controlling shares in finance, media and aviation companies. Production in Gazprom's mature fields in the Gulf of Ob and in Western Siberia is declining and new developments are necessary in order to maintain existing supply arrangements. New exploration and development is centred around the Barents Sea and the Yamal Peninsula. However, infrastructure is a major constraint for developing this resource. For example, in the Timon-Pechara region of Murmansk (some 1600 kilometres to the north-east of Moscow) vast quantities of gas are burnt off with no way to transport it as high quality sweet oil is extracted (Howell and Nakhle, 2008). Developing new technologies to deal with this wasted resource, such as liquefied natural gas terminals, could address this.

With long common boarders with the largest energy consumer in the world, Russia is in a unique position to take advantage of facilitating a Chinese 'dash-for-gas' of the sort which has been so successful at driving down emissions in Britain and Europe. China currently imports only 10% of its energy needs owing to its plentiful supplies of coal, which fuel 70% of its energy requirements (Hook, 2011). This small proportion of imports is still large in an absolute sense, equivalent to the energy required to power the world's sixth largest economy, Britain. As escalating energy demand and tightened environmental requirements place pressure to secure new, cleaner sources of energy, two new pipelines from the west through Kazakhstan and the east through the Amur offer Russia important access to this vast market.

Building a Chinese market will however require the development of new gas fields. For example, the relatively underdeveloped former Soviet state of Turkmenistan has the world's fourth largest gas reserves centring around the Caspian Sea and has been a focus for Gazprom investment with a new pipeline crossing through Uzbekistan and Kazakhstan into north-western China. However, like Europe, the interplay of politics and energy pricing are likely provide significant non-technical related barriers to the full development of Russian gas export potential to China.

7.8 Low public and official awareness

Data collected in a multi-country survey by the World Bank (2010) suggests 72% of Russians think that climate change is a serious problem, compared with 90% of Brazilians, 80% of Indians and Indonesians, and 60% of Chinese. Of the seven countries in the survey, Russia has the second largest percentage (5%) of those who think that climate change is not a problem. This compares with 12% of Americans, 4% of French, and 3% of Indians. Of the same seven countries surveyed, Russia has the most negative response regarding willingness to pay for climate action with 62% of Russians not prepared to pay anything compared with 59% in Brazil, 38% in the United States, 35% in France, 34% in India and only

16% of Chinese not prepared to pay anything. This research suggests there is little appreciation of the environmental externality associated with energy use in Russia.

A lack of competition is also a feature of Russian energy markets. This would not be a problem if governance was good enough to encourage efficiency and good performance. The Russian model seems to be a 'guided' form of market, where the state has a decisive voice in economic management. However, because of weak governance, policy implementation is often frustrated by the predatory behaviour of government officials who may regard a profitable state-run business, its assets and its real-estate available for their own personal interests. Competition could provide some discipline on market participants, but such reforms can be difficult to implement when the government itself has a large financial stake in the market place.

Such problems were recognised in paragraph 44 of the Climate Change Doctrine which states:

> "Taking into account a possible conflict of interests between the executors of climate policy, professional and other civil organisations will play an important role in preventing the escalation of such conflicts and tensions, as well as corrupt lobbying by particular interest groups."

Allowing journalists and NGOs to work without fear of reprisal and promoting the rule of law through a transparent legal system would strengthen governance to support either a state-based or more competition friendly energy sector.

In June 2007, a report prepared for the Russian security agencies suggested that official attitudes towards climate change may be changing. Entitled "The World Around Russia:

2017", the study pointed out a variety of threats from global warming, ranging from the possible influx of immigrants from countries becoming too hot in the south (areas already plagued with bloody ethnic rivalries); and the potential for damage to the infrastructure of its oil and gas fields as a result of the melting of the permafrost (Centre for Comprehensive European and International Studies, 2007). In July 2008, the World Wildlife Fund (WWF) reported that global warming was pushing Central Asia to "the edge of a catastrophe" and was leading to increased migration from Central Asia into Russia (Kokorin 2008).

Prioritising climate change within the concerns, strategies and norms of the defence and intelligence communities is an important line of power to tap in a country where the members of the intelligence community also occupy key positions in business and politics. As Fletcher (2009) has suggested, constructing climate change as an existential threat to the nation state can position the politics of climate change 'above politics or something [that] overflows the normal political logic of weighing issues against each other'.

7.9 Conclusions

Having painfully reduced GHG emissions by around 50% from 1990 to 2008, and with 36% of the country's electricity generation coming from zero carbon sources along with a large proportion of fossil fuel use coming from relatively clean natural gas, Russians may feel, with justification, that they have over-performed against climate change benchmarks. Although emissions fell for reasons far removed from concern about climate change, this 'achievement' is particularly noteworthy given the pace at which emissions have grown in other major countries such as the United States, Japan and China.

Public opinion surveys suggest most Russians would prefer politicians to focus on reducing poverty, taming inflation, and creating employment opportunities rather than climate issues. However, if there is one conclusion that can be drawn from the Russian case it is that there are powerful political and economic levers outside of what is traditionally considered climate policy which can profoundly affect carbon emissions. Framing climate policy this way offers a constructive pathway to consider a range of emissions reduction strategies, focusing on measures which support Russia's foreign and domestic strategic interests.

It is important to recognise that Dmitri Medvedev, the current President, is also a former chairman of Gazprom. The board of this large vertically integrated state-run energy monopoly is made up in the most part by members of the Russian cabinet and the company has ownership interests across the economy (and in several countries). It is the wealth generated from exploiting Russia's vast fossil fuel reserves that has underwritten its economic recovery following its calamitous attempt to switch from a planned to a market economy without first establishing the institutions to facilitate such a shift. Thus, it is hard to imagine an effective GHG reduction strategy being implemented which does not align with the interests of Gazprom. Because natural gas is a crucial bridging technology for the gradual transition towards a low carbon economy, the development of Russia's gas fields and export markets to Europe and China can deliver substantial GHG reductions domestically and abroad. Such strategies are explored in the intersecting agendas of economic modernisation, innovation and energy efficiency agenda and the development of European gas markets and the potential for Russia to help facilitate a Chinese 'dash-for-gas'.

One of the main barriers to the successful execution of this strategy is the perception that Russia is an unpredictable trade partner with non-transparent legal institutions, riddled with corruption, where economic interests can be trumped by political priorities driven by the Kremlin. One path to address these concerns, which undermine foreign and domestic investment, could be the gradual move to implement the provisions set out in the requirements for Russian membership to the WTO. In Russia's case, this has also had an important climate change dimension with membership of the trade pact being diplomatically tied by Europe to Russian participation in global climate governance under the Kyoto Protocol. This highlights how Russia's economic interests are tied with the environmental agenda being driven through other countries' legislatures. Thus, in order to take its place amongst the community of nations, Russian participation in global climate governance should be seen as fundamental. The large volume of Russian carbon credits available for sale, along with the inward investment opportunities that can be facilitated through the flexibility mechanisms of the Kyoto Protocol, offers Russia further avenues to pursue its strategic interests.

The securitisation of the climate change agenda in Russia is an emerging trend which maybe being implemented to counter climate change's otherwise low public and official profile. Subject to its harsh winters, Russia is likely to benefit from some degree of mild warming, whether through the need for reduced heating, increased access to arctic shipping routes and petroleum reserves, an extended growing season for agriculture or as Mr Putin once quipped "the need to buy fewer fur coats". However, as a report for the Russian security agencies ('The world around Russia: 2017') highlights, Russia also faces serious climatic risks – especially from political destabilisation and changing migration patterns along its southern borders. Here, the potential for natural resource rich, but politically fragile countries, to fail due to ethnic and religious tensions is exacerbated by global warming. This has profound implications for Russian internal cohesion and security as well as the resources Russia must spend stabilising its central Asian allies and protecting against other foreign powers gaining influence.

As one might expect in a system that has been termed a 'super-presidential' regime, climate policy is also likely to be significantly influenced by the outcome of the political struggle between President Medvedev and Prime Minister Putin in the 2012 Presidential election (though other candidates may still present themselves). Mr Medvedev has positioned himself as something of a reformer, launching the climate change doctrine, pushing an innovation agenda to decouple Russian growth from the fossil fuel sector, emphasising the need for democratic reform, and speaking out against corruption in support of improvements to the rule of the law. In contrast, Mr Putin tends to refer to Russia as an 'energy superpower', talks up the health of the economy, and is relatively silent on issues of governance and corruption. Although these differences maybe merely stylistic, they may also signal a looming split in leadership style. As we observed in Figure 7.1, changes in leadership can have a profound impact on economic and GHG outcomes.

Ultimately, Russia's position on climate change will be formed through its own political processes. In the words of the Russian Climate Change Doctrine, "... the balance between economic efficiency and social justice, the elimination of potential conflicts of interest related to climate change consequences ... is a matter of political choice". Exploring the optics of this political choice in Russia has been the focus of this chapter.

Chapter 8 Conclusion and summary for policy-makers

Testimony of Dr. Alan Greenspan to the

Committee of Government Oversight and Reform, US Congress

October 23, 2008

DR GREENSPAN: *Thank you for this opportunity to testify before you this morning. We are in the midst of a once-in-a-century credit tsunami. Central banks and governments are being required to take unprecedented measures. You, importantly, represent those who are feeling the brunt of the crisis in their workplaces and homes. I hope to address their concerns today…*

… those of us who have looked to the self-interest of lending institutions to protect shareholder equity (especially me) are in a state of shocked disbelief. Such counterparty surveillance is a central pillar of our financial markets' state of balance. If it fails, as occurred this year, market stability is undermined….

In recent decades, a vast risk management and pricing system has evolved, combining the best insights of mathematicians and finance experts supported by major advances in computer and communications technology. A Nobel Prize was awarded for the discovery of the pricing model that underpins much of the advance in derivative markets. This modern risk management paradigm held sway for decades. The whole intellectual edifice, however, collapsed in the summer of last year because

> *the data inputed into the risk management models generally covered only the last two decades, a period of euphoria….*
>
> *There are additional regulatory changes that this breakdown of the central pillar of competitive markets requires in order to return to stability…*

8.1 Out of equilibrium: crisis and the response offered by evolutionary economic geography

While the current crisis in financial markets has had a terrible impact on economies around the world, sparking mass unemployment, company and government failures, widespread social protest and counter-protest, it nevertheless is a fascinating time to be writing a doctoral thesis on economic and technological change. This is because ours is a society in transition, searching for a new paradigm to make better sense of events around us.

What recent events highlight is the failure of current institutions to sustainably manage the forces of economic change in society. As noted by John Maynard Keynes (1935:383):

> The ideas of economists and political philosophers, both when they are right, and when they are wrong, are more powerful than commonly understood. Indeed the world is ruled by little else'.

While this quote from Keynes perhaps overplays the hand of economists as a group, the current crisis represents not just a threat to established organisations. As as households, banks and governments struggle to maintain cohesion in the face of events seemingly outside their control the crisis is is just as much a threat to the established theories and ideologies which informed these agents.

Each person, firm and government agency in the economy carries with them some sort of theory or way of seeing the world which enables them to deal with information and coordination problems and helps enable them to carry out their roles – whether supporting a family, generating profits or pursuing their notion of the public interest. Over the course of time, theoretical constructs have helped inform and build the diverse co-evolving networks of organisations and institutions we observe in the world around us: families, businesses, schools, universities, hospitals, the military and other forms of government all seek to control the elements of the problems that society sets out to solve. Differing theoretical approaches to problem solving and the different objectives defined by each political system go a great way to understand the diversity of social and economic outcomes we observe in the world around us. Faced now with the irreconcilability of events and theory, many of these cognitive anchors have been cast adrift by the force of the crisis.

This crisis is also transpiring at a time when governments are trying to put in place institutional frameworks to manage climate change risks at the national and global levels. As Lord Nicholas Stern and others have noted, the crisis in managing risk in the financial sector and the management of risk in the climate system are inextricably linked. This link is through the co-evolution of institutions and organisations we have to manage risk more generally in society.

There is considerable empirical evidence that people fail to accurately evaluate risk in many arena's of life (Gigerenzer, 2002; Kahneman and Tversky, 1979). This suggests that it is reasonable to expect institutions to evolve to address this inaccurate assessment of risk. However, as discussed in Chapter 4, a balance must be struck between authoritarian control on one side and respect for non-interference and self determination on the other. The recent crisis suggests respect for the governance powers of self-interested market institutions has suffered a blow; and the pendulum is swinging now towards a more structured approach to regulating market behaviour. However, what is argued for in this thesis is not a return to the old debate of market versus the state – but a more mature recognition that what is needed is not more or less regulation, but *better* regulation. For while agents may be 'boundedly rational' and subject to path dependency, they are also always capable of learning, adapting and innovating to solve the problems of the day. This will be taken up below in the section on policy implications under Brian Arthur's theme 'not a heavy hand, not an invisible hand, but a guiding hand' (1999:2).

This discussion on the importance of the role of economic thinking and teaching in shaping how actors view the world, and engage with it, sets the stage for the aims and motivation of this thesis. Firstly, to articulate a theoretical approach to the study of the economy that provides a synthesis between 'economic' equilibrium based neoclassical theory and 'political', institutionally rich evolutionary theories. The second aim of this thesis is to show how such a theoretical approach might be set to work to examine the shift to a low carbon economy. Taken together, it is hoped that Parts One and Two of this thesis present a compelling and coherent agenda for the realignment of the mainstream economic paradigm towards greater economic realism and more sustainable growth.

This type of analysis aims to place the focus of enquiry on understanding change in the actual world as it is, rather than in some hypothetical world constructed for the sake of parsimony. Methodologically, it involves a rather straightforwardly descriptive and empirical research programme adopting an amalgam of inductive *a posteriori* analysis of geographically centred economic trends and commentary on the cut and thrust of politics placed within an historical context (Barnes et al., 2007). This empirical focus is then buttressed by taking a reflexive and pluralistic approach to theoretical conversation with the data by drawing on both equilibrium and evolutionary based perspectives. It is an integrated approach, insofar as it aims to reintroduce political analysis and the normative formation of institutions back into mainstream economics, which tends to take those institutions for granted and as homogenous across nations. It sees economic behaviour as being informed primarily by technologies and institutions, evolving in ways which, while not random, cannot be described fully or perhaps at all by the standard tools of neoclassical logic. Deductive models and theories, when applied, should therefore be context specific.

A significant part of this programme is therefore to investigate the processes of belief formation that informs the behaviour of individuals, firms and governments in the economy. For a complex issue, such as the shift to a low carbon society, the role of politics is central to this task. In most cases, societies learn about themselves through politics, and the process of public debate and discussion, is itself, central to driving change in society (Schön, 1973). Indeed, it can be argued that prices in markets can be seen as being determined as much by the clash of competing narratives of the world as by the interaction of demand and supply (Kay, 2011).

8.1.1 Positivist versus normative ideas in economics

Our theories and ways of seeing the world are built on and shaped by our shifting values: of war and peace; of the relative importance of work versus leisure; our acceptance of collective control over individual freedom; our ideas of justice; of equity and social mobility; and, at the centre of enquiry for this thesis - of our relationship with technology and the natural environment.

Some may argue that it is not the economist's place to interrogate such normative matters; that they are better left to other disciplines such as philosophy, politics or sociology to deal with. From this perspective, some have made the point that economics should concern itself only with the description and explanation of economic phenomena. "Positive economics is in principle independent of any particular ethical position or normative judgments" (Friedman, 1953). It describes "what is", as opposed to normative economics, which deals with "what ought to be" (Keynes, 1890).

Thus from the position of positive economics, individual preferences are taken as given, or as exogenously determined. Thus, while changing preferences may have a significant effect on economic outcomes they are only considered insofar as they are reflected or revealed in market transactions – the 'laws of demand and supply' rule.

On one level, this approach has appeal because it attempts to divorce economics from subjectivist influences and pushes it towards establishing a set of universal laws or truths with a limited set of axioms based on rational behaviour and competitive markets. Thus, as shown in Chapter Two, different elements of the economic system can be separated out, and their relationships studied. For example, the response of a quantity of a good or service supplied to changes in prices of that or other goods and services; or the relative desirability of carbon taxation over emissions trading under different types of uncertainty.

However, economics is not just the study of the interactions of particles in a controlled experiment, as might be the case in physics or chemistry. Its use as a way of understanding the world is not separate from the evolutionary processes shaping the social institutions we put in place to solve social problems. For example, policies that aim to correct for 'market failure' have embedded in them the implicit objective of recreating a state of perfect competition in the economy – a condition that almost certainly does not exist in the actual economy. Thus when arguments are made for 'letting the market decide', or for an 'optimal policy' this language and its institutional outcome is a product of neoclassical logic. Thus theory does not only have the power to describe phenomena, but also, through the political process and evolution of regulations, it influences the nature of institutions and the behaviour of organisations themselves. We are now confronted with a situation where these theories have created institutions and organisations which can no longer control change in the actual world. This has been revealed by the current crisis and defines the exigency for a new approach.

8.2 Summary of research conducted in this thesis

Chapter One begins by articulating an integrated approach to economic and political change developed by drawing on theories which have been influential in human geography including form political geography; institutional economics; evolutionary economics; innovation studies; the neo-Schumpeterian school; neoclassical economics and behavioural economics among others. Theoretically, the contribution that this thesis makes most significantly is towards to advancement of evolutionary economic geography, a field which to draws together several theories in economic geography and related disciplines, under an active openness to engaged pluralism Barnes and Sheppard (2010). Here this agenda is pursued in the context of the policies and processes inherent in the shift to a low carbon economy.

This approach builds on the research project set out by authors such as Joseph Schumpeter (1933, 1942), Nathan Rosenberg (1976, 1982), Chris Freeman (1987, 2001), Robert Nelson (1992), Frank Geels (2002, 2004) and others to place particular emphasis on the role of technology in driving economic change and its intersection with decision-making, both individually and collectively. This perspective is then brought to bear on the question of the low carbon transformation of society and the analysis of the processes by which the economic landscape – the spatial organisation of economic production, distribution and consumption – is transformed over time (Boshma and Martin, 2007:539).

Placing technology as the central force driving change in the economy, rather than simply modelling it as responding to shifts in factor prices is particularly relevant for the study of greenhouse gas mitigation. This is because emissions are largely a function of various technologies that are employed in the generation of energy. These technologies are also characterised by increasing returns, path dependency and behavioural biases that make low carbon investments often unresponsive to carbon price signals alone. Indeed, it is suggested that a possible answer to the question posed by Ayres (1962:xvii) as to which is the dog and which is the tail when considering price versus technological competition in securing competitive advantage, may relate to the degree to which increasing returns characterise the system under analysis.

Here it is important to note that 'technology' is not just seen as embodying a particular object, such as a light bulb or certain type of power source, but also the associated knowledge and behaviours which must be employed for it to be used in society (Searle, 1995, 1999,2001).

In Part Two, this approach is used to provide a broad theoretical setting for the exploration of several case studies regarding the shift to a low carbon economy. Chapter Four sets out to investigate transformation within the market for lighting through the adoption of energy efficient CFLs in Germany and the impact of the phased ban on inefficient incandescent lamps. Germany was chosen as a country to base the case study as it is one of the global technological leaders in lightbulb manufacture, combined with having a relatively tech-savvy and environmentally conscious consumer population. This research also focused on Germany as a result of a research sabbatical undertaken at the Institute of Psychology, Department of Personality and Social Psychology, at the University of Otto-Von-Guericke, in Magdeburg, which facilitated part of the work.

In Chapter Five, the realignment of 'the market' in order to incorporate greater environmental values is investigated through a discussion of the case for emissions trading in CO_2. This Chapter's main contribution is to establish emissions trading within the logic of an evolutionary institutional approach as part of a suite of policy options targeted at different stages of the innovation chain (Grubb, 2004).

In Chapter Six the political economy of climate change and greenhouse gas mitigation in Australia is investigated. Australia represents an interesting case study on the shift to a low carbon economy for several reasons. Firstly, it has one of the highest per capita carbon emissions in the world and an economy heavily reliant on the extraction, use and export of fossil fuels. Secondly, climate change has been a heavily contested issue in Australian politics especially leading up to the 2007 Federal election which saw a change in government and significant shift towards stronger action on climate change. Australia also has a modern, dynamic economy with strong democratic institutions which suggests that, if successful at reversing emissions growth, it could act as a positive showcase to the world.

The final chapter of Part Two investigates the political economy of climate change and greenhouse gas emissions in Russia. This case study is particularly significant given that, in addition to Russia being the world's third or fourth largest national emitter of GHGs, Russian emissions fell by around 51% between 1990 and 2008. One important message from this case study is that it reflects the general conclusion taken from the widely discredited Washington Consensus that *institutions matter.* While, according to theory, the deregulation of the state-run economy and subsequent shift to a market economy should have boosted the economy, it led to ten years of economic collapse with painful social, economic and political consequences. Over this period, state assets were cannibalised and sold off for short-term profit as political networks which supported central planning were disbanded creating gaps in the highly coordinated production network. This precipitated what has been termed the *disorganisation* of the Russian economy, coordinated in significant part by the rise of an armed oligarchy. Theoretically, this Chapter also vividly highlights one extreme case of economic transition and how broader political and economic forces can significantly affect GHG outcomes and drive changes in the structure of the economy. It presents a compelling case study of how the naïve implementation of a policy agenda based on 'market triumphalism' with little reference to historical and geographical context sent one of the world's great superpowers into a spiral of economic decline which was only stopped with the election of Vladimir Putin and reassertion of the security apparatus in 1999.

8.3 Recommendations for policy makers: 'Not a heavy hand, not an invisible hand, but a guiding hand'

A significant aim of this thesis has been to look at flexibility and stability in the economy within the broader context of the political economy of energy and climate change and integrate equilibrium ideas from standard welfare economics into a evolutionary framework. In Chapter One, the overarching framework of this approach was encapsulated in Figures 1.1, 1.2 and 1.3, emphasising the wide diversity of policy tools available and the need for a clearer sense of policy timing and sequencing to combat the negative effects of lock-in. Now, in this conclusion, a summary of the main insights of this analysis will be drawn out for policy makers. While focusing on energy and climate change, these recommendations have high degree of relevance for other domains of public policy.

8.3.1 A shift in analytical framing: from equilibrium to evolution

The problem of climate change and policy choice is most often seen through the logic of neoclassical economics and the theory of externalities which descends from the standard welfare economics of Edgeworth (1881), Dalton (1920), Pigou (1932), Hicks (1939) and others. Under this approach, policy intervention is usually framed in terms of "correcting for market failure" where the objective is to nudge the economy back towards its natural and ideal state of perfect competition. At the core of this paradigm, so well summarized by Gary Becker (1976) and cited by Kay (2011) are: "the combined assumptions of maximazing behavior, market equilibrium and stable preferences, used relentlessly and consistently, form the heart of the [that is, *their*] economic approach".

What I wish to argue here is that the dominance of this approach in economics has unhelpfully constrained the scope of analysis of the shift to a lower carbon economy and our approach to policy choice in general. It does this by focusing attention on too narrow a set of problems, most obviously in the climate context – the perennial policy chestnut, 'to tax or to trade'. This approach has too limited a scope of analytical tools at its disposal in order to rigorously evaluate other forms of regulation, such as the decision to phase out incandescent light bulbs, which requires an assessment of behavioural and path dependent barriers and requires both qualitative and quantitative analysis in an out-of-equilibrium setting. In addition, the mainstream approach has a relatively uniform view of the policy requirements across the various stages of the innovation chain, with the focus being on price-based policy in a demand and supply framework. As Acemoglu et al. (forthcoming) have argued, this reliance on a carbon price alone may lead to unnecessary price inflation in energy supply in the short term, as clean energy alternatives are too immature to compete in the market.

It is suggested that a way forward is to adopt an approach which brings the 'political' back into the analysis of economy and positions the neoclassical view of the world as an appropriately contextualised and relatively short lived 'stable state' within an overarching evolutionary paradigm. This alternative view sees economic behaviour as being primarily influenced by organisations, technologies and institutions, of which the price mechanism is but one (albeit important) institution. These technologies and institutions co-evolve in a way which is highly sensitive to their historical features, so careful description of prevailing conditions is an essential analytical feature of this approach. Therefore all theoretical models, including the standard welfare approach, which can help connect observed phenomena to broader narratives and make sense of large amounts of information, must always be context specific when applied.

Regarding such an evolutionary paradigm, Giovani Dosi (2011) writes:

> … such a perspective attempts to understand a wide set of economic phenomena – ranging from microeconomic behaviours to the features of industrial structures and dynamics, all the way to the properties of aggregate growth and development – as outcomes of far from-equilibrium interactions among heterogeneous agents, characterised by endogenous preferences, most often "boundedly rational" but

always capable of learning, adapting and innovating with respect to their understandings of the world in which they operate, the technologies they master, their organisational forms and their behavioural repertoires.

And on methodological grounds, it is far from disdaining formal modelling and statistical analysis. The research programme is, however, largely *inductive*, taking very seriously indeed empirical regularities at all levels of observation as discipline for the modelling assumptions.

The dominance of the neoclassical paradigm has led to the framing of policy choice and 'action on climate change' in particular ways. A pre-requisite for action under the standard mainstream approach is to first identify policies in terms of their respective 'costs on society' which are put alongside the benefits of the intervention (e.g. Stern, 2006). Importantly, this assumes the foundation of a competitive equilibrium exists and can be used as a reference point. It can be argued that this analytical logic has created an unhelpful narrative in the public domain based on its assumptions in a way that is misleading and may bias decision-making against action to reduce emissions. This problem was recently brought out in the 4th Arrow Lecture of the Committee for Global Thought at Columbia University (2011) in the discussion following Partha Dasgupta's presentation 'Persons and time in the welfare economics of climate change'. In response to Dasgupta's lecture, Jeffery Sachs comments:

The climate change problem does not have to be posed in terms of trading off today versus the future because another thing that is possible is to think about it as a question of what kind of capital society today is going to have in the future. A little more physical capital, or a little more natural capital. So consumption could be held

> constant in this generation and still take into account climate change. There is no real issue of intertemporal tadeoff between the present generation and the future but rather a question of us as stewards for nature and whether the future would prefer more built buildings and factories or a safer climate. In this case the discount rate is irrelevant, the only rate that matters is the marginal productivity of capital and the damages that would be incurred or avoided on the natural capital side. It is not absolutely clear that the future need pay for this; but our role as stewards for the future is inescapable. Stewardship doesn't necessarily mean a decline in present consumption. It could mean a different way of effectively leaving capital for the future.

The framing logic of the standard welfare approach is clearly brought out in Dasgupta's response:

> Jeff Sachs is quite right, of course, but the model needs to be articulated if we as stewards want to think about what they [future generations] would like in the form of the capital mix. Jeff Sachs was thinking of a world which is inefficient, where you don't have to give up anything to alter the mix; and that is fine – it is a win-win situation. In the pristine form that I was presenting the problem, we are not in a win-win situation; there has to be some trade-off.

This exchange clearly highlights the profoundly different conclusions that adopting an out-of-equilibrium, evolutionary view of the world (a state of inefficiency, in Dasgupta's words) can have versus one based on the efficient world of a model, where there has to be trade-offs.

A practical manifestation of this, which was discussed in Chapter Four, is the ongoing debate around the Porter Hypothesis (Foxton, 2011c). Based on his research in strategic management, Porter (1991) and his colleagues (Porter and van der Linde, 1995a, 1995b) argue that the competitive advantage of firms lies in their capacity for innovation. Neoclassical economists generally assume that, for firms operating in competitive markets, forcing those firms to meet regulatory standards will necessarily push up their costs. However, Porter argued that well-designed environmental regulation can trigger innovation giving rise to economic benefits that may offset the costs of compliance, so called 'innovation offsets'. In this case, these offsets could lead to both reductions in environmental damage and boost the competitive advantage of firms undertaking the innovation. For example, advantages could accrue to firms that are first movers in developing a new product or service that is then widely taken up – especially if such products and services significantly increase firm efficiency. Likewise, firms in countries that have strong environmental legislation promoting innovation are likely to have an advantage in that they will be a good position to export the results of that innovation when other countries introduce similar legislation. The Danish wind energy sector is a good example here (Karnøe, 2012).

The counter arguments to the Porter hypothesis (e.g. Palmer *et al.*, 1995:119) essentially start from the assumption that firms typically operate at or near the 'efficiency frontier' (perfect competition) minimising private production costs. Furthermore, critics argue that even if efficiency improving investments exist, they argue that requiring firms to undertake these through regulation may 'crowd out' other more productive investment. Finally, the critics highlight that there is no reason why governments better understand the potential for efficiency than firms themselves.

This debate is one where inductive arguments based on empirically grounded case studies, (e.g. the 'Factor Four' arguments of Amory Lovins (e.g. von Weizsacker, *et al.*, 1997; Hawken *et al.,* 1999) are set against logical statement of deductive equilibrium-based modelling (Jorgenson and Wilcoxen, 1990; and Hazilla and Kopp, 1990).

Research in systems theory has pointed out that 'regulation' can either be 'good' or 'bad' at promoting vibrant profitable industry and what is needed is not 'less' or 'more' regulation, but better 'well-designed' regulation (Ashford, 1993; Porter van der Linde, 1995; Foxton and Kemp, 2006). This body of work has identified several criteria for well designed regulation including: setting strict standards to promote innovation, but with flexibility as to the means; keeping the regulatory focus on desired environmental outcomes, not particular technologies; the use of market incentives to promote continuous environmental improvements; making regulatory processes more stable and predictable, in order for firms to be able to undertake long-term planning; the use of phase-in periods, to enable firms to make investments in new technology in line with normal capital turnover; and promoting innovation at the source of the emissions through input substitution, product reformulation or process redesign (Foxton, 2011c:133-134).

8.3.2 Dynamic reflexive policy design

Under neoclassical theory, where intervention in the economy is limited to internalising externalities through the price mechanism, there is little logical need for the staging of economic policy. This, however, unrealistically assumes the absence of path-dependent or behavioural biases amongst investors (Unruh, 2000, 2002, 2006). In Figure 1.1, these issues are explicitly separated out in the notion of 'technological pathways', each of which comprise of technologies exhibiting different degrees of maturity and lock-in. It is suggested in this framework that relative price changes have their main effect on technologies and actors whose products or services are already in the market. This may encourage technological replication or transformation, but is less likely to influence transition. Such fundamental qualitative change in technological usage is likely to be longer-tem in nature and require shifts in other institutions, particularly supply-push policies, in addition to the demand-pull of market prices. In requiring a more rigorous understanding of the historical setting of policy, an evolutionary approach also provides a stronger focus on the actions required to dismantle previous the regimes of institutional support for high-carbon technology; as well as providing incentives for the newer wave of low-carbon investment.

8.3.3 'To tax or to trade?' is not the question: universalist ideas of optimal policy are wrong

Most often, in the provision of policy advice and in the teaching environmental economics courses, emissions trading is contrasted with environmental taxation and regulatory standards (for example, Table 5.1). The costs of abatement and damage costs of pollution are then typically modelled allowing for different levels of uncertainty in each (Weitzman, 1974) and an optimal policy prescription derived – emissions trading when damages from pollution are high; taxes, if policy makers are more worried about excessive costs of abatement on industry. In Chapter Five, it was argued that in reality, the economy is riddled with 'market failure' and the diversity of economic and political structures make it impossible to conclude that there is a silver-bullet solution to climate change, such as the implementation of carbon pricing through an ETS, taxation or both. Instead, it was argued that a 'silver buckshot' approach is required which integrates industry policy, research and development, demonstration experiments and early market support (Rayner, 2010).

In order to complement the precise, but narrow, picture offered by the cost and benefit framework of the standard welfare approach, an evolutionary perspective shifts the focus towards the systems of innovation. These are heterogeneous, historically embedded networks of national, regional and industrial systems and settled patterns of behaviour (Mowery and Rosenberg, 1989; Archibugi and Michie, 1998; Michie, *et al.*, 2002). For example, Anderson (2001:37) describes how some institutional economists in the tradition of evolutionary economics refer to 'systems of innovation' in which they point to the existence of 'collective entrepreneurship' (Lundvall, 1992:9-10), while other institutional economists focus on technological trajectories and paradigms as special kinds of institutions (Dosi, 1982, 1988; Perez, 1983; Freeman, Clark and Soete, 1982; Freeman and Perez, 1988).

By a 'national system of innovation' what is meant is 'the network of institutions in the public and private sectors whose activities and interactions initiate, import and diffuse new technologies' (Freeman, 1987:1). The concept has since been developed more generally for 'systems of innovation', including national, regional or sectoral systems, and encompasses all important factors (including prices) that influence the development, diffusion, and use of innovations, as well as the relations between these factors. As summarised by Edquist (2001:1623):

> A central insight provided by the systems-of-innovation approach is that firms do not generally innovate in isolation, but do so in interaction with other organisational actors (such as other firms, universities, or standard setting agencies) and that this

> interaction is shaped by (and shapes) the framework of existing institutional rules (laws, norms, technical standards). The approach takes into consideration the actions of both firms and governments. In short, this conceptual approach regards innovation as a process of interactive learning.

This **r**esearch suggests that some actors can become hubs for a range of similar other supporting investments and behaviours – for example the electrification of the Israeli vehicle fleet requires new investment in solar energy; vehicle manufacturing; recharging infrastructure; electronics companies. This model is now being replicated around the world, in a good example of interactive learning (see www.betterplace.com).

8.3.4 Institutionalising policy learning to encourage flexibility

In his work on the learning society Donald Schön (1973) spoke of the profound challenge that the increasing pace of technological change poses for what he called 'the stable state' in society. Schön bases the foundation of this stable state on a deep psychological need to believe in certain central aspects of our lives, for example our professional, religious or national identity. He goes onto argue that, in the North American context at least, this need for stability is institutionalised in the social domain, despite the apparent acceptance of change and approval of dynamism, as a social coping mechanism to deal with the threat that uncertainty challenges us with. In his *Reith Lectures* Schön (1970) argues:

> Language about change is talk about very small change; trivial in relation to a massive unquestioned stability. We preserve the stable state through processes we are largely unaware of.

This tendency to fight to remain the same can be seen as having a direct analogy to notions of path dependency in the evolutionary economics literature (Arthur, 1989; David, 1985).

Where Schön's work is particularly useful is in throwing some light on the processes of destabilisation and de-locking of high-carbon technology, and the potential for the exercise of human agency or choice, through his idea of the 'learning society'.

Here, the impetus for change comes from an individual, business or government which finds itself facing economic and social challenges which no longer align with existing institutional and organisational structures. The inability to control the elements of the system and provide a solution to the social problem at hand – in our case the impetus to reduce GHG emissions – produces uncertainty and anxiety among agents. This is likely manifest itself in the sparking of innovations to address the problem, such as the growth of socio-technical niches (Figure 1.2). However, as the threat of anxiety and change increases and strikes at more central regions of the stable state, for example established patterns of employment and consumer behaviour, a conservative counter-reaction is likely. This theoretical perspective helps perhaps understand the difficulty in shifting behaviour to implement energy efficiency or institute a meaningful legislative programme to reduce GHG (Chapters 4 and 6).

At this point several responses are possible, not by any means all progressive (e.g. Diamond, 2005) and In Chapter 7 the case of the poorly managed Russian transition from communism to a market-oriented economy and its GHG implications was explored. However, as Diamond notes in his conclusion unlike evolution in the natural environment, or earlier collapsed civilisations, social evolution today is not blind but is intensely self aware. For instance, Beinhocker, (2007:232) reflects that:

> While complexity economics strips away our illusions of control over our economic fate, it also hands us a lever – a lever that we have always possessed but never fully

appreciated. *We may not be able to predict or direct economic evolution, but we can design our institutions and societies to be better or worse evolvers* [emphasis added].

The challenge set out here for policy makers, and social scientists as their advisors, is to help build institutions which enable society to transform itself to meet the challenges of the day while minimising the disruption or suffering that may be caused by the transformation or transition.

This raises the question that if the task is to encourage policy learning and system flexibility, how is this to be done?

From a public policy perspective, the first step is to view government as an organisation which carries with it the idea of public learning. This encapsulates the way public authorities interact with the wider socio-technical system to either acquire a new capacity for action or drop older behaviours and activities when they are no longer useful (Schön, 1973).

The political process itself is also one of the ways society learns about itself and can adapt its institutional and organisational structure (Ranson, 1998:9). For example, public deliberation, far from being a barrier to technocratic 'solutions' such as carbon taxation, emissions trading, policy making or a ban on incandescent light bulbs, can be seen as fundamental to an effective learning system.

For example, Chris Freeman (1992:191-192) emphasises, not only the importance of applying economic incentives via regulation to stimulate innovation, but also, the mobilisation of public opinion around the different technological possibilities:

In practice most countries have begun to use a combination of economic incentives and legal regulations. However, the effectiveness of these measures depends on :

1. The degree of public support for the policies. Consequently methods of public persuasion and mobilisation of public opinion also play an important role. Historically, voluntary groups and organisations have made the major contribution to this mobilisation… The success of the environmentalist movement in the 1970s and 1980s has meant that now governmental agencies also often participate in public advocacy and persuasion, albeit not to the extent nor with the same degree of convictions as some 'Greens' might wish.
2. A continuing high rate of technical change.

What can be considered some recent examples of this sort of co-evolution in learning institutions and new organisational configurations in the United Kingdom are:

- The independent Committee on Climate Change, set up to advise the government on carbon budgets and preparing for the impacts of climate change.
- The Carbon Trust, which provides support to help business and the public sector boost business returns by cutting carbon emissions, saving energy and commercialising low carbon technologies.
- The Green Investment Bank, which aims to catalyse investment in low carbon technologies and support economic growth. It has been specifically established as a 'new institution, rather than a series of government interventions', to target low carbon investment. While the government sets its strategic direction, it is has been given legislative independence to operate

at an arms length of the government, to reduce the risk of political capture of new investments.

An important insight that comes out of this is that the reduction of GHG emissions is as much an ethical project in addition to a technical project driven by science and policy makers. For instance, it suggests that if emissions are to be reduced it will not be because an emissions trading scheme was implemented which allowed polluters to buy and sell emissions permits - such policies are simply mechanisms. For meaningful emissions reductions to occur, it will require people's attitudes to have changed along with their sense of responsibility regarding GHG pollution. Indeed, Michael Sandel (2006) goes further to suggest that the attempt to empty politics from moral controversy through market-based logic, while superficially seeming to be a way of respecting our differences, is actually corrosive on democratic life:

> Market mimicking governance takes people's preferences as given and fixed. But when we deliberate as citizens in democratic argument the whole point of the activity is to critically reflect on our preferences - to improve them.

This discussion suggests that whatever the technological solutions that may be invented, the process of public debate and discussion is central to supporting their diffusion in the shift to a low carbon society.

8.4 Future Research

As noted at the start of this Chapter, although the current financial and economic crisis has been tragic in terms of lost opportunities, increased unemployment, financial hardship and economic uncertainty; it nevertheless provides a sense of urgency and focus for research into the nature of our economic and political system. In this endeavour, economic and political geography has an important role to play in contributing to the reinjection of a sense of realism back into the ideas that shape policy. In this respect, this thesis follows an agenda articulated by Clark (2011), first by arguing for the re-introduction of the 'political' into the study of economics, and secondly to increase the importance of the notion of 'value' which has been lost in the ambivalence of the neoclassical approach with respects to the 'good' society. The second current of this research agenda, has been to investigate the nature and scope of decision-making, using empirical studies to show that it is subject to 'behavioural biases' and 'anomalies', rather than the simple-minded 'rationality' assumed by the neoclassical models.

This research agenda was recently well articulated as part of the Routledge Studies in Political Economy, in the *The Political Economy of the Environment* (Deitz, *et al.,* 2011). This work was informed by a series of workshops in Oxford, Leeds, Cambridge and Bolzano: *Towards a New Complexity Economics for Sustainability*, funded by the Economic and Social Research Council (participated in by the author) and is a significant source of inspiration for future directions in this area. On a more general level, the research programme articulated by the Institute for New Economic Thinking is also a source of inspiration in this area, and offers a good opportunity for those who seek to integrate the study of environmental governance with the cutting edge of on-going reform in the fields of finance and economics.

With respects to the programme of research that the author has been building in this thesis, and in other research and teaching, there are several important themes and projects that can be developed further. These are summarised in the following sub-sections.

8.4.1 The geography of carbon markets

Despite attracting a controversial debate across politics, business and academia, greenhouse gas emissions trading schemes have emerged over the last decade as one of humanity's primary mechanisms to reduce the risks of dangerous, anthropogenic climate change. According to the World Bank, the annual value of the carbon market has grown from around $US 10 billion in 2005 to around $US 150 billion in 2010. This wave of new finance has supported the installation of low carbon infrastructure, created a new asset class to be traded by banks and exchanges across the world and spawned tens of thousands of new businesses as entrepreneurs rush to meet the demand for carbon credits in cost effective, innovative ways. However, carbon markets have also drawn fierce criticism from both sides of the environmental debate. Some believe that the costs of greenhouse gas pollution have been exaggerated and emissions trading schemes impose an unacceptable cost on the economy. At the other end of the spectrum, some environmental activists argue that turning environmental values into tradable commodities undermines the moral fabric of society that sustainable stewardship of the planet requires and that polluting activities should simply be outlawed, like drugs. Other, more pragmatic critics, argue that emissions trading schemes have not actually reduced pollution and have proved to be an expensive distraction or even made things worse as in the case of HFC_{23} emissions in China.

The rapid growth of emissions trading schemes as a solution to GHG mitigation suggests that there is a powerful research exigency to study the development and performance of these schemes around the world in a manner which can facilitate policy learning and identify the opportunities and threats for various actors. This research would aim to broaden and deepen the primarily descriptive research agenda set out in the author's co-authored book, *Carbon markets: an international business guide* (Brohé et al, 2009).

8.4.2 Evaluating 'green growth': evolutionary economic geography and case studies of renewable energy diffusion and infrastructure investment

One thing which both equilibrium and evolutionary economists would agree is that technology is fundamental to growth and change in the economy. However, as described in this thesis, the case for a coherent approach to technology policy has been languishing behind the veil of the dominant neoclassical market-based logic. With its emphasis on engaged pluralism, evolutionary economic geography offers a valuable contribution to provide such a coherent policy. While providing a powerful analytical framework for mature technologies already in the market, the standard welfare economics approach lacks the theoretical and methodological tools to adequately understand the full range of investment barriers for renewable energy vis fossil fuel investments or similar qualitative shift in technologies in other sectors (Howarth, 2012). If not taken into account, such barriers can lead to unnecessary energy price inflation in the short run, and in the long-term, an undermining of the economic and industrial structure of the economy.

In order to analyse such barriers, a broader range of empirically-focused methodological tools needs to be brought into play including: data collection to establish the historical, technological and political conditions in which renewable energy technologies become established (or not); survey methods to assess the cognitive processes of individuals that inform low-carbon investments; close-dialogue discussions with experts; qualitative discourse analysis to assess the shaping of social and political institutions that must underpin any low-carbon transformation; and statistical analysis to evaluate significant trends and relationships between variables. Such mixed methods offer the flexibility to inform an analysis at levels which are appropriate to the different stages of the theoretical arguments inherent in the evolutionary approach (such as summarised in Figure 1.1).

The exigency for research in this area has been brought into sharp focus by the 'green growth' strategies that have emerged in many countries following the 2008 financial crisis and ensuing recession (Bernard, et al. 2009; OECD, 2012). These events have opened the pathway for a new era of industrial activism, challenging established modes of thought in public policy away from 'market-based policy' as an end in itself, towards a more 'evidence-based' policy mantra. While this 'widening and deepening' of policy intervention to achieve social goals represents an, albeit somewhat pyrrhic, victory for proponents of Schumpeterian-influenced 'innovation' or 'evolutionary' policies, it also confronts society with a new set of research questions. Most urgent, perhaps, is the empirical question as to whether new institutions have become more or less effective at delivering environmentally sustainable growth and employment as a result of recent interventions.

The 2012 special issue of *European Planning Studies* on path dependence and new path creation in renewable energy technologies sets out a research agenda which forms part of the new wave in evolutionary economic geography in relation to energy and climate change mitigation (Simmie, 2012) and with respects to climate policy more generally (Howarth, 2012). A major thrust of this research is to achieve a better understanding of the relationships between the structural barriers generated by path dependence and the agents who are seeking to generate new technological pathways. The objective of this research, is that through shedding light on the diffusion process, lessons can be learned to accelerate the transition from carbon based energy systems to renewable and other more sustainable technologies in the fastest, most cost effective and equitable way.

This research uses a mixture of methodologies that are appropriate to different stages of the development of the new technological pathway involving: historical description of the technological, economic and political conditions in which power technologies evolved; the use of patent information databases to profile the spatial distribution of innovation and to identify key firms and agents involved; and the use of close dialogue interviews to investigate the perceptions of key individuals and firms in this process. The goal of this work is to establish sets of comparative case studies – for example looking at path creation (or lack thereof) between the German, Danish and UK wind sectors – and use this as a basis to assess immediate and strategic contemporary issues, such as the impact of China as a major consumer and manufacturer of wind technology.

8.5 Conclusion

As Lord Nicholas Stern and others have noted, the current economic crisis and climate change challenges are inextricably linked. It is hoped that the lessons learned from failure of our economic logic and associated institutions which led to a collapse in the financial system are used as a learning experience to mitigate a much greater crisis in our natural systems. This thesis hopes to have drawn attention to these issues and to have moved beyond a simple critique of the failings of the past to offer a positive and constructive agenda for change.

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