More-Than-Rational Modelling:
The Pragmatics and Politics of Social Simulation
in Fisheries Management

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Abstract

Social simulation methods such as agent-based modelling are making inroads into the tool sets of economists and environmental scientists. Responding to critiques of mainstream economic models, agent-based modellers promise increased behavioural realism by modelling the more-than-rational aspects of economic action in socio-ecological systems. This thesis examines agent-based modelling in fisheries management by ethnographically following the efforts of an international scientific consortium to develop an agent-based fisheries model on to the sites of its intended use at the West Coast of the United States. In a dialogue with pragmatic and performative accounts of modelling in science and technology studies, economic sociology, and geography, this project offers an empirically grounded contribution to debates about the politics of knowledge in environmental science and the performativity of economics. The thesis elaborates a relational and materialist account of social simulation and documents how the practices of agent-based modellers are entwined with the politics of fisheries management. The thesis finds that scientific aspects of the agent-based model like agent algorithms and coupling decisions were co-produced with its political context of model use; that efforts to reform the array of calculative practices enacting fisheries economies contend with infrastructural relations between science and policy; and that computational policy optimisation rests on assumptions about policy process that are at odds with its political dimension. As a result, the thesis argues that more-than-rational modelling unsettles rationalist notions of science, economics, and policy, disclosing instead the socio-materiality of scientific modelling, the normative dimension of economic calculation, and the irreducibly antagonistic aspects of politics at work in a scientific effort to reform economic modelling for fisheries management. The thesis concludes by suggesting that recovering the normativity of rational calculation and the politics of knowledge in the analytical framework of economic performativity contributes to understanding the production of economic difference in the context of geographical debates about marketised environmental governance.

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List of acronyms

ABM	Agent-Based Model
ANT	Actor-Network Theory
EBFM	Ecosystem-Based Fisheries Management
EIS	Environmental Impact Statement
FMP	Fishery Management Plan
GAP	Groundfish Advisory Subpanel
IDE	Integrated Development Environment
IFQ	Individual Fishing Quota
ITQ	Individual Transferable Quota
MPA	Marine Protected Area
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSY	Maximum Sustainable Yield
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service (NOAA Fisheries)
PFMC	Pacific Fishery Management Council
SSC	Scientific and Statistical Committee
STS	Science and Technology Studies

Chapter 1 **Introduction**

Agent-based modelling is the vanishing point at which problematisations of the human in heterodox economics and the environmental sciences converge.
A computational method for simulating social systems, agent-based modelling generates the aggregate dynamics of a system from the repeated interactions of a multitude of artificial agents typically representing human actors. The currency of this social simulation method in contemporary science raises questions about changing understandings and algorithmic reworkings of human dimensions in the context of economic and environmental crises.

How to represent the economic agent in turbulent markets? The global financial crash of 2008 has brought to those concerned with modelling economic systems a growing recognition that certain foundational assumptions in economic models are in need of review (Colander et al., 2009). The failure of the mainstream economic models in use at central banks and regulatory agencies to predict the financial crisis has been attributed to these models' reliance on neoclassical microfoundations: the rational agent of neoclassical economics possesses an omniscient clairvoyance about economic information and superhuman calculative capacities that allow for its instantaneous and perfectly rational reaction to price signals in such a way that model markets always equilibrate (Haldane, 2009). Taking the near collapse of the financial system as a most poignant empirical refutation of these model assumptions, a heterodox reform programme demands from the economics discipline to shift its focus towards the more-than-rational dimensions of human behaviour, acknowleding the empirical limitations of economic rationality and the disequilibrating dynamics endogeneously arising from the interactions of a multitude of economic agents rather than being the result of external stressors (Arthur, 2013; Farmer & Foley, 2009; Geanakoplos et al., 2012; Tesfatsion & Judd, 2006). In addition to its roots in the science of complex systems, this heterodox programme draws on several decades of research into the cognitive and behavioural dimensions of decision-making which cast serious doubt on the figure of the rational actor undergirding mainstream economics (Kahneman, 2011; Thaler, 2000). Against this backdrop of waning belief in the inherent rationality of markets, the confluence of cognitive science, behavioural psychology and economics recently translated into expert advice to policy-makers to remedy the experimentally diagnosed cognitive and behavioural shortcomings of the consumer-citizen through the design of informational architectures which, so the promise goes, gently nudge people towards more rational choices in markets of all sorts (Dolan et al., 2010; Sunstein & Thaler, 2009). In the wake of the financial crisis, editorials and opinion pieces in high-level scientific journals such as Nature (Buchanan, 2009; Farmer & Foley, 2009) as well as business publications such as The Economist ("Agents of change," 2010) and the recent Blackett review by the UK Government Office for Science (2018) agree on agent-based modelling as the method best suited to representing the more-than-rational dimensions of economic behaviour and predicting the rather turbulent dynamics of empirical economies.

How to represent the human in changing environments? The Anthropocene hypothesis (Crutzen, 2002) brought to the environmental sciences a growing recognition of human agency in global environmental change, focussing on human behaviour both as inextricably entangled with environmental processes and as a leverage point for strategies of governing environments. Earth system science's understanding of human dimensions of environmental change shifted from human behaviour impacting the dynamics of biogeophysical systems as an external stressor to endogenous dynamics arising from feedbacks between coupled social and environmental systems (Schellnhuber, 1999). This shift towards a more integrated perspective has a fairly recent history: global change research efforts such as the International Geosphere-Biosphere Programme explicitly problematised social dynamics in core projects such as Land Use and Cover Change, developing around the turn of the millennium integrated socio-environmental models which rendered intelligible the Earth system as comprising both biogeophysical processes and their coupling with human activity (Uhrqvist, 2014; Uhrqvist & Lövbrand, 2014). Within this programme, agent-based modelling of land-use decisions emerged as a site of interdisciplinary frictions between remote sensing science and the place-based studies of geography and anthropology. These frictions were eventually resolved in attempts to bridge generic drivers of environmental change with the heterogeneity of situated human-environment relations in an integrated land-use science whose emphasis on multiple possible system states resonated with the complex systems imaginary of Earth system science (Uhrqvist & Lövbrand, 2014: 348). From these modelling efforts, the Earth system emerged as a coupled system within which human activity figures as inseparable from biogeophysical processes rather than impacting on them; a major precept of the Anthropocene hypothesis. Consequently, a recent programmatic intervention into methodological debates within Anthropocene research presents agent-based models as well positioned to represent the interdependence of human decision-making and environmental process, specifically emphasising their potential to model system responses to behavioural change and to allow for the computational optimisation of policy regimes (Verburg et al., 2016).

Two crises, one model – yet there exists surprisingly little social scientific scholarship on the way in which heterodox economics inform the integration of human dimensions into environmental modelling and management practices. This is all the more surprising as there exists by now a robust body of geographical literature concerned with the manner in which economic theories, models and methods are put to work for environmental and natural resource governance: political ecology documents the valorisation practices rendering various nonhuman entities available as services and commodities and inserting them into circuits of exchange; this body of work then often proceeds to decry these processes as part of a general neoliberalisation of nature and points out various ironies posed by unruly natures troubling their commodification (e.g. Bakker, 2010; Robertson, 2012). From a pragmatist perspective, another set of literatures describes the operation of various socio-material practices assembling markets for emissions, ecosystem services, energy resources and so forth. Rather than attempting to reveal market-based governance as resting on deceptive premises, this latter literature tends to emphasise the performative agency of mainstream economics co-constituting the markets it purports to represent (e.g. Callon, 2007; Mackenzie, Muniesa, Siu, & Didier, 2007). In contrast, this thesis takes as its focus the more-than-rational modelling practices of heterodox economics for environmental management.

This thesis relates an account of the merging of two parallel ambitions, namely integrating human dimensions into environmental management and reforming economic modelling, in a project by an international research consortium to construct an agent-based model for the management of global fisheries. Through an ethnographic study following efforts by modellers constructing a computational model on to the sites of its intended use for fisheries policy-making, this thesis interrogates the pragmatics and politics of more-than-rational modelling as an epistemic technique in which heterodox economists and environmental scientists invest their hopes for better knowing and governing coupled social and environmental systems. These hopes are trained on the promise of agent-based modelling to simulate the emergence of collective behavioural patterns from the interactions of a multitude of more-than-rational agents. The thesis advances an understanding of modelling as a pragmatic pursuit in which epistemological, ontological and political dimensions are entangled in the co-production (Jasanoff, 2004) of models and their contexts of use. Drawing on pragmatist scholarship on modelling which stresses the entwinement of scientific modelling practices and extra-scientific practices of model use (Svetlova & Dirksen, 2014), the thesis documents how specific design aspects in heterodox economic modelling are derived from the management contexts in which these models are put to work.

At this point, a brief note on terminology seems apposite. I take "heterodoxy" to be a category which is performed by the modellers in this study themselves. Whereas the modellers did not see the need to explicitly label themselves heterodox economists, their scientific practices and organisational ties manifestly situated them within an intellectual current that militates against what some in the economics discipline perceive to be the dominance of the neoclassical school of thought (cf. George, 2008). While practically developing an economic model, in fact none of the participating scientists held academic appointments at economics departments. Instead they were drawn from across the environmental and human sciences. The principal investigator, a physical geographer, held an appointment to a leading heterodox economics think tank founded in the wake of the financial crash with the explicit mission to overcome neoclassical orthodoxy in the discipline. Substantively, in their writings the modellers heavily drew on literatures from outside of the academic discipline of economics, chiefly complexity theory and behavioural psychology. Given the stated objectives of the modellers to overcome assumptions about rationality and equilibrium in economic systems commonly associated with the neoclassical paradigm, it stands to reason that they were "doing" heterodox economics, if not explicitly labelling themselves heterodox economists.

The diverse schools of economic thought within the heterodox intellectual current are grouped together in the literature on account of their difference from the orthodox, neoclassical school of thought in particular with respect to theoretical assumptions about rationality and equilibrium as well as modelling methodologies (cf. Dequech, 2007; Dow, 2008). However, the boundaries between which schools of thought in the economics discipline get to be accepted as orthodox and which as heterodox remain contested. Some authors dispute the extent to which behavioural economics in particular should still be considered heterodox given the inroads it has made into the discipline. For instance, reviewing recent behavioural economics textbooks, historian of economics Heukelom (2014: 103) argues that "behavioural economics has become mainstream". However, he cautions that a number of competing theories of economic behaviour vie for replacing the micro-assumptions of economic rationality that had dominated the discipline until the late twentieth century. Moreover, theories of economic behaviour drawing on the psychological sciences were taken up in the economics discipline on account of their acceptance of rational choice theory as a "valid normative benchmark" (Heukelom, 2014: 92) from which observed economic behaviour deviates. Such continuities between neoclassical and behavioural conceptions of economic choice continue to provoke active debate within the economics discipline about the boundaries between mainstream and heterodox economics (cf. Truc, 2018).

A further argument still complicates the boundaries between mainstream and heterodox economics. Economics occupies a somewhat unique position among the social science disciplines on account of its strong orientation towards, and frequent borrowing of metaphors and models from, the natural sciences. As historian of economics Mirowski (1989) documents, the physics of energy in particular had a strong influence on the development of what eventually came to be known as the dominant neoclassical school of thought. Furthermore, various authors note how the mathematisation following from economics' orientation towards the "hard" sciences provides a resource for economists' own disciplinary identity, and indeed presumed superiority, among the social sciences as well as for legitimating their unique influence as a policy-shaping discipline (Fourcade, Ollion & Algan, 2015; Colander, 2005). If orientation towards the natural sciences and mathematisation form core elements of the disciplinary identity of economics after the ascendancy of the neoclassical paradigm, then degrees of adherence to these disciplinary norms might provide further criteria with which to assess degrees of difference of schools of thought usually considered heterodox to the neoclassical orthodoxy. On this measure, the version of economic heterodoxy investigated in this thesis indeed tacks rather closely to these disciplinary norms. For instance, a common critique levelled by complexity economists at the neoclassical school of thought argues that the latter would work with an outdated physics of equilibrium systems rather than taking note of more recent developments in the physics of disequilibrium systems and their intersection with the life sciences (Beinhocker, 2007; Haldane, 2016).[1] As a result, I take the work of the modellers under investigation in this thesis to be a symptom of a dispute within the economics discipline in which the question which schools of economic thought should be considered mainstream or heterodox remains a matter of open debate.[2]

Efforts to integrate human dimensions into environmental models envision the reform of the knowledge practices underwriting environmental governance. Drawing on a detailed case study following the envisioning and construction of an agent-based model for fisheries management at the American West Coast, the thesis examines how such a reform effort contends with incumbent infrastructural relations (Slota & Bowker, 2017; Star, 1999) between science and policy-making which restrict the range of methods with which socio-natures become known and futures are rendered calculable. These infrastructural relations result from settlements between different actors in fisheries management struggling over the credibility of different methods for rendering future natures calculable, investing different calculative means for performing futures with distributive stakes (cf. Beckert, 2016). Whereas the modellers expend much energy making a case for the novel epistemic and regulatory potentials which the inclusion of previously omitted human dimensions promises, the case study explores how a relational understanding of environmental knowledge infrastructures might account for the efficacy of more-than-rational modelling efforts

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[1] I will elaborate on this interdisciplinary trafficking in economic theorising in chapter four. Moreover, in chapter six I will discuss how adherence to a scientific norm of universal validity of economic laws played a role in distinguishing between acceptable and unacceptable forms of (heterodox) economic theorising within the fisheries modelling consortium.

[2] I will elaborate on this disciplinary dispute in chapter six.

to affect the reform of regulatory practices and the manner in which epistemic potentials of social simulation are shaped by the socio-material relations organising environmental management.

Moreover, this thesis investigates how the algorithmic reworking of human behaviour in more-than-rational modelling might be contingent on the power relations obtaining in environmental management which modellers negotiate in the process of model development. This negotiation shapes a specific politics of knowledge (Landström & Whatmore, 2014) in more-than-rational modelling: scholars in geography as well as the environmental social sciences and humanities criticise the narrow range of disciplines and epistemologies permitted to inform current efforts at human dimensions modelling, questioning in particular the privileging of models of the human drawn from the positivist social sciences such as psychology and economics (Castree et al., 2014). Detailing a dispute between modellers about divergent and normatively inflected ontologies of human behaviour informed by different disciplines, the thesis identifies a condition enabling the privileging of psychological and economic expertise: the manner in which modellers conceived of fishing behaviour as a form of constrained optimisation had been shaped by their efforts to make the model relevant to specific powerful actors in fisheries management, excluding other actors who might have provoked more heterogeneous conceptions of human dimensions. As a result, the thesis examines how more-than-rational modelling is shaped by the political contexts of model use which constrains the range of epistemologies permitted to inform efforts to integrate human dimensions into socio-environmental models (cf. Svetlova & Dirksen, 2014).

1.1 Beyond the rational actor

The artificial agent in agent-based modelling discloses how the human becomes problematised as a more-than-rational actor in the encounter between heterodox economics and the environmental sciences. Rather than fitting models to past statistical data or assuming global dynamics of systems, agent-based modelling populates a simulated environment with artificial agents acting according to theoretically or empirically derived interaction rules and then models how agent behaviours adapt to changing conditions, giving rise to aggregate system dynamics (Bonabeau, 2002; Epstein & Axtell, 1996; Gilbert, 2008; Gilbert & Troitzsch, 2005). Computational social scientists first developing agent-based models had been specifically interested in probing certain doxa of neoclassical economics which presuppose the perfect rationality of economic agents for the existence of efficient markets, exploring instead the aggregate effects of interacting agents with bounded rationality (Epstein, 2006). Qualifying neoclassical assumptions about the computational capacities of economic actors, bounded rationality refers to modalities of action based on relatively simple decision rules, i.e. heuristics, rather than cognitively costly mathematical optimisation (Bendor, 2002; Simon, 1983). That agent-based models are able to represent interactions between agents and environments in a spatially explicit manner draws the interest of geographers and environmental scientists (Hare & Deadman, 2004; O'Sullivan & Haklay, 2000).[3] On the issue of agent-based modelling, metaphorical trafficking between economics and ecology is common (Bier & Schinkel, 2016). A prominent collaboration between

[3] With added emphasis on the modelling of norms, values and behaviours in artificial agents, the International Benchmarking Review for UK Human Geography argues that agent-based modelling should provide a "point of departure" for remedying what is perceived as a relative neglect of quantitative methods in the discipline (Economic and Social Research Council, 2013: 16).

ecologist Lord Robert May and Bank of England economist Andrew Haldane (Haldane & May, 2011) on the topic of banking ecosystems testifies to this passage between ecological science and the post-crash heterodox current in economics.

The convergence of cognate concerns with the human by economists and environmental scientists in agent-based modelling is perhaps most developed in research on the management of common-pool resources. Influential in natural resource economics, the tragedy of the commons theory assumes selfish and autonomous agents trapped in a social dilemma wherein individually optimising resource exploitation strategies give rise to the overall decline of the resource (Hardin, 1968). However, later research by Nobel economist Elinor Ostrom (2010) heavily qualified the tragedy of the commons as empirically unsubstantiated for many cases of common-pool resource management. As a result, the controversy around the tragedy of the commons provoked numerous agent-based models simulating the emergence of diverse resource management outcomes contingent on the specific configuration of simulated agents and the policies governing their behaviour (e.g. Heckbert, Baynes, & Reeson, 2010; Janssen & Ostrom, 2006; Poteete, Janssen, & Ostrom, 2010). The human actor assumes a much more prominent role in these simulated socio-ecologies: ecologists recognise the need to include formal representations of human action in environmental models, question the assumptions as to rational action embodied in the formal models of mainstream economics, and turn instead to integrating findings from psychological or field research with agent-based software tools developed by computational social science in order to build ecological economic models (Janssen & Jager, 2000). Attempts at cataloguing the sprawling practitioner literature on agent-based, socio-ecological modelling attest to the currency of this specific problematisation of human action in environmental research (e.g. Bousquet & Le Page, 2004; Hare & Deadman, 2004).

This problematisation of the human agent has received relatively little attention in social studies of the environment. For instance, in their editorial introducing a thematic section of articles on the performativity of social science methods in environmental change, Asdal and Marres (2014: 2055) acknowledge that

> social scientific expertise is gaining recognition as a contributor of models, methods, and devices for addressing environmental issues by intervening in practices and shifting arrangements, and in both popular and professional literatures social science is now frequently presented as a critical resource for the measurement, prediction, and facilitation of technological, ecological, societal, and organizational change.

However, the research they introduce rarely engages with the way the social sciences problematise human actors, instead taking as its object accounting and other valuation practices rendering nonhuman entities legible to social institutions, how social scientific methods inform the design of organisational arrangements for public participation in environmental issues, and the performativity of economics for the construction of market-oriented policy regimes and natural resource economies. The latter field of research has been particularly productive, documenting how the theories, models and calculative devices of economics take on a material force in their own right when put to work for the constitution of markets for emissions, ecosystem services, energy resources and other marketised socio-material hybrids (e.g. Dempsey, 2016; Kama, 2013; MacKenzie, 2009; Muniesa, Millo, & Callon, 2007).
A concern shared among many of these studies is the way in which the social sciences partake in the formatting of human-environment relations as hybrid entanglements that take work to maintain in practice, by necessity frame relations in such a way as to exclude other possible forms of hybridity, and thus are open to interrogation as to

their political effects. Other social studies of the environment focus more explicitly on the manner in which technologies of government fashion environmental subjects (Agrawal, 2005) or question the enrolment of anthropology into the international politics of biodiversity conservation (Blok, 2014). However, much less is known about the manner in which the environmental sciences explicitly draw on theories and models from the social sciences to model the human as an integral part of the ecological and physical systems they study and the performative politics following from the embedding of these models into the knowledge infrastructures supporting environmental governance.

Efforts to model human dimensions in the environmental sciences raise a number of entangled epistemological, ontological and political questions. Some geographers and scholars working in the environmental social sciences and humanities have critically remarked on the theories, methods and models with which human dimensions are currently brought into environmental change research. In a widely cited contribution, Castree et al. (2014) argue that a narrow framing of human dimensions in global environmental change research constrains the range of imaginable environmental futures and may thereby privilege the societal status quo. Noting agent-based modelling as a common technique for integrating human dimensions into environmental models, they emphasise how the privileging of positivist social and human sciences such as economics and psychology, with their affinity to the quantitative practices of the natural sciences, excludes the interpretive social sciences and humanities. However, that also excludes "a sense of humans as diverse, interpretive creatures who frequently disagree about values, means and ends“ (Castree et al., 2014: 765). Their programmatic intervention calls for the inclusion of a broader disciplinary range of social sciences and humanities as a corrective for what they perceive to be a missing diversity of epistemologies and normative orientations with the effect of restricting the range of political choices global environmental change research offers societies.

Agent-based models raise particular questions about the ontological commitments embodied in environmental modelling practices. Noting the growing popularity of agent-based modelling among geographers and spatial scientists, O'Sullivan and Haklay (2000) caution against an unacknowledged individualist ontology of the social implicit in many ABM applications. Surveying a number of agent-based models, they note that these models commonly feature agents as individuals, assume social structures to emerge unidirectionally from the aggregate interactions of agents at the micro level, and tend to reduce agent's behavioural complexity, including the capacity to reflect, for pragmatic reasons (O'Sullivan & Haklay, 2000: 1413). The inclusion of reflexivity and of social theory acknowleding structure as a force preceding and shaping the individual in geographical agent-based models, they conclude, remains an intriguing but unrealised potential. Among the agent-based models surveyed, the groundbreaking Sugarscape simulation by Joshua Epstein and Robert Axtell (1996) has probably been most influential for shaping the field of computational social science. Whereas O'Sullivan and Haklay (2000: 1414) strongly object to what they perceive as a reductive ontology of society and culture embodied in the simulated emergence of collective affiliations in the Sugarscape model, its figuring of the relation between agent and environment in particular should raise questions about some of the ontological commitments inscribed into agent-based models for environmental research. For the Sugarscape simulation, agents are defined as autonomous entities equipped with the capacity to act according to behavioural rules. The environment, on the other hand, is defined as "a medium separate from the agents, *on* which the agents operate and *with* which they interact" (Epstein & Axtell, 1996: 5; original emphasis). Such a dualist ontology of nature and society which renders the former a passive background for the actions of the latter, while common to Western metaphysics, stands in stark contrast to geographical scholarship which has emphasised the hybridity and liveliness of environmental matters (Whatmore, 2002). Ontological commitments of this kind embodied in agent-based models would also suggest carefully examining the practices which enact the ontological cuts purifying natural and social kinds and inscribing such modernist divisions (Latour, 1993) into simulation software.

Agent-based modelling has been met with critique from social theorists problematising agency as an effect of heterogeneous networks rather than the capacity of autonomous agents. In a provocative contribution to one of the premier journals in the field of social simulation, Venturini, Jensen and Latour (2015) dismiss social simulation outright in favour of network analyses of digital traces:

> Simulating the emergence of macro structures from micro interactions has never been an optimal research strategy (...) Its main justification – the possibility to bypass the supposed micro/macro divide – lost much of its interest since the advent of digital media. Empirical studies show that, contrarily to what most social simulations assume, collective action does not originate at the micro level of individual atoms and does not end up in a macro level of stable structures. Instead, actions distribute in intricate and heterogeneous networks than (sic!) fold and deploy creating differences but not discontinuities.

One need not share the optimism for certain digital methods of these authors to recognise the challenge posed by the emergentist ontology of the social embodied in agent-based modelling to that of actor-network theory: the latter renders nonhuman entities co-constitutive of social action (Latour, 1990b, 2005b) and dissolves the micro-macro distinction in continuously proliferating heterogeneous assemblages (Callon & Latour, 1981), thus standing in stark contrast to the methodological individualism embodied in many social simulations. However, given the currency of agent-based modelling in geography, it would represent a missed opportunity to simply dismiss this method on account of the incompatibility of its ontological assumptions with current critical research agendas in cultural and environmental geography. A more fruitful route would be to carefully examine the theories and practices involved in the construction of social simulations, the forces shaping design choices in the process of modelling, and in turn the difference computational models might make to the worlds they purport to represent. Such an approach could even hope to contribute to a tradition of geographical scholarship reflecting and modifying, rather than dismissing, quantitative and computational methods of geographical research with a view to eventually reaching across methodological divides in the discipline for the assembling of hybrid tool sets in the service of critical research agendas (Barnes, 2009; Kwan & Schwanen, 2009; on ABM as a mixed method in geography see Millington & Wainwright, 2016).

1.2 Towards theorising more-than-rational modelling

The title of this thesis invokes the more-than-rational dimension of agent-based simulation for fisheries management. Rationality, of course, is a term as ubiquitous as it is ambiguous, its polysemy only exacerbated through the various specialised employments of the notion of rationality within different disciplines and contexts (cf. Rysiew, 2012). Instead of attempting an unduly constricting general definition of rationality, this thesis will empirically map out, and then proceed to problematise, the various ways in which claims to rationality are involved in agent-based modelling for fisheries management. That is to say, the more-than-rational is at stake in multiple ways throughout the thesis. In what follows I will introduce four different senses of rationality and briefly sketch out the various ways in which they are challenged, unsettled or exceeded by the economic, scientific, and policy-making practices which I will relate throughout this thesis. By way of elaborating on these four senses of rationality I also wish to briefly introduce the analytical frameworks originating in geography, science and technology studies, and economic sociology on which this thesis draws for theorising more-than-rational modelling in fisheries management.

The first sense of rationality refers to the economic rationalisation of fisheries. Political ecology has noted how successive rationalisation programmes in various parts of the world have established fisheries management regimes which turn on the allocation of tradeable property rights (Mansfield, 2004). These market-oriented forms of marine governance are informed by bioeconomic models embodying neoclassical economic theories which assume that, if the maximising behaviour of fishers as rational agents is left unconstrained by property rights, a tragedy of the commons will occur (Hubbard, 2014). Introducing tradeable property rights based on population models forecasting a total harvest which can then be allocated as catch shares to fishers, these management regimes attempt to enlist individual rational decision-making for the maximisation of social and environmental welfare defined as sustained, efficient resource exploitation (Mansfield, 2004: 316). Geographers note how the calculative infrastructures subtending this form of market-based governance enact a specifically economic "disciplinary imagination of the ocean“ in which "fishers are economic agents that harvest interchangeable, controllable units of resource within a spatially indistinct and bounded area" (Cardwell & Thornton, 2015: 161). At the American West Coast, the result of previous rationalisation efforts forms the incumbent configuration of imaginary and infrastructure in which agent-based modellers attempt to introduce computational methods for knowing fishers as more-than-rational actors. This attempt challenges the established arrangements of fisheries management which enact human-environment relations as relations between a representative rational agent and a single-species resource. The literature on socio-technical imaginaries (Jasanoff, 2015b) provides an analytical framework for understanding the process by which agent-based modellers imagine more-than-rational ocean futures, enlist the support of others, and translate their visions into calculative infrastructures enacting different kinds of socio-natures. Science and technology studies note the imaginative work involved in technoscientific projects (Fujimura, 2003; Suchman, 2012). In order to marshal resources and enlist support for their projects, scientists have to envision futures in which the knowledges and artefacts they develop are rendered meaningful and persuade others that these futures are desirable and attainable. These envisionings draw on established cultural discourses of desirable futures attainable through technoscientific progress. In the case examined in this thesis, this envisioning renders more-than-rational modelling efforts plausible and timely through metaphorical trafficking between narratives of crisis and control in finance and fisheries. Reading a relational theory of infrastructure proposed by STS scholars (Bowker, Baker, Millerand, & Ribes, 2010; Slota & Bowker, 2017; Star, 1999) alongside studies on the performativity of environmental knowledge infrastructures (Blok, Nakazora, & Winthereik, 2016), I examine how the enactment of more-than-rational ocean futures contends with incumbent infrastructural relations between scientific modelling and policy-making in rationalised fisheries.

Secondly, a further import of rationality concerns scientific simulation as a practice irreducible to logical reasoning or adherence to explicit methodological procedures. Science studies scholars have argued on behalf of praxeographic analyses of science for explaining successful technoscientific orderings as results of pragmatic constructions rather than "a rational mind or a more constraining scientific method" (Latour, 1990: 19) affording scientific rationality privileged access to an objective reality external to practices of knowledge-making. Ethnographies of science in the field and laboratory have contributed to a pragmatist theory of scientific representation stressing the artefacts and human labours involved in creating and maintaining chains of inscriptions along which claims to faithfully represent some part of the world can travel (Latour, 1999a). Understanding the more-than-rational dimension of simulation modelling, then, entails an analytical shift towards the material practices with which simulation models are constructed. Whereas scholars in science studies (Knuuttila, 2005) and geography (Landström, Whatmore, & Lane, 2013) emphasise the epistemic productivity of models as material artefacts, less is known about the way software-based computer simulation, too, proceeds through the negotiation of material affordances. Simulation as a practice-in-the-making overflows prescriptive procedures when modellers craft software objects, suggesting scientific simulation as a pragmatic pursuit where epistemic work is irreducible to logical reasoning but crucially hinges on the skillful practical negotiation of lively materialities. Creating model abstractions, modellers inscribe domain descriptions into software objects which simulate a system when code is executed. Rather than resulting from a strict adherence to methodological prescriptions, model abstractions are contingent results of crafting together layered affordances in situations of interdisciplinary collaboration between modellers and domain experts. Joining a sensibility towards the sociality of code practices from software studies (Goffey & Fuller, 2012; Mackenzie, 2006) with a materialist theory of media objects (Fuller, 2005) aids in theorising the materiality of abstraction as a representational practice in computational simulation. Decentering the rational mind by expanding analytical scope to include the heterogeneous assemblages involved in the making of software, a materialist praxeography of abstraction work brings into relief the more-than-rational dimension of computer simulation.

The third sense of rationality regards the manner in which different assumptions as to the rationality of fisher's decision-making raise normative and political questions. "Are Fishermen Rational?" asks a paper in a resource economics journal, arguing that observed fishing behaviour contradicts neoclassical economic assumptions about rational action and that modellers should integrate findings from behavioural economics in order to better predict fishing behaviour (Holland, 2008). Geographers have documented how theories about the more-than-rational dimensions of human decision-making from behavioural economics have informed public policy, shaping the design of informational environments which co-constitute the agentic capacities of deciding subjects (Boeckler & Berndt, 2012; Whitehead, Jones, & Pykett, 2011). Science and technology studies suggest understanding scientific claims, such as about the nature of human rationality, as performative rather than representational, training their analytical lens on the epistemic and material practices through which knowledge claims are made simultaneously with the worlds they purport to describe (e.g. Barad, 2003). Influential in economic sociology, the performativity programme asks how economic theory is put to work in the form of calculative devices which equip economic actors and thereby perform rational action in empirical markets (Callon, 1999; Mackenzie, 2009). Assembling a socio-technical infrastructure enacting markets for catch shares, rationalisation programmes in fisheries management have been analysed as to their performative efficacy in shaping the calculative capacities of fishers as rational actors (Holm & Nielsen, 2007). However, the performativity programme has been criticised for neglecting heterodox economic theories and the political and normative dimensions of economic performance, reducing the social study of economies to technical analyses of the prosthetics equipping market action (Bryan, Martin, Montgomerie, & Williams, 2012; Mirowski & Nik-Kah, 2007). Analysing a dispute between fisheries modellers about the the conceptual underpinnings of agent algorithms, this thesis brings the heterodox economics of fishing behaviour into a dialogue with the performativity programme. The thesis will relate how agent-based modellers simultaneously grappled with the normative legacy of economic knowledge of rational action and the socio-material relations through which economic rationalities are enacted in a dispute about the conceptual underpinnings of different decision algorithms of the fisher agent. From this empirical basis, the thesis examines how more-than-rational modelling incorporates normatively inflected theories of economic decision-making whose performative efficacy is contingent on the political stratagems into which economic knowledge becomes enlisted.

Finally, the fourth meaning of rationality involves the deployment of computational optimisation as part of attempts at increasing the soundness and expediency of environmental policy-making. An important ambition of socio-ecological simulation concerns putting models to use for the optimisation of environmental policies (cf. Verburg et al., 2016). Such optimisation efforts stand in the tradition of policy analysis casting problems of political decision-making as amenable to formal calculative treatment (Erickson et al., 2013; Fischer, 2003; Thomas, 2015). In the case examined in this thesis, computational search techniques fed by simulation-generated data are deployed for identifying policies which optimise predefined objectives, thereby promising to increase the soundness of the reasoning underlying fisheries policy-making. This promise of policy optimisation responds to the slowness of adapting current management regimes to changing environments and unintended effects of policies. However, as an expert problematisation of environmental governance, policy optimisation figures policy-making as a primarily technical challenge of deploying calculative techniques for increasing the rationality of policy decisions, screening out refractory elements troubling expert calculation (Li, 2007). In contrast, political geography (Barry, 2013) and science studies (Marres, 2007b) have emphasised the political moment sparked by the articulation of environmental issues as socio-material hybrids: drawing on a radical democratic theory of the political (Mouffe, 2005) this thesis investigates how fisheries policy-making proceeds through the articulation of irreducibly antagonistic attachments to material issues. Confronting computational policy optimisation with policy-making in practice discloses the political as a moment of dissensus irreducible to the rational deliberation of optimised policy alternatives, suggesting instead a policy process characterised by messy negotiations of power relations and irreconcilable ways of being materially implicated in the worlds of fishing and science. Computational policy optimisation, then, provides a site for interrogating how anti-political potentials limiting the articulation of disagreement obtain in attempts to rationalise decision-making in environmental governance.

To summarise, rationality is at stake in at least four different ways in the case study which I will present: first, heterodox modellers question the soundness of previous rationalisation efforts in fisheries management based on orthodox economic models, promising instead ways of managing fisheries which harness the more-than-rational decision-making strategies of fishers; second, the scientific practice of computational modelling is irreducible to the reasoning mind of the scientist, suggesting a richer account of science-in-the-making which gives due place to the agentic contribution of the material and political contexts in which modelling proceeds; third, the rationality of fisher's economic reasoning is explicitly problematised by modellers, leading them to a dispute about different ways of formalising the economic decision whose closure raises normative and political questions; and fourth, assumptions on the part of modellers about the rationality of science-based policy-making are at odds with the politics of applied fisheries management. Subsequent empirical chapters will elaborate how these various notions of rationality become destabilised during the practical pursuit of science, economics, and politics.

A more precise rendering of the the term "more-than-rational modelling" can now be attempted. More-than-rational modelling refers to the ways in which heterodox economic modellers build agent-based models capable of simulating the effects of modes of economic decision-making which depart from neoclassical assumptions as to rational action. Yet more-than-rational modelling equally means that computer modelling itself is a materially and politically mediated practice in which more than the reasoning mind of the scientist is involved, thus unsettling rationalist notions of science, even though this dimension remains unproblematised by the modellers themselves. Consequently, the "more-than-rational" in more-than-rational modelling applies both to the agents being modelled and to the practice of modelling. However, it applies differently: whereas fishers' economic rationality is explicitly problematised in the modelling practices of scientists, the thesis will disclose how these same scientists do not necessarily regard their own modelling practice as providing grounds for problematising rationalist notions of computational science or the environmental politics which such science is meant to support.

As a result, the term more-than-rational modelling raises the question about the distribution of rationality enacted in such attempts to move beyond the rational actor in environmental modelling. Geographers previously raised a similar question with respect to the translation of behavioural psychology and neuroscience into public policy (Whitehead, Jones & Pykett, 2011). It is from this work that I take the term "more-than-rational". Investigating the influence on British public policy of theories about human decision-making developed by behavioural psychologists and neuroscientists, Whitehead, Jones & Pykett (2011: 2820) discuss the "political and ethical issues that arise from the more-than-rational framing of human decision-making that is encoded in policies" aiming for behaviour change in policy areas such as transport and gambling. Psychological and neuroscientific research suggest a model of human decision-making in which environmental, procedural, bodily and emotional factors routinely shape decisions in such a way that their observed outcomes deviate from those expected were one to follow the theoretical assumptions of neoclassical economics. Whitehead, Jones & Pykett (2011: 2824) take this more-than-rational deciding subject, experimentally disclosed as embodied and decentered, to resonate with recent concerns with affect in social theory and geographical research. However, they diagnose a decoupling and distribution of rationality and irrationality in the applications of psychological and neuroscientific insights in British public policy. These applications tend to designate some segments of the population as in need of interventions aiming at re-rationalising their decisions by shaping the environments in which decision-making proceeds, yet leaving the presumed rationality of the government expert charged with devising such interventions unquestioned. In other words, whereas scientific research would characterise any human decision-making as involving a more-than-rational dimension, the translation of these scientific insights into policy designs decouples and distributes ir/rationality by singling out some decision-making as irrational and in need of correction by rational experts.

Throughout subsequent chapters, I will demonstrate how a similar decoupling and distribution of rationality obtains in the case of more-than-rational modelling for fisheries management. Whereas the modellers understand and formalise fishers as economic agents whose decision-making deviates from the norm of economic rationality, it is only the latter's behaviour which is singled out and made a target of modelling practices and management strategies whose own presumptions of rationality remain unquestioned. Moreover, Whitehead, Jones & Pykett (2011: 2820) argue that acknowledgment of the more-than-rational dimensions of any and all decision-making harbors the potential of embracing "the creative potential of inexpert knowledge" in public life, lamenting the instrumentalism displayed by recent translations of behavioural psychology and neuroscience into public policy.

Throughout subsequent chapters I will return to this theme, discussing how fishers' non-expert knowledge is systematically excluded from the modelling efforts of scientists.

However, this raises the question of whether these specific translations between science and policy would not be more aptly characterised as less-than-rational rather than more-than-rational, given that deficiencies of rationality form their main diagnosis and target of intervention? Indeed, Whitehead, Jones & Pykett (2011) variously figure the deciding subject disclosed by behavioural and psychological science as either irrational, boundedly rational, less-than-rational, more-than-rational or more-than-economic. Little precision is given to these terms apart from intimating an affirmative stance towards the term more-than-rational as evoking the complex interplay of rational and irrational dimensions in decision-making which neuroscience and psychology would suggest. In contrast, I wish to suggest venturing beyond the neuroscientific and psychological forms of knowledge-making, in the affirmation of which Whitehead, Jones & Pykett (2011) ground their analysis, in order to relate concerns with rationality to those with social agency elaborated in more-than-human geographies (Whatmore, 2002). A core element of these geographies is the attempt to elaborate an account of agency as an effect of processes of association between humans and non-humans, thereby working towards a materialist account of social life which decenters the human subject in favour of a more distributed notion of social process in a more-than-human-world (Whatmore, 2002: 5). Actor-network theorists have made similar attempts at decentering the human agent, explaining both rational economic action and the knowledge claims of scientists as generated by heterogeneous, socio-technical networks (Callon, 1999; Latour, 1987). Drawing on actor-network theory, geographers have investigated how behaviour change policies consciously work on the design of such networks in order to generate rationality effects (Berndt & Boeckler, 2016). Placed in this context, the term more-than-rational modelling indicates the more-than-human dimensions of reasoning as an equipped practice that is spread out into the world and rests on environmental supports. Insisting that the reasoning of both fishers and fisheries modellers is shaped by specific associations with nonhuman elements, the term more-than-rational modelling retains a symmetrical perspective on their respective knowledges, thus preventing premature closure of the question whose reasoning should be considered rational and whose less so. In turn, this perspective also allows for investigating how, and with which consequences, specific knowledges and ways of reasoning get to be elevated to the status of informing the environmental policy process.

1.3 Research questions

Parallel problematisations of the human in heterodox economics and the environmental sciences converge on agent-based modelling and its central figure, the more-than-rational agent. Natural resource management in particular serves as a focal point at which this convergence translates into socio-environmental modelling efforts aimed at informing policy-making. Whereas agent-based modelling extends beyond the confines of mainstream economic theory, the more-than-rational agent tends to be problematised by a narrow range of disciplines, theories and methods. This raises the question of the "politics of knowledge" (Landström & Whatmore, 2014) in social simulation for environmental management which, as previous geographical research on environmental modelling suggests, might be fruitfully addressed by examining the entwinement of modelling and management practices.

Consequently, this thesis takes as its research objective to examine the "how" of environmental modelling and management, setting forth a detailed empirical exploration of the practices with which modellers simultaneously construct models and the worlds in which they come to matter. Emphasising practices, and in particular technoscientific practices, as materially mediated and productive has become a way for scholars in geography as well as science and technology studies to complicate notions of science that would postulate an independent reality waiting to be discovered (Powell, 2007). Instead, ethnographies of scientific knowledge practices render science as an array of activities which co-perform both their knowledge objects and the socio-material arrangements in which these objects matter (Latour, 1999b; Law, 2004; Mol, 2002). These praxeographies render science a practice in which entangled questions of epistemological, ontological, and normative import obtain. As a result, the research questions guiding this thesis aim for the exploration of entangled questions of knowledge-making with computer simulation, the enactment of socio-natures in fisheries management, and the political relations in which attempts at reforming the calculative practices of environmental management are embroiled.

As a broad objective, the thesis aims to interrogate how more-than-rational modelling becomes embedded into the array of practices and techniques which enact specific socio-natures. In turn, it aims to examine the way in which political assumptions about how these socio-natures should be governed inform the design choices and enrolment efforts that hold together environmental models as heterogeneous socio-material networks. More specifically, this thesis presents the case of agent-based modelling for fisheries management in order to examine how more-than-rational modelling takes hold in the knowledge practices of fisheries management, to observe the construction of a computer simulation model through a series of material practices, and to confront the ambitions of agent-based modellers with the situated practices of fisheries management in order to explore the difference computational social science methods make for environmental governance.

However, agent-based modelling in fisheries management has yet to come into being. A relatively novel computational method, agent-based modelling contends with the established array of calculative techniques and organisational arrangements in natural resource management. Previous research in geography and STS suggests these environmental knowledge infrastructures as sites of contestation in which power relations between scientists, policy-makers, resource users and other actors are at stake (Blok et al., 2016; Lippert, Krause, & Klaus, 2015). Consequently, the first research question asks:

1. *How does agent-based modelling take hold in environmental management?*

Moreover, this thesis asks how agent-based modellers empirically select the ideas and tools guiding their problematisations as they pursue their epistemic quest. As fairly complex and opaque pieces of software, agent-based models may embody hidden ontological and normative commitments the interrogation of which necessitates observing modelling practices in situ as a way of bringing to light the material, practical, and political circumstances shaping the choices made in model construction. Previous research on modelling suggests that the relational materiality of computer modelling is important for the epistemic practices of science and for the policy contexts in which models are put to use (Knuuttila, 2005; Svetlova & Dirksen, 2014). Therefore, the second research questions inquires:

2. *How does the materiality of social simulation affect modelling and management practices?*

To the extent that agent-based modellers succeed in putting their theories and models to work, they might affect economic, political and environmental relations. Geographers have argued that, rather than disclosing a stable and singular Nature, the epistemic practices of science are enlisted into performances of plural socio-natures (Bingham & Hinchcliffe, 2008). This would raise questions about the way in which specific computational methods partake in the constitution of different socio-natures. Thus the third research question asks:

3. *What difference do computational methods make for fabricating socio-natures?*

The study explored these three questions through a one-year, multi-sited, participatory observation with computational modellers in Britain and the United States as well as fishers, science advisors and policy-makers working in a fisheries management organisation on the West Coast of the United States. The agent-based model in question did not spring whole cloth from the minds of modellers. Resources had to be marshalled, funding bodies persuaded, important stakeholders identified and laboriously brought into the fold, all while solving problems of interdisciplinary collaboration and negotiating the affordances of computational technologies. Whereas the modelling consortium pursued a multi-year project, this thesis only follows the work of modellers and fisheries management actors throughout the first year of model delevopment. The agent-based modellers in this study pursued an ambitious reform project that attempted to change an established bioeconomic paradigm of fisheries management with the help of agent-based modelling. However, those actors in fisheries management, whose practices they tried to augment and equip had to grapple with their own problems. These problems issued from the legal and organisational arrangements formatting science-policy relations in American fisheries management and political challenges sparked by frictions between the divergent interests of fishers, scientists and policy-makers. Situating agent-based modelling within this broader context of environmental policy-making, this thesis throws into relief the limits which ambitious projects of rendering governance computational might encounter when coming up against the politics of natural resource management in practice. In turn, it allows an exploration of how computational methods can become devices which, rather than merely furnishing evidence for policy-making, instead equip and co-constitute political settings in which competing performances of socio-natures are at stake. The following section gives an overview of how these questions are addressed throughout the different chapters of this thesis.

1.4 Overview of chapters

This thesis comprises eight chapters. The next two chapters review relevant literature and detail methodological considerations respectively. There follow four chapters based on the empirical findings of this thesis each aiming to bring to the fore a different aspect of more-than-rational modelling. A concluding chapter draws together the empirical findings in order to summarise, discuss some conclusions, and outline further issues and questions arising from this research. The following section will provide a brief overview of each chapter.

Chapter 2 Literature review

This chapter discusses the literatures with which this thesis engages in a dialogue and to which it hopes to contribute. Three principle sets of literatures are reviewed. First, I discuss a literature on scientific modelling and simulation primarily drawn from science and technology studies. I divide this literature into constructionist and interactionist strands: the former is primarily interested in the epistemic productivity of model materialities and modelling practices in scientific settings, and the latter investigates the co-production of epistemic and political order between scientific modelling and the use of models in policy settings. I conclude this review with a discussion of recent STS and geographical research on modelling practices as entwined with practices of model use and suggest that such research might be complemented by STS and geographical work on knowledge infrastructures.

The second set of reviewed literatures is drawn from across STS, economic sociology and geography and concerns the performativity of economics. These literatures share a commitment to investigating the economy as performative effect of calculative practices, yet differ in their emphasis on economic diversity. Critically revisiting the concept of calculative agency, I argue that its roots in the neoclassical theory of rational action had been gradually elided. Reviewing how economic performativity has been deployed in geographical research on fisheries management, I suggest empirically revisiting substantive differences in economic calculation. Finally, I review a set of literatures working towards a rematerialisation of political theory. These literatures decenter the human in political life, bringing to the fore the artefacts and materially mediated practices co-constituting political collectivities. I discuss how STS and geographical scholarship have joined this analytical focus on the materiality of politics with the question of the political: a radical democratic theory of the political might aid in accounting for irreconcilable antagonisms between socio-material collectivities which suggests limits to rationalist models of politics.

Chapter 3 Methodology

Placing the question of the epistemological commitments of this thesis squarely within the field, the chapter commences with a brief discussion of the performativity, partiality and situatedness of research as a generative, contingent, and relational process. The selection of case study and elaboration of research questions is then discussed as the result of an iterative process of bringing into conversation theory-informed problematisations of the performativity of modelling and generative engagements with the field which productively unsettled these problematisations. A rationale for multi-sited ethnography is laid out followed by reflections on the specificity of ethnographies of technoscience particularly with respect to the epistemic generativity of role negotiations, questions of interactional expertise, and the digital mediation of presence in fieldwork. The chapter concludes by discussing the advantages and critically reflecting on the limitations posed by the methodological choices of this study.

Chapter 4 Contested future natures: embedding agent-based modelling into the knowledge infrastructures of fisheries management

More-than-rational fisheries modelling has to contend with fisheries management regimes that are the result of previous rationalisation efforts. This chapter examines the process by which more-than-rational modelling takes hold in the environmental knowledge infrastructures of fisheries management at the American West Coast. After elaborating theories of socio-technical imaginaries and infrastructural relations from science and technology studies and geography, the chapter proceeds to trace how agent-based modellers envision future marine governance by metaphorical trafficking between fisheries ecology and macroprudential regulation theory. The chapter theorises the actor category of "socialising the model" as a form of infrastructuring work which, by eliciting design proposals in conversations with elite actors in fisheries management, simultaneously engineers the material and social relations embedding agent-based modelling into the organisational arrangements between science and policy in West Coast fisheries management. These arrangements are examined as the result of settlements between diverse fisheries management actors investing credibility contests over calculative techniques with distributive stakes and as a result constraining the suite of permissible models in applied management. It is argued that efforts to embed agent-based modelling into the environmental knowledge infrastructures of fisheries management at the West Coast have to contend with competing enactments of future fisheries as either single-species resources or ecosystems which, in turn, has consequences for the design of credible models.

Chapter 5 Agile abstraction: circulating reference in computer simulation

Based on an ethnography of modelling with software, this chapter works towards a relational and materialist account of scientific representation in the context of computer simulation. A theory of scientific representation foregrounding material practices over the rational mind is augmented with two further literatures: first, an analytic of the relational materiality of boundary objects in order to account for the interdisciplinarity of modelling work and, second, media ecology as a concept evoking the lively materiality of scientific work in the digitally mediated environment of computer simulation. Through a detailed praxeography of an episode of modelling concerning the inscription of "habitat" into software code, the chapter examines the abstraction work by which an interdisciplinary team of modellers organises a chain of inscriptions circulating reference between model and target domains. Inscribing "habitat" into the Java programming language, the team has to coordinate collaboration between the differently equipped expert knowledge practices of marine science and software development. In contrast to field or laboratory science, the resulting chain of inscriptions in computer simulation circulates reference from language to code. It is argued that abstraction work activates agentic capacities enacting classificatory cuts in models by contingently crafting together layered affordances of heterogeneous materials including iteratively generated boundary objects, agile design methodologies, and object-oriented programming tools. The chapter concludes with reflections on the specific materiality of object-oriented programming in more-than-rational modelling.

Chapter 6 "This is a manager's tool!" Rationality, agency, and heterodox calculativeness

The more-than-rational agent is the central figure of agent-based modelling. After discussing how rationality and agency are at stake in two different algorithmic solutions for simulating locational choice of artificial fisher agents, this chapter describes a dispute between agent-based modellers about the conceptual underpinnings of different approaches to formalising agent decision-making. Although both sides in the dispute wish to eschew the mainstream economic theory of rational action, they disagree on questions of universality and purposiveness of more-than-rational decision-making in fisheries. Interrogating this dispute between a philosopher and an ecological economist in the modelling consortium discloses how both mainstream and heterodox economic theories of decision-making and their respective calculative techniques are inflected with normative issues. This empirical finding is then brought into a dialogue with the performativity programme in economic sociology. It is argued that, by universalising calculative agency, theorists of the performativity of economics divest economic calculativeness of its normative telos and cultural contingency, thus forfeiting critical potential to engage with the normative dimensions economic actors themselves grapple with. As a result, this chapter offers an empirically grounded contribution to debates about heterodoxy, normativity, and politics in the literature on pragmatist sociologies and geographies of market economies.

Chapter 7 Just add noise: the anti-politics of computational policy optimisation

Departing from an episode of ethnographic failure, this chapter takes two different senses of "noise" as the starting point of an interrogation of the anti-political potential of computational policy optimisation: noise as a distortion of information or noise as an index of the generativity of mediation. Modellers aim to increase the soundness of fisheries policy-making by employing simulation and machine learning techniques for the automated discovery of mathematically optimal environmental policies. The chapter argues that policy optimisation amounts to an expert problematisation of policy-making which turns on the translation of policies into parameters and political articulation into calculation. An ethnography of policy-making in action at the Pacific Fishery Management Council serves as the contrast against which the anti-political potential of policy optimisation is discussed. Drawing on materialist accounts of politics in geography and science and technolgy studies, the chapter details through a close examination of deliberations about fishing gear liberalisations across industry and scientific advisory bodies how fisheries policy-making proceeds as the articulation of issues characterised by irreconcilably antagonistic ties to the material worlds at stake in fisheries policy. The chapter argues that these antagonistic attachments to issues are irreducible to the rational deliberation of optimal policy alternatives. Rather than that, these issues are noisily articulated in the political clamour of mutual translations and enrolment efforts between industry, science, and regulators, suggesting an anti-political effect of policy optimisation devices framing political situations in such a way that the articulation of issues becomes limited.

Chapter 8 Conclusion

The concluding chapter draws together key findings of the empirical chapters and summarises their contribution to the theoretical literature in geography, science and technology studies, and economic sociology. I argue that the work of embedding more-than-rational modelling into the organisational arrangements of environmental management incorporates imaginative and infrastructural dimensions. In order to enlist support, modellers envision desirable environmental futures realised with the aid of the more-than-rational models they wish to develop. Offering an empirically grounded analysis of model co-production as infrastructuring work, I suggest that the entwinement of model construction and environmental policy-making can be fruitfully theorised by drawing together STS work on socio-technical imaginaries and a relational theory of infrastructure. A further finding offers a contribution to the pragmatist literature on scientific representation: I identify "agile abstraction" as a process with which interdisciplinary modellers collaborate for the circulation of reference. I highlight the difference of this representational work from field and laboratory science arising from the specific materiality of computation which simulation modellers have to negotiate and suggest ways in which STS and geographical scholarship on modelling might benefit from media theories of the socio-materiality of software. Arguing that environmental policy-making proceeds through irreducibly antagonistic articulations of material issues, I suggest that computational policy optimisation incorporates an anti-political dimension in its attempt at increasing the rationality of environmental policy. Based on the empirical finding that heterodox economists grapple with questions of difference and normativity in the design of calculative devices, I offer a critical revision of the concept "calculation" in the economic performativity literature and argue that the analytical framework of economic performativity effaces the specifically neoclassical roots of its concept of calculation. Summarising how the effacement of economic difference is practically entangled with the politics of knowledge in modelling, I discuss implications of this finding for geographical research on the difference calculative assemblages make for the marketisation of socio-natures. The chapter concludes with discussing "the loop" as an isomorphism between algorithmic logic and social organisation in computer simulation which suggests potentials for future research on the socio-materiality of cognition in more-than-rational modelling.

Chapter 2 **Literature review**

How might we approach the nexus between rationality, science, and the "human" suggested by the problematisation of human dimensions in the more-than-rational modelling efforts of economics and the environmental sciences? Decentering the rational human subject as prime mover of social process, geographical and feminist scholarship suggests an analytical shift towards materialities and practices informing a framework for approaching this problem. Cultural geographers have turned their attention towards questions of materiality, affect, and practice in order to produce more-than-human geographies (Whatmore, 2006). These geographies tend to share analytical commitments to examining materially mediated practices, attending to the agentic force of things, and mapping heterogenous socio-material assemblages. In so doing, they decenter the human subject, language, and meaning in favour of examining embodied encounters with material worlds; encounters in which what counts as "human" is made and remade through technoscientific and environmental practices. That is to say, more-than-human cultural geographies expand their scope to include the generative force of materialities for cultural processes that are no longer exclusively the result of reasoning human subjects. This analytical commitment to decentering the rational mind is shared by poststructuralist anti-humanism and feminist posthuman theory which, however, more forecefully call attention to the privileging of rationality in the philosophical and political project of humanism (Braidotti, 2016). The Western philosophical tradition of humanism, these literatures argue, has figured the human as a disembodied subject of rational thought. Identifying the particularity of claims to universal human reason, these critiques contend that a gendered and racialised indexing of reason to a norm of male European subjectivity historically justified the exclusion and oppression of the female and non-European others against whom the rational human subject became defined. By insisting on the embodied and embedded nature of thought, including scientific reasoning, poststructuralist anti-humanism and posthuman feminist theory gesture towards the more-than-human dimensions of rationality.

Whereas these strands of theory certainly raise exciting philosophical and urgent political questions, the aim of this chapter is more narrowly focussed in scope: this chapter will present literatures primarily drawn from across geography, science and technology studies, and economic sociology in order to discuss how they might aid examining the making of more-than-rational agents in scientific modelling practices and interrogating the material politics in which such efforts are implicated. The chapter is organised into three sections: the first section, Practicing Simulation, will discuss literatures from science and technology studies and geography stressing the pragmatic dimension of scientific modelling and querying its implication in the practices of policy-making. The second section, Performing Economies, reviews literature primarily drawn from, and in response to, the performativity programme in economic sociology which investigates how economic theory and models are put to work for the fabrication of economies. The final section, Rematerialising Politics, discusses attempts across science and technology studies and political geography to return to accounts of political process its material dimension, querying its implication for theories of the political. In lieu of a conclusion I will briefly indicate at the end of each section how subsequent chapters will take the reviewed literatures forward. Their differences notwithstanding, the literatures reviewed in this chapter share common concerns with the human and rationality addressed in more-than-human geographies and posthuman theories: these concerns include emphasis on materialities and practical performances as analytical devices for decentering the rational mind in accounts of scientific processes, examining the making of economic rationalities, and querying the limits of rationalist models of politics.

2.1 Practicing simulation

Modelling and simulation have received renewed attention by philosophers, historians, and sociologists of science. While philosophers and historians of science tend to ask entangled epistemological and historical questions of models in various scientific disciplines, the social studies of science investigate modelling practices with respect to their materiality, sociality, and politics. The former perspective examines how modellers reason about those aspects of the world represented by models. In contrast, the latter perspective explores dimensions of modelling exceeding concerns with reasoning and representation, extending to the material practices of model construction and the various uses of models in contexts that are not primarily epistemically oriented. In this section, I will at first briefly discuss how an epistemological perspective on economic modelling leads into questions of practice. After elaborating an analytical perspective on modelling forming part of a "practice turn" (Schatzki, 2001) in social theory, I will then move into discussing how work in the social studies of science and technology (STS) and geography might help to analyse modelling as a socio-material practice specifically in environmental management contexts.

Scholarship on the history of economic modelling illustrates the epistemological perspective on models. Noting the shift from verbal narrative accounts of the economy to model-based arguments in economics, historian Mary S. Morgan (2012:

5) asks how the discipline changed from "reasoning with words to reasoning with models" between its classical period and the late twentieth century and "what exactly is involved in scientific reasoning with such objects". Through a series of historical case studies on the construction of prominent models in economics, Morgan articulates a chiefly epistemological concern with models as working objects of economists. By way of their relational capacity as representational objects, economic models "function both as objects to enquire into and as objects to enquire with" (Morgan, 2012: 31). Models allow economists both to investigate model worlds in their own right through formal experimentation and to reason about the aspects of the world these models purport to represent through informal inferences expressed in verbal narrative. Over time, she argues, modelling changed the very manner in which economists perceive and reason about the world: in a tripartite process of, first, giving an account of the world in a formal and rule-bound model representation, second, working with this model as an instrument for experimentation which discloses new aspects of model worlds, and finally third, coming to perceive these new aspects in the world in a naturalised sense "where they no longer use those models to interpret the world, but they see those models at work in the world" (Morgan, 2012: 406). Rather than an isomorphic relation securing correspondence between model and world, Morgan suggests that it is the capacity for experimenting on representations through which modellers draw inferences from models. As a result, she emphasises the centrality of informal narrative for establishing the inferental link between model and world (Morgan, 2012: 408). Moreover, from the inside perspective of the economics discipline, correspondence need no longer necessarily be established in logical or scientifically rational terms (Morgan, 2012: 408). Rather than that, Morgan contends, economists secure correspondence through

a shared way of perceiving and reasoning with the help of models as well as a set of shared craft skills of model building the mastery of which bestows prestige as well as belonging to a discipline communally committed to building, and reasoning with, models (Morgan, 2012: 399).

However, scientific modelling raises questions beyond the capacity of models as tools for reasoning about the world. Morgan's emphasis on model building as both a craft and social undertaking gestures at a more-than-rational dimension of modelling: noting that "forming models is not driven by a logical process but rather involves the scientist's intuitive, imaginative, and creative qualities", she argues that "model-making is a skilled job" based not just on articulated, scientific knowledge but also "tacit, craft-based knowledge" (Morgan, 2012: 25). Moreover, economic models "offer recipes for acting directly in the world" (Morgan, 2012: 402) which carry a normative component when models are used for the creation and governance of markets or the justification of policy decisions. As a result, modelling raises not just epistemological questions about the ways in which modellers are able to make knowledge claims about those aspects of the world they model, but also about the social and material practice of modelling in its own right. An emerging literature in the social studies of science and technology takes on these latter questions.

Following a distinction proposed by Jasanoff (2004), the STS-informed literature on scientific modelling can be divided into two broad genres: first, a constitutive literature analysing the practices of scientists as they create models, and second, an interactionist literature querying the role of model practices in exchanges between scientists and other social actors such as policy-makers and publics. The first body of literature is concerned with, inter alia, the material affordances shaping the epistemic process of modelling (Knuuttila, 2005; Landström et al., 2013), the multivalent character of models relative to different actors and practices (Landström, Whatmore, & Lane, 2011; Merz, 1999), or their facilitating of interdisciplinary scientific work (Galison, 1996). The second body of literature is concerned with the mediating work between science, politics, and publics done by models, including their use in decision-making (Landström, Whatmore, Lane, et al., 2011; Svetlova & Dirksen, 2014), their role for coordinating between different actors (Sundberg, 2007; Van Egmond & Zeiss, 2010), and how model knowledges travel between science and politics (Jasanoff & Wynne, 1998). Recent geographical work conjoins constructivist and interactionist concerns, documenting how modelling as a practice straddles boundaries between knowledge production and application as well as science and politics respectively (e.g. Lane, Landström, & Whatmore, 2011). Following a brief exposition of the practice approach to scientific modelling, I shall discuss these constitutive and interactionist literatures in greater detail and suggest how their respective concerns may be complemented by drawing on further literatures from STS, software studies and geography.

Recent work in STS has begun to develop a practice-oriented approach to simulation. Rather than attempting to establish the epistemological status of modelling, this approach takes interest in computer models as objects in their own right which are constructed through, productively involved in, and supporting a variety of scientific practices (Knuuttila, Merz, & Mattila, 2006). This work builds on a development within science studies which from the 1980s onwards moved towards empirically studying "scientific practice, what scientists actually do" (Pickering, 1992: 2) rather than taking scientific knowledge to be the primary object of epistemological, or sociological, inquiry. This shift towards science-as-practice rather than science-as-knowledge focusses in particular on "the material dimension of practice" as part of rendering the "richness of doing science, the dense work of building instruments, planning, running, and interpreting experiments, elaborating theory, negotiating with laboratory managements, journals, grant-giving agencies and so on" (Pickering, 1992: 3). Attending to science as activity rather than representation, the practice approach tends to trouble binary distinctions between nature/society, subject/object, or knowledge/action: emphasising the contingent assembly and stabilisation of heterogeneous elements – "social, institutional, conceptual, material" (Pickering, 1992: 14) – in the situated practices of scientists, the practice approach both militates against notions of scientific knowledge as primarily structured by social interests or as the work of the rational mind producing representations of an external reality.

The practice approach in science studies has contributed to what some scholars designate a "practice turn" in social theory which encompasses a broad variety of accounts of "practices as embodied, materially mediated arrays of human activity centrally organised around shared practical understanding" (Schatzki, 2001: 11). Practice theorists tend to render accounts of activities as dependent on shared skills and understandings rather than being governed by explicit rules. In these accounts, nonhuman entities are taken to be woven into the sets of activities generating and stabilising social life. However, emphasis differs with respect to the attribution of agentic capacities to nonhuman entities: actor-network and posthuman theorists decenter the human subject of action, for instance by producing symmetrical accounts of agency as an effect of associations between heterogeneous human and nonhuman actants (Latour, 2005b). Other practice theorists, however, maintain "the relative unity and integrity of human agency" (Schatzki, 2001: 20). Nevertheless, the prioritisation of practices gives due place to the materiality of reasoning as an activity involving with the body and various objects more than the rational mind: from the practice-oriented perspective, knowledge exceeds the cognitive dimension, becoming "mediated both by interactions between people and by arrangements in the world" including "setups of the material environment" (Schatzki, 2001: 21).

Informed by the various theoretical dispositions grouped under the practice approach, STS studies explore the sociality and materiality of scientific modelling as a practice. Knuuttila et al. (2006: 8) summarise how these studies figure computer models as "results of interdisciplinary work" which require enlisting "many different resources" and whose "potential to mediate between different theories, scientific activities and social worlds needs to be carefully negotiated among the actors concerned". Interdisciplinary collaboration, heterogeneous resources shaping scientific knowledge-making, and material mediations between different actors as negotiated achievements emerge as central issues in practice-oriented research on scientific modelling. Moreover, claiming that models may "assume autonomous agency" (Knuuttila et al., 2006: 8), the authors single out the issue of agency in particular for research on modelling.

On the question of materiality and agency in modelling, Knuuttila (2005; see also Knuuttila & Voutilainen, 2003) has advanced the concept "epistemic artefact" to account for the manner in which models as artificially constructed material things shape the knowledge practices of modellers: models are epistemically generative on account of the materially embodied affordances they offer to the exploratory practices of modellers. The term affordance has been proposed by Gibson (1979) as a way of accounting for the relation between environment and organism: material properties of an environment invite some activities and perceptions of an organism and constrain others, which he takes to imply that meaning is to be located neither in objective properties of materials nor in subjective capacities of organisms but rather in specific relations between organism and environment. Knuuttila (2005: 58) appropriates the term affordances in order to account for the way in which "the materiality of an artefact constrains the uses to which it can be put". Co-constituting agentic capacities by enabling some actions and constraining others, models as artefacts invite modellers to explore their affordances and in the process generate new problems and knowledges (Knuuttila, 2005: 48). Figuring models as epistemic artefacts builds on Rheinberger's (2005) notion of the "epistemic thing". Focussing on the material dimension of scientific knowledge-production, Rheinberger (2005: 406) proposes thinking of the scientific objects explored in experimental setups as elusive and underdetermined material things whose epistemic productivity is due to their "preliminarity ... what we do not yet know about them", thus provoking their further exploration and investment with meaning. Rheinberger (2005: 409) holds epistemic things to be distinct from technical objects which are known and stabilised as "the frozen product of former epistemic activity". However, Knuuttila's proposal to think of models as epistemic artefacts takes into account their technicity: whereas in experimental research the as-yet-unknown behaviours of the epistemic thing provoke active exploration and the making of new knowledge, in the case of exploring the behaviour of models their affordances are results of intentional and skillful prior technical constructions (Knuuttila, 2005: 35).

The material difference between experimentation and modelling leads Landström et al. (2013) to examine how learning proceeds in computer modelling practices. Taking as a starting point the novelty of simulation as a scientific practice, they argue that "computer simulation does not physically interact with the phenomenon, rather it takes abstractions of the material world, in the form of mathematical formulations of physical laws, and sees how they behave in combination, through computer code" (Landström et al., 2013: 680). This shifts simulation from a practice of creating new scientific knowledge, and hence an epistemological concern, to a practice of learning best conceived in a performative sense wherein the "doing" of modelling becomes epistemically generative in a sense that is not reducible to establishing a representational relation between model and world. Whereas learning in computer simulation does not encounter the physical constraints necessary for scientific knowledge-making in experimental settings, it nevertheless proceeds along the exploration of material constraints specific to the use of computational tools. The environmental models upon whose construction Landström et al. (2013) reflect incorporate affordances as productive obstacles around which modellers improvise and in the process learn about the environments they model. Rather than being effortlessly malleable, models incorporate obduracies forcing modellers to reflect and deploy their specific skills and resources for exploring different paths forwards in order to achieve their aims. These obduracies stem from the character of computational models as complex socio-technical networks incorporating many interdependent elements where changes in single elements proliferate across the network, posing obstacles to attempts at manipulating the system. In this productive improvisation around material obstacles lies the generative materiality of modelling which, however, is to be understood as a relational effect between modeller and model: "affordances link to obstacles via an actor with appropriate expertise to improvise in the situation" (Landström et al., 2013: 689).

In the concept of affordances, materiality and relationality thus come to the fore as key dimensions aiding an analysis of modelling practices. However, Knuuttila (2005) operates with a concept of affordances predicated on a notion of material properties as objective physical concreteness. Ingold (2007) proposes a more relational and processual ontology of material properties. Redirecting analytical attention from the being of a thing to its becoming, Ingold cautions against ascribing essential characteristics to materials, instead rendering them dynamic in the sense that materials “partake in the very process of the world's ongoing generation and regeneration” (2007: 9). Insofar as they are part of environments in which perception takes place, the properties of materials “cannot be identified as fixed, essential attributes of things” but rather must be “practically experienced” (Ingold 2007: 14) and rendered intelligible in accounts of unfolding relational processes. Such an emphasis on relationality and processuality reorients analysis towards the dynamic unfolding of a model's capacities within varying practices and places of modelling.

The relational materiality of models leads into questions how models are enacted as different objects in different activities and, by extension, how model-based forms of expertise are enacted within different material setups and activities. On the first question, Merz’ (1999) study of modelling in particle physics argues for understanding models as multivalent objects. Expanding on Rheinberger’s distinction between epistemic things and technical objects, Merz identifies different modes of modelling which enact models in different ways. Simultaneously epistemic objects, whose open-endedness and unpredictable behaviour potentially generates new knowledge, and technological things, remaining black-boxed as applications of taken-for-granted knowledge, models are different kinds of objects relative to the ways in which different actors are interested in them. Theorising different object conceptions with respect to modelling, Merz argues for a relational ontology of models contingent on the specific settings and their practical requirements, e.g. authorship and use, in which models come to matter. In a similar vein, Landström and Whatmore (2014) classify different modes of modelling in their study of flood risk management. However, they are specifically interested in extending the concept of expertise to include the material setups and practices involved in the making of specific forms of flood risk expertise. Landström and Whatmore (2014) identify different socio-material relationships and attendant knowledge making practices participating in the making of flood risk expertise: the first is a mode of "virtual engineering" in which commercial consultants engage with models as standardised, proprietary software packages. The consultants do not work directly with the mathematics formalising the general dynamics of flooding, rather they adapt black-boxed models incorporating these dynamics to local parameters within tight institutional and cost constraints of public commissioning in Britain. The second modality is "mathematical experimentation" carried out by university scientists. Flood models, here, are primarily mathematical objects incorporating formalisations of different disciplinary commitments and theories, produced with the aim of making complex physical phenomena intellectually tractable, and always requiring further improvement and development. Attending to relationality and materiality in modelling practices works towards understanding the more-than-rational dimensions of model construction:

exceeding the cognitive domain, modelling expertise incorporates material setups and practical skills.

From an interactionist perspective, a different set of literatures in STS and geography stresses the entanglement of science and policy in model production and use. These studies expand the scope from investigating scientific practices of modelling towards including the practices in which models come to matter for the making of policy and management decisions. In contrast to rationalist notions of policy-making that would posit a linear model by which science furnishes evidence on the basis of which policy is made (Fischer, 1989, 2003), these studies suggest a nonlinear relation between modelling and policy-making marked by ambiguities and porous boundaries. In the context of environmental modelling Jasanoff and Wynne (1998) argue that models and policy are co-produced. That is to say, rather than policy-makers "rationally apply(ing) the products of science to formulating policy responses“ (Jasanoff & Wynne, 1998: 2), the very production of scientific models as well as their success in informing policy and gaining assent is shaped by the political contexts in which scientific modelling takes place. Instead of assuming a linear model of science informing policy, co-productionist analyses of modelling suggest attending to the simulteanous construction of epistemic and political order in the process of model development and use. Written in in order to complement the work of the Intergovernmental Panel on Climate Change from a social science perspective, Jasanoff and Wynne's (1998) examination of issues in climate modelling highlights recurrent problems that subsequent studies on environmental modelling would further investigate in other contexts. These include the different functions environmental models have relative to science and policy as well as the manner in which modellers may key their design choices to the specific demands decision-making places on model-based evidence.

Modelling promises policy-makers potentials for governing complex phenomena through their systematic analysis. However, attempts at translating epistemic authority into political authority have to grapple with "ambiguities in the design of models" which raise "issues about their use in policy-making" (Jasanoff & Wynne, 1998: 7). Models are different things in science and policy: whereas scientists may share an understanding of models as "cognitive heuristics that help advance theoretical diagnosis and understanding", in policy settings these "same models may instead be treated as truth machines, capable of producing realistic representations and authoritative predictions for policy" (Jasanoff & Wynne, 1998: 62). Demands for justifying decisions placed upon policy-makers may "stifle free expressions of uncertainty" (Jasanoff & Wynne, 1998: 62), leading modellers to deliberately emphasise or downplay model uncertainty depending on the audience to whom they narrate the significance of model results.

In addition to shaping the narratives rendering model results meaningful, the specific demands of policy settings may also shape scientific decisions in model design. Indeed, some practitioners are keenly aware of the different properties enabling models to effectively enrol policy actors in different stages of the policy-making process (Daalen, Dresen, & Janssen, 2002). Models developed for policy audiences may be characterised by a "reduction of complexity and flattening of variablity" (Jasanoff & Wynne, 1998: 62). Such reductions can arise from attempts at rendering more salient those variables scientists assume to be controllable by policy-makers, making models reflect "modelers' prior conceptions of feasible points of intervention and management" (Jasanoff & Wynne, 1998: 61). In her investigation of ecological modelling for biodiversity conservation, Dempsey (2016) reports a similar observation when relating a paradox ecologists face when attempting to render their work legible to governance institutions. Embracing complexity in the form of stochastic and nonlinear relations in ecosystems, ecologists however face pressure to exclude complexity from policy-relevant models:

> Ecologists want to make politics more rational, science-based and attentive to complexities and unknowns so as to help societies 'make better decisions' but the institutions they aim to influence ... demand simple knowledge and sound bites; they demand a kind of science that seems to be quite unscientific (Dempsey, 2016: 115).

Dempsey critiques an undue imposition of political constraints onto scientific modelling practices arising from the tension between ecologists' complex understandings of socio-ecologies and liberal governance institutions' demands for simplicity and uncertainty reduction. Attempts to resolve this tension tend to focus on investments into more expertise and new models rather than either critiquing the logic by which liberal governance institutions diffuse responsibility or making explicit fundamental epistemic limitations posed by complex systems (Dempsey, 2016: 21). However, Jasanoff and Wynne (1998: 62) suggest a more nuanced and multi-directional account of the mutual shaping of model and policy: pragmatic choices on the part of modellers regarding technical feasibility and resource constraints can in turn shape policy-makers' beliefs "as to what can reasonably be predicted" and governed: if policy-relevant models incorporate a certain instrumentalism justifying unreasonable expectations about potentials of controlling modelled phenomena, this might also be underwritten by simplifying assumptions embodied in models which are results of pragmatic decisions made in the process of model construction. Jasanoff and Wynne caution against a naturalisation effect following from the invisibility of such practical contingencies of modelling to policy audiences: to the extent that contingent assumptions and pragmatic exigencies of modelling remain unexamined by policy audiences, models become "deployed and reproduced without explication or critical reflection, as if they were natural, that is, contained entirely within the realm of scientifically produced knowledge" (Jasanoff & Wynne, 1998: 76).

Further studies suggest exploring the specific characteristics of the management contexts in which models are put to work in order to account for the entwinement of scientific modelling and policy-making. For instance, Lane et al. (2011: 1804) demonstrate in the context of British flood risk assessment and management practices how "scientific analysis is strongly entwined with both policy ... and management". Rather than risk modelling remaining independent from risk management, the "suite of practices" (Lane et al., 2011: 1786) comprising risk analysis is shaped by the demand to express risk in the monetary terms in which it can be enlisted to justify management interventions. In turn, this restricts the range of modelling methodologies and possible environmental futures considered in scientific analysis. Svetlova and Dirksen (2014: 561) argue that models incorporated into "areas which are not solely epistemically oriented" raise questions hitherto left unadressed by the practice-oriented literature on scientific modelling. These questions arise from the specific demands of the decision-making situations in which model results underwrite decisions which gives modelling for decision-making two distinct characteristics: first, the entwinement of modelling and decision-making is irreducible to a linear transfer of scientific expertise into political authority, suggesting an expanded notion of policy decision-making that includes choices made already in the commissioning and design of models. Second, the fatefulness of decisions may place a high demand for legitimisation and justification on managers and policy-makers which in turn shapes model development practices. Consequently, the authors call for reorienting analytic attention towards "the roles of model users and their prospective purposes, as well as the importance of internal and external audiences, processes of judgment, justification, and negotiation" (Svetlova & Dirksen, 2014: 563). As decision situations are characterised by the "fatefulness" of achieving closure in a situation of indeterminacy, questions of legitimisation, justification, and acceptance of model-based knowledge claims become particularly prominent, especially when there is "a need to justify model results and related decisions to a much broader audience than in the field of science" (Svetlova & Dirksen, 2014: 566). In the context of modelling for decision-making, strict separations between model development in the scientific realm and model use in policy should not be assumed: as "scientific and practical criteria and interests are intertwined" in model development, studies of modelling practices in policy contexts should attend to the ways in which "scientific aspects may derive from this 'working life'" (Svetlova & Dirksen, 2014: 563) of models. Noting that few studies exist which address modelling from this analytical perspective, the authors call for tracing the circulation of models through different organisational settings and documenting their different uses and characteristics (Svetlova & Dirksen, 2014: 573).

Subsequent chapters will expand on these literatures, investigating agent-based modelling as a materially mediated practice implicated in the political contexts in which models are put to work. In chapter five, the analytical focus on materiality and relationality suggested by the practice-oriented literature on modelling will inform a materialist ethnography of the interdisciplinary work of environmental modellers as they collaboratively "abstract" entities and digitally render them in software code. However, the chapter will draw on an additional set of literatures from new media studies (Fuller, 2005; Goffey & Fuller, 2012; Mackenzie, 2006) in order to contribute to the practice-oriented literature on modelling an account of computer simulation practices attuned to the specific materiality of informational environments. The co-productionist literature casts doubt on a rationalist notion of the relationship between modelling and policy-making, suggesting instead analytical attention to the specific characteristics of the management settings which may shape design choices of modellers. Consequently, investigation of the practical entwinement of science and policy in agent-based modelling for fisheries management is spread over several chapters of this thesis. Chapter four in particular argues on behalf of the analytical contribution scholarship on infrastructures (Blok et al., 2016; Slota & Bowker, 2017; Star, 1999) can make to theorising how the specific science-policy relations obtaining in the fisheries management organisations in which models are put to work are related to their material affordances and constrain the suite of models permitted to inform policy decisions. In addition, chapter seven documents how the resolution of a dispute between modellers about different approaches to formalising a more-than-rational economic agent had been informed by the management context of the model. The next section will turn to a set of literatures engaging the question of economic agency and rationality.

2.2 Performing economies

Rationality forms a point of contention between economists and sociologists: assumed in economics and declared to be reductive by sociology, rational action has become the focus of attempts to theorise the economy as a performative effect of economic knowledges and practices. After briefly outlining a sociological perspective on the study of the economy, the main part of this section will review literatures drawn from across economic sociology and geography that take aim at the work economic knowledges and calculative practices do for the fabrication of various economies. The question of rational action as a performative effect of calculative devices will be discussed with a view towards how the literature on economic performativity attends to the possibility of economic difference.

Economic sociologists distinguish their specifically sociological perspective on the economy from that of economic science by stressing the embeddedness of economic actors and action in wider social relations (Swedberg & Smelser, 2005). Opposed to the methodological individualism holding sway over mainstream economic theory, economic sociologists understand the economic actor as a socially constructed entity embedded within relations with other actors in society, formatted by power, and invested with meaning. Similar differences obtain with respect to economic action. Whereas mainstream economic theory explains economic outcomes by axiomatically assuming rational action in the sense of individual optimising behaviour, economic sociologists tend to allow for different rationalities beyond optimisation and take rational action as a phenomenon to be explained.

The neglect of the embeddednes of economic actors, actions, and by extension, markets in economically consequential social relations is a common critique levelled at economic theory by economic sociologists. Indeed, in recent economic sociology embeddedness serves as the "core concept indicating a sociological approach to the economy" (Beckert, 2007: 7). First proposed by Polanyi (1957), embeddedness descriptively refers to the institutional anchoring of any form of economic exchange and prescriptively serves to argue for the regulation of market economies in order to avoid social instability. Later elaboration has shifted this meaning of embeddedness. In a programmatic paper, Granovetter (1985) intervenes in a debate about economic action between economists and sociologists. He argues that the embeddedness of economic actors in social networks, and by extension the structure of these networks, shapes economic outcomes rather than economic action being either reducible to axiomatic assumptions about rationality or entirely determined by social norms. Rejecting what he considers to be under- and over-socialised accounts of economic action in economics and sociology, respectively, Granovetter (1985: 487) argues that

> Actors do not behave or decide as atoms outside a social context, nor do they adhere slavishly to a script written for them by the particular intersection of social categories that they happen to occupy. Their attempts at purposive action are instead embedded in concrete, ongoing systems of social relations.

This relational, rather than institutional, notion of embeddedness should prove highly influential for the distinct conceptualisation of economic action in economic sociology. More recently, economic sociologists have turned towards considering the role economic knowledges and materiality play in formatting the actions taking place in the empirical economies which both economists and economic sociologists claim to study. Informed by the social study of science and technology as well as actor-network theory, economic sociologists have started to theorise the "material embeddedness" (Pinch & Swedberg, 2008: 6) of economic action, foregrounding the panoply of artefacts populating empirical economies and the variety of devices equipping economic action. As socio-material hybrids, these artefacts and devices form part of the fabric of relations in which economic action is embedded, generating specific agentic capacities when incorporated into heterogeneous, socio-technical assemblages that "work together in the choreography of any modern economy" (Pinch & Swedberg, 2008: 11). Moreover, moving beyond questions of representation, this new materialist economic sociology draws on theories of the performativity of scientific knowledge practices elaborated in science and technology studies in order to investigate, in Michel Callon's (1998) turn of phrase, the "embeddedness of economic markets in economics". Rather than dismissing economics as reductive, the literature comprising this attempt at rematerialising economic sociology brings into focus how economic knowledges are performed through socio-material practices involving a variety of calculative devices. The remainder of this section will discuss in more detail this materialist and performative approach to economic sociology, paying particular attention to its treatment of economic difference.

The economy, Mitchell (2008) writes, is a relatively recent invention. Beginning in the mid-twentieth century, his argument goes, the term economy began to no longer exclusively refer to a practice of stewarding, but increasingly to a distinct and bounded object of knowledge and power. Capacities for both conceiving of and administering this new object were a result of calculative practices. Simultaneously technical and economic, calculative practices are central to Mitchell's account of the construction of socio-technical networks which make up the infrastructures supporting the flow of goods, services, information, and money: "forms of technical calculation, distribution and the control of flows, addressing, accounting and billing, and much more helped to constitute the world that would gradually take shape and be identified as the economy" (Mitchell, 2008: 1119). Economists had a role to play in the making of the economy. Rather than merely describing an economic reality taking shape independently, the economics discipline helped "devise the forms of calculation in terms of which new kinds of socio-technical practice were organized, to monitor these forms of practice as though they formed a self-regulating system, and to put forward rival accounts of how the system worked" (Mitchell, 2008: 1116-1117). The plurality of calculative devices supporting accounts of the economy, and the rivalling projects of organising socio-technical networks in which they are embroiled, point towards the analytical possibility of de-essentialising the economy: what counts as economic, and what shape any given economy takes, is the historically contingent outcome of competing projects. In these projects, successful calculative devices are not necessarily those that fulfil certain mathematical criteria, but rather those that aid the imagination and practical construction of techno-economic networks and help "persuade others that they are superior to rival models and calculations" (Mitchell, 2008: 1118). From this perspective, which takes the ordering work of calculation as a starting point, the economy comes into view as "a project, or a series of competing projects, of rival attempts to establish metrological regimes, based upon new technologies of organization, measurement, calculation, and representation" (Mitchell, 2008: 1120).

In his study on the making of modern Egypt, Mitchell (2002) illustrates how the Egyptian economy materially and discursively emerged from practices enacting a "new politics of calculation" and proceeded to operate through a "series of boundaries, distinctions, exceptions and exclusions" (Mitchell, 2002: 8-9). Cadastral maps, statistics, surveys, technical knowledge developed in response to infrastructure projects as well as novel evidentiary practices provoked by courts adjudicating property disputes brought into being new ways of knowing social actors, quantities, and equivalences that created the economy both as an epistemic object and as a series of socially binding and materially inscribed distinctions between the "monetary and nonmonetary, national and foreign, consumption and investment, public and private, nature and technology, tangible and intangible, owner and nonowner" (Mitchell, 2002: 9). Tracing how the establishment of colonial order in Egypt proceeded through the development of economic and technical knowledges, Mitchell emphasises how Western claims about modernisation as the universal progress of reason were founded on the systematic exclusion and silencing of the colonised and nonhuman Other. The conception of an Egyptian economy as a separate realm, subject to universal laws which are accessible to human reason, by colonial and postcolonial elites alike presupposed the discursive erasure both of the violence involved in establishing specific social and spatial relations in Egypt and the agentic contributions of nonhuman actors which stabilised these relations, giving them their specificity and contingency. Representational practices of distancing, such as the production of national statistics and maps, take centre stage in Mitchell's account of the emergence of the Egyptian economy as a novel object of knowledge. However, insisting on the material force of representations on account of their orienting function for social action, Mitchell militates against understanding the making of an economy as a discursive process alone. Instead, he argues that new "forms of calculation (...) did not emerge as a new representation of existing realities, but in new arrangements that would help simplify the world into reality and its calculation" (Mitchell, 2002: 95). That is to say, Mitchell gestures at the performativity of economic knowledge practices. Yet Mitchell also alerts us to the absences, silences, and excluded differences in the process of constituting the boundedness of the economy as a realm of calculation. The "constitutive outside"

(Mitchell, 2002: 291) of the economy has to be held in place by law, politics and policing, and in the Egyptian case examined, frequent violent exclusion, in order to contain that which would disturb and interrupt economic calculation.

Perhaps because of the debt it owes to a Foucauldian (2004) genealogy of the mutual constitution of objects of knowledge and technologies of power, Mitchell's analysis of the emergence of the economy as an effect of calculative techniques emphasises the historical contingency of what eventually comes to be known and administered as the economy. His work is in conversation with a performative turn in economic sociology. Rather than assuming the economy to exist independently from its representation in economics, the theory of performativity aims to explain how the work of economists partakes in the enactment of what counts as economic (Butler, 2010). Drawing on speech act theory, the performative turn in economic sociology understands the theories, models, and calculative techniques of economists as forming part of discursive acts that help to bring into being the very economic phenomena which economics purports to represent. De-essentialising the economy as an effect of repeated performative acts, the theory of performativity implies the possibility of economic difference. However, this possibility has seen divergent treatments in scholarship on economic performativity. In what follows, I will first review a geographical literature which foregrounds the plurality of economic knowledges for a performative politics of economic difference. Then I will discuss how the school of economic sociology following Michel Callon tends to privilege mainstream economics in its focus on the prosthetics equipping rational action in market economies.

In conversation with economic sociology and feminist theory, a geographical research programme on economic diversity brings the economy into view as a "contested terrain" and "an effect of various kinds of performativity" (St Martin, Roelvink, & Gibson-Graham, 2015: 1). Rethinking the economy as a site of difference rather than a social totality motivates geographical and other social research that intervenes into local arrangements that make up the economy as "a field with a variety of potentials that is open to experimentation" (St Martin et al., 2015: 1). In this programme, the performativity of economic knowledges becomes both an analytical frame for thinking about economic process and underwrites a reflexive, normative commitment to transformative social research into, and frequently in collaboration with actors in, local economies. Conceived during academic debates about capitalist globalisation in the 1990s, this programme had been originally motivated by a feminist critique of what geographers J.K. Gibson-Graham (1996) called "capitalocentrism" which they identified as the tendency within primarily Marxist accounts to represent global capitalism as a social totality. In a poststructuralist gesture, Gibson-Graham proceed to deconstruct capitalism as the dominant term in a capitalist/noncapitalist binary system, enlisting inter alia feminist economics to demonstrate with the continued persistence, if not prevalence, of noncapitalist forms of labour, enterprise, and surplus distribution the implausibility of the assumption that globalisation rendered capitalism an all-encompassing, hegemonic mode of production. Theirs is an anti-essentialist project of theorising capitalism as relationally constituted, partial, plural, and fragmented. The capitalist economy emerges as a "set of practices scattered over a landscape" (Gibson-Graham, 1996: 254) rather than a systemic whole, figuring capitalism as one among many coexisting or contending ways of doing economy within a "world of economic difference"

(Gibson-Graham, 1996: 3). Allying poststructuralist theory with a normative commitment to anti-capitalist economic alterity, Gibson-Graham (1996: 7) stress the "performative force of economic representation", placing economic knowledge-making practices centre stage in an unabashedly activist project of knowing capitalism differently in order to contribute to the enactment of other economies.

The early outline of the economic diversity research programme mainly trained its critique on the disempowering effects of totalising representations of capitalism (Gibson-Graham, 1996). Later elaborations engaged more closely with theories of performativity, including the Callon school of economic sociology as a "complementary counterpoint" (St Martin et al., 2015: 7), in order to pursue participatory action research with local communities for the experimental construction of socio-technical assemblages with the potential to enact economic alterity. In the latter regard, geographical work with fishing communities in New England stands out as a particularly relevant example for the purpose of this thesis. Deploying a strategy of "reading for difference" (Gibson-Graham, 2008), Snyder and St Martin (2015) examine the diverse and competing rationalities obtaining in fishing communities and fisheries management at the Northeast Atlantic coast. Whereas the bioeconomic models underwriting fisheries management regimes figure fishers as individual entrepreneurs maximising their profits according to the axiomatic assumption of rational action, Snyder & St Martin (2015) recover divergent rationalities of kinship, collective identity, and stewardship motivating fishing behaviour. While rendered invisible by fisheries economics and its calculative practices, these diverse ways of reasoning about fishing persist alongside, and trouble, notions of a singular and homogeneous economic rationality. The authors acknowledge the performative efficacy of the neoclassical models of human dimensions incorporated into fisheries management assemblages which foreground "the motivations and profits of individual fishers rather than the needs and well-being of fishing communities" (Snyder & St Martin, 2015: 30). Noting their effect of displacing "nonrational logics of how fish are known by fishers" (Snyder & St Martin, 2015: 30), Snyder and St Martin engage fishing communities in participatory research for the construction of different calculative devices foregrounding community and environmental concerns. Their report on the participatory assembling of a heterogeneous network comprising calculative devices such as fishing and habitat maps as well as community shares and other elements which eventually enacted a community-supported fisheries economy in Port Clyde, Maine, reads as a study of rivalry between calculative devices which pays its analytical dues to the historical contingency of economic performances. Snyder & St Martin (2015: 48) urge those working on the performativity of economic knowledges to account for economic difference:

> To focus only on what has become hegemonic would, however, only produce knowledge about what is hegemonic, thereby leaving us with greatly impoverished economic imaginations.

However, this commitment towards economic difference is less present in the studies comprising the school of economic sociology associated with the work of Michel Callon. These studies bring into view the manner in which the theories, models, and calculative devices furnished by the economics discipline are not independent from, but rather constitutive of, empirical economies. Tracing how economic theories, models, and devices are involved in the construction of empirical economies, the performativity programme in economic sociology understands economies as enacted through socio-technical practices of which the knowledge practices of economists form a crucial part (Callon, 2007; MacKenzie, 2006). Informed by the social studies of science and technology, Michel Callon (1998) formulated a programmatic intervention into economic sociology which should contribute to its performative turn. In this intervention, Callon questions what he perceives as a weak critique sociologists had hitherto levelled at economics, namely that economic theories would be overly abstract and dismissive of the empirical richness of social and cultural relations in which economic action is embedded. In an analytical move analogous to the social study of science (cf. Barry & Slater, 2002), Callon (1998) claims that the knowledge practices of economists, rather than unduly abstracting from the empirical richness of an independent social reality, instead materially format and produce their knowledge objects. Like other sciences, then, economics comes into view as performative:

> Economics, in the broad sense of the term, performs, shapes, and formats the economy, rather than observing how it functions (Callon, 1998: 2).

In a play on the Polanyian concept of the embeddedness of markets in societies, Callon argues that the "economy is embedded not in society but in economics, provided one incorporates within economics all the knowledge and practices, so often denigrated, that make up for example accounting and marketing" (Callon, 1998: 30). Empirically investigating the performativity of economics, then, entails following the work of economists in this expanded sense. Highlighting the empirical centrality for the performativity perspective of academic economics and business studies, Callon claims that the performation of the economy "is largely carried out through the intervention of professional economists" (Callon, 1998: 30) who devise and circulate the theories, models, and calculative devices which come to equip the actions of economic actors and form part of the socio-technical infrastructure of markets.

The performativity programme theorises economic action as formatted by the calculative tools equipping economic actors. Taking agency to be an effect of heterogeneous actor-networks (cf. Latour, 2005), the technical design of markets and the devices equipping economic actors come into view as producing calculative agency. Calculative agency, for Callon (1998: 4), is the capacity to order the world in such a way that optimisation becomes possible:

> For an agent to be able to calculate – i.e. to rank – her decisions, she must at least be able to draw up a list of actions that she can undertake, and describe the effects of these actions on the world in which she is situated. This presupposes the existence in organised form of all the relevant information on different states of the world and on the consequences of all conceivable courses of action and the access of all this information to the agent. Thus she will not only be able to get an idea of possible goals and rank them, but also mobilise the resources required to attain them.

This definition of calculative agency, or calculativeness, conforms to the definition of rational action in neoclassical economics. In his 1998 introduction to a programmatic anthology on economic performativity, Callon acknowledges in a footnote the compatibility of his concept of calculativeness to the theory of rational action, claiming however that it is broader in scope because it is "defining the conditions in which rational action can emerge" (Callon, 1998: 52). Callon lifts his notion of calculativeness from the writings of economist Oliver Williamson who, in turn, defines calculativeness with reference to Gary Becker's (1976) work on the "economic approach". This genealogy of calculativeness, a modality of action which Callon accepts as indexing the economic, merits some closer attention. For Becker, the economic approach is an analytical method with three axiomatic assumptions about social actors, namely 1) that they exhibit maximising behaviour, 2) that they will coordinate with some form of market, and 3) that their preferences remain unchanged. Indeed, as Becker claims, the economic approach views "all human behaviour ... as involving participants who maximise their utility from a stable set of preferences and accumulate an optimal amount of information and other inputs in a variety of markets" (Becker, 1976: 14). These assumptions are consistent with the theory of rational action in neoclassical economics (of which Becker is of course a major proponent). The theory of rational action incorporates both a description and normative prescription of social action as a form of optimisation for the achievement of individual preferences (Ermakoff, 2017). Rational action originates in the neoclassical school of thought which became dominant in the economics discipline during the latter half of the twentieth century (Amadae, 2003). Drawing on actor-network theory, the performativity programme after Callon proceeds to decenter and de-essentialise the rational actor of neoclassical economics, explaining calculative capacities as effects of heterogeneous actor-networks (Michel Callon, 1999). From this relational materialist and processual perspective, calculative capacities to order, rank, and optimise depend on the tools and devices enlisted into the network of an economic actor. These devices allow operations of framing, i.e. the ordering of relations "which makes it possible to provide a clear list of the entities, states of the world, possible actions and expected outcome of these actions" (Callon, 1999: 190). Rather than inhering in an essential sense in an economic actor, rational action is rendered an achievement crucially dependent on the calculative equipment an economic actor brings to the market. It stands to reason, then, to interpret Callon's analytical programme as an attempt to denaturalise the rational actor of neoclassical economics from a constructivist perspective.

However, this specific definition of calculative agency as the capacity to act in such a way as to perform the neoclassical theory of rational action, while acknowledged by Callon (1998) in his initial proposal, is obscured in the literature that later elaborated the performativity programme. In Callon's (1999) later development of the actor-network theory approach to calculative agency, the indebtedness of his definition of calculative agency to neoclassical economics can still be traced by following his references from Williamson to Becker. Yet in Callon and Muniesa's (2005) theory of markets as collective calculative devices, calculation is divested of its roots in neoclassical theory and instead rendered a non-specific material practice of ordering devoid of its initially normative and prescriptive inflection as maximisation. With reference to the anthropology of everyday mathematics, Callon and Muniesa define calculation in "a very general" way deliberately set apart from numerical or quantitative operations as "establishing distinctions between things or states of the world, and by imagining and estimating courses of action associated with those things or with those states as well as their consequences" (Callon & Muniesa, 2005: 1231). Explicitly distinguishing their definition of calculation from judgment, they go on to define calculation as a series of material practices by which things and states are detached from their relations, framed as distinct entities in a calculative space, and subjected to transformations and manipulations in such a way that an evaluative result can be obtained. Capacities for "isolating objects from their contexts, grouping them in the same frame, establishing original relations between them, classifying them and summing them up" (Callon & Muniesa, 2005: 1232) are generated through associating human actors with the calculative equipment that allows market transactions to occur as relational processes co-constructing preference sets and qualified goods or services. This definition of calculation remains entirely consistent with the neoclassical theory of rational choice and its axiomatic of a rational actor with ordered, coherent, and transitive preferences and the capacity to estimate which course of action will realise that which is most preferred by the actor. However, Callon and Muniesa's redefinition of calculativeness obscures the ties to neoclassical economics which had still been visible in the earliest proposals for an ANT-informed anthropology of economic agency. This elision remains unproblematised throughout the later elaborations of the performativity programme. In what follows I will discuss two literatures that followed in the wake of the performative turn: firstly, a literature in the social studies of finance investigating the performativity of financial modelling, and secondly, a literature on market devices which informs geographical work on market-based environmental governance and fisheries economies.

Elaborating the performativity thesis, the social studies of finance empirically investigate the construction of economic agents and the performativity of financial modelling. Mackenzie (2009) highlights the materiality of economic action, noting the performative agency of the tools equipping actors on financial markets. Because embodied actors have limited cognitive capacities to process information, they enlist

> conceptual tools that simplify the cognitive task of grasping what is going on in a market (...) such a tool is more than a representation of a market: it is a constitutive part of economic action, shaping such action and its consequences for economic processes (Mackenzie, 2009: 3).

Mackenzie's (2006a) landmark historiography of derivative markets investigates how the Black-Scholes model of option pricing became a constitutive part of the actions of financial traders, performing the market for derivatives in such a way that market prices eventually corresponded to their prediction in the underlying model. In this sense, the financial model "did more than analyse markets; it altered them" (Mackenzie, 2006a: 12) by circulating in the form of theoretical price sheets equipping the actions of financial traders and becoming part of market infrastructures through its incorporation into trading software. Yet he concedes that the performativity of an economic theory or model is difficult to evidence empirically, involving some form of observation before and after and a degree of conjecture as to the causal relation operative in the change of states (Mackenzie, 2006a: 21).

While Mackenzie shares with Callon a distributed notion of agency and a decentered theory of the economic actor, Mackenzie's concept of performativity is more circumspect and differentiated as to the efficacy of market performativity. Mackenzie (2006a: 16) distinguishes between three levels of performativity: first, generic performativity in which an aspect of economics is performed in the sense of being used in an economic practice by a market participant, regulator or policy maker. Second, effective performativity in which an aspect of economics, by being used, makes a difference in an economic process. And third, strong economic performativity (in the sense of a perlocutionary utterance suggested by speech act theory) where economics succeeds at speaking its theory into being, altering economic processes "in ways that bear on their conformity to the aspect of economics in question" (Mackenzie, 2006a: 18). This more differentiated notion of performativity affords professional economists and their knowledge practices a less heroic role, instead suggesting the multi-directional interplay of agencies in the process of performing economic theory: practitioners, too, are held to have influence on the construction of economic models and economic theory might only affect markets to the degree that it is successfully integrated into the infrastructures formatting market action (Mackenzie, 2006a: 250). The extent to which incumbent economic infrastructures allow for the embedding of novel calculative devices, then, takes on a crucial role for enabling or constraining the performative agency of economic theory and models. Indeed, later studies of financial modelling found that model performativity varies strongly between settings and type of model, being contingent on modalities of use shaped by different calculative cultures which bestow on quantitative analysis varying degrees of authority and salience (Svetlova, 2012).

Another set of literatures elaborates the performativity thesis by investigating processes of "economisation" (Çalışkan & Callon, 2009, 2010) and the various "market devices" (Muniesa et al., 2007) involved in the construction of market economies. While following in the wake the performative turn, these literatures can be distinguished from earlier work on the performativity of economics by their methodological choice to start in medias res of empirical markets, tracing the socio-technical networks subtending market action (Pellandini-Simányi, 2016). Economisation research investigates the formation of economies through the operations of economizing processes incorporating economic theories, institutional and technical arrangements which generate specific capacities for action and cognition, and objects whose materiality shapes the modalities of their valuation (Çalışkan & Callon, 2010: 2). Proposing to investigate how devices and technical practices such as accounting methods, financial analysis, metrics etc. subtend contemporary market economies, this literature takes aim at the construction and maintenance of materialities as stable, exchangeable goods, the arrangements realising calculative capacities of different actors competing in the definition and valuation of goods, and the performative mechanisms by which representations of market economies contribute to their very formation. Moving from substance to process, the influence of Deleuzian philosophy on this attempt to de-essentialise the economy as an effect of economising processes is perhaps most visible in the concept of the economising *agencement*. Elaborating on the Foucauldian (Foucault, 1978) concept of the *dispositif* or apparatus as a material-discursive network with subjectivating effects, Deleuze (2006) locates the subject within the network, placing human and nonhuman elements on the same ontological plane. An economising agencement, or market device, is a heterogeneous network of human and nonhuman elements that "renders things, behaviours and processes economic" (Muniesa et al., 2007: 3). Influential beyond economic sociology, the literature on market devices and economic performativity has informed analyses of market-based environmental governance and natural resource management.

Specific to the process of rendering nonhuman nature economic, studies in STS, geography and political ecology have investigated the calculative practices through which market-based environmental governance is enacted. Noting the work necessary to render nonhuman nature qualifiable, commensurable, and exchangeable, these studies bring into focus the techniques involved in constituting markets for catch quotas (Holm & Nielsen, 2007), carbon credits (Mackenzie, 2009), biodiversity offsets (Dempsey, 2016), wetland credits (Nost, 2015), and other ecosystem services (Dempsey & Robertson, 2012). These practices of "enterprising nature" (Dempsey, 2016) lead to a proliferation of calculative devices which attempt to tame unruly materialities by rendering "the qualities of ecosystems, and rich socioecological relations, into representative forms that can be compared, ranked, and ordered quantitatively" (Dempsey, 2016: 10). For instance, the construction of markets for carbon emission permits involves designing a socio-technical assemblage incorporating measurement devices and intricate accounting techniques for rendering emissions from different sources commensurable and exchangeable (Mackenzie, 2009). A literature on resource materialities investigates the process by which materials are made ready for exploitation and trade as stabilised and qualified natural resource commodities (Richardson & Weszkalnys, 2014). This literature examines the work of market devices as they pacify materials by disentangling them from the multiple relations in which they are embedded, defining and stabilizing a set of relations which qualify materials as resources, and placing conflicting relations outside of the frame. A series of studies on North Atlantic fisheries examines the simultaneous performance of fish as tradeable resource and fishers as rational actors. The assembly of an economising agencement incorporating tradeable property rights, electronic catch share exchanges, population forecasting models, electronic vessel monitoring systems, etc. transformed the fishery from a largely unregulated subsistence economy into a market embedded in transnational networks of distribution and regulation (Holm & Nielsen, 2007; Johnsen, Holm, Sinclair, & Bavington, 2009). The new set of relations into which the calculative apparatuses of fisheries management entangled fisherfolk and fish did not leave their ontologies intact but performed them as rational actors and single-species biomass, respectively, with the important qualification added that this transformation remains partial and troubled by an unruly nature making itself known in higher fish mortality than predicted. In contrast, Hébert (2014: 23) suggests that market devices do not always "mesh felicitously" with other historically stabilised arrangements: in the case of commercial salmon fisheries in southwest Alaska, the framings attempted via the introduction of exchangeable property rights were contested. She attributes their eventual failure to competing strong attachments to a regime of non-exchangeable fishing permits allowing fisherfolk a stronger position against other market actors and the clash of qualification techniques for upmarket salmon with traditional catch and indigenous food preparation habits. As a consequence, Hébert points towards "layers of history" (2014: 28) resisting the performative work of market devices:

historically stabilised cultural practices may oppose the performances of economic models underpinning techno-economic regimes of fisheries management.

The performativity programme in economic sociology has been met with criticism which challenged its narrow focus on the performativity of neoclassical economics enacting market economies (Lezaun, 2017), its neglect of the differences and controversies within the economics discipline (Mirowski & Nik-Kah, 2007), and the central place it affords the knowledge practices of economists (Bryan et al., 2012) which sidelines the work of political actors co-performing economies in contested ways (Blok, 2011). In chapter six, I will examine a dispute between heterodox economic modellers with a view to making an empirically informed contribution to this literature that critically revisits the concept of calculation, drawing out how difference and normativity are at stake in devising the calculative capacities of more-than-rational agents. Discussing the theoretical implications of these findings, chapter eight will attempt to bring a geographical literature on neoliberalisation into a dialogue with concerns about economic difference.

2.3 Rematerialising politics

This section reviews a set of literatures drawn from across political geography, science and technology studies, and democratic theory which together suggest an analytical framework attuned to the more-than-rational dimension of fisheries governance. Radical democratic theory understands the moment of the political as articulating irreconcilable antagonisms that cannot be resolved through technical analysis or rational deliberation, but rather need to be decided in the medium of power. Science and technology studies examine the instability and contentiousness of the scientific facts underwriting technical analysis, rendering matters of nature as political concerns. Work in political geography examines how political devices format and organise dispute about contested materialities. In what follows I wish to bring these literatures into a dialogue in order to sketch an analytical framework for examining the articulation of political conflict irreducible to divergent ways of reasoning about contested materials but also involving ways of being practically implicated in them.

It is a peculiarity of Western modernity, Latour (1993) argues, to separate the two realms of nature and society and then declare each domain to be subject to a fundamentally different regime of representation. Whereas natural kinds come to be represented by science as a practice purporting to disinterestedly disclose transhistorical laws governing a universal natural domain, politics concerns itself with the representation of historically contingent and conflicting interests in societies riven with divergent interpretations and open to future change. This modern constitution of separate realms of nature and society is explained as the result of practices of purification sorting hybrid networks of nonhumans and humans into distinct categories authorising science and politics, respectively, to speak on their behalf. However, Latour (2004) claims, the constant proliferation of socio-natural hybrids through the transformative work of technoscience (cf. Haraway, 1987) as well as environmentalist practice troubles the modernist work of purification: novel technological artefacts as well as environmental issues resist their classification as either natural or social, blurring the distinction between the representational regimes of science and politics. As a consequence, Latour gestures at a political theory oriented towards the ubiquity and relationality of nonhuman kinds in human affairs.

Such a theory would eschew the modernist distinction between an objective and uncontestable nature disclosed by science and a subjective and contested society governed by politics. Instead it would aim to account for messy objects, hybrid matters of concern, risky entanglements of humans and nonhumans, and the proliferation of "imbroglios of science, politics, economy, law, religion, technology, fiction" (Latour, 1993: 2) in technoscientific cultures.

Attempting to account for the materiality of political life, Latour (2005a) emphasises that both scientific and political representation take work: speaking on behalf of universal nature or the general public rests on mediating procedures which, on closer inspection, betray the facilitation of both political and scientific claims by complex representational machinery. Political theory, Latour argues, has only accounted for the procedures facilitating the assembly of diverse human interests in a general will; the social studies of science, he claims, may aid in understanding that science, too, deploys practical procedures to render diverse nonhuman entities as a singular nature. Rendering these scientific procedures visible would shift the objects of politics from stable and singular matters of fact authorised by science towards contested and plural "matters of concern" which "bind all of us in ways that map out a public space profoundly different from what is usually recognised under the label of the 'political'" (Latour, 2005a: 15). Latour's call to consider problematic technoscientific and environmental objects as matters of concern extends to abandoning unity and totality as organising principles of political theory and instead pluralise the collectivities of an "object-oriented democracy" (Latour, 2005a: 26). Matters of concern gather in themselves conflicting interests, polyvalent meanings and divergent material attachments in heterogeneous tangles rather than providing a universally shared factual basis for the negotiation of interests. As a consequence, Latour sketches a tableau of political life comprised of multiple, heterogeneous collectivities of humans and nonhumans rather than the binary realms of nature and society.

Responding to the call for a rematerialisation of political theory, geographers have emphasised the constitutive role of material entities and processes in social and political life. Braun and Whatmore (2010) emphasise the agentic capacities of nonhuman entities partaking in the constitution of the common world with which political theory is concerned. Echoing Latour's diagnosis of the proliferation of hybrids in technoscientific cultures, Braun and Whatmore (2010: x) suggest that "the potency of technological objects and more-than-human agents in the fabric of political association and social conduct has been increasingly evident". Going beyond concerns with the proliferation of hybrid matters of concern as occasions of political deliberation, Braun and Whatmore introduce a useful distinction into thinking about the role of materiality in political life. Materials are doubly constitutive: gathering publics around their controversial capacities, objects co-constitute political collectivities; formatting the conduct of politics, techniques equip political action (Braun & Whatmore, 2010: xv). Thus rendered active participants in political process, the indeterminate agentic capacities of nonhuman entities contingent on their relations to other entities raises anew the question of the nature and place of the political no longer conceivable in exclusively human terms:

> What, and where, is the 'political' when emergent properties cannot be predicted, when all the actors cannot be known in advance, and when immanent causality necessarily bedevils political calculation? (Braun & Whatmore, 2010: xxiii)

Recent work in political geography and science and technology studies has elaborated on the doubly constitutive role of materials in political life. In what follows I wish to discuss two approaches theorising the technologies equipping political practices and the political processes sparked by contested objects. Barry (2002) proposes the notion of political devices to describe the material dimension of political action. Similar to the way in which market devices equip economic agents, political devices comprise "a whole array of material devices and forms of knowledge which serve to frame political action“ (Barry, 2002: 269). From this perspective, politics could be seen as a matter of technical experts such as policy analysts and their respective calculative equipment and practices which would stand in contrast to approaches to politics that emphasise struggle and conflict over the technical work of administration. However, Barry contends that politics involves both protest and procedure: "Politics, after all, is both about contestation and the containment of contestation" (2002: 270). Drawing on radical democratic theory, Barry (2002: 270) distinguishes between politics as a "set of technical practices, forms of knowledge and institutions" and the political as an "index of the space of disagreement". An analysis of the technologies of politics, then, would interrogate a given political device as to its work of politicising or de-politicising a situation, i.e. whether it "opens up the possibility for disagreement" (Barry, 2002: 270). Legislation, technical regulation, and calculation then come into view as specifically equipped practices which harbor anti-political potentials for containing and limiting disagreement about political matters and processing them into order. However, these practices might also occasion moments of the political in the sense of disagreement and conflict: the technoscientific practices of measurement on which the enactment of calculation and regulation depend incorporate instabilities and ambiguities upon which political actors might seize to articulate disagreement with broader concerns (Barry, 2002: 280). With regards to the entanglement of politics and economics, then, analysing the operation of political devices can be read as an attempt to interrogate the (anti-)political work necessary for purifying and pacifying a space of the economic. That is to say, it takes work to regularise economic conduct in such a way that it remains undisturbed from the intrusion of political contestation (Barry, 2002: 273).

The distinction between politics and the political is drawn from the work of Chantal Mouffe (2000, 2005). Responding to what she perceives as a crisis of liberal democracies, Mouffe argues that contemporary political practices, and the liberal political theories legitimating them, obscure the antagonistic character of political collectivity by privileging consensus and compromise over conflict and contestation. Through a poststructuralist reading of the Schmittian distinction between friend and enemy as the distinction proper to politics, Mouffe argues that the necessarily exclusionary practices of othering constitutive to the formation of any collective identity introduce an irreducibly antagonistic dimension into politics. For Mouffe, a situation is properly political if it allows for the articulation of these irreconcilable antagonisms. Politics, on the other hand, denotes the practices containing and processing these antagonisms into order.

Whereas Mouffe figures the antagonistic dimension of the political in discursive terms, Barry (2013) attempts to return a sense of materiality to political articulations. Materials, he argues, are enriched with information produced about their properties. Science and technology studies figure material properties as relational, dynamic, and contingent on different knowledge practices (cf. Mol, 2002). As a result, disagreement about material properties may proliferate into public knowledge controversies (cf. Whatmore, 2009). In these controversies, multiple forms of expertise stand in conflict in such a way that decisions might have to be taken without a firm factual ground in which to anchor political consensus. As a result, Barry (2013: 12) argues that

> material objects should not be thought of as the stable ground on which the instabilities generated by disputes between human actors are played out; rather, they should be understood as forming an integral element of evolving controversies.

In this sense, an irreducibly antagonistic dimension is returned to political processes in which the relational properties of materials are at stake (Barry, 2013: 7-8). The operations of various political devices for organising dispute about material properties can then be analysed with a view to the extent to which they open or foreclose the articulation of dissensus and antagonism.

Whereas Barry's notion of informationally enriched materials incorporates a performative understanding of material ontologies drawn from science and technology studies, the antagonistic articulations he identifies primarily play out in the realm of regimes of measurement and various documentary and evidentiary practices comprising a politics of knowledge about materials. In what follows, I wish to sketch a further dimension of relational materiality from which the political in the sense of antagonistic collectivities may issue. In material politics, I will suggest, irreconcilable ways of being practically implicated in materials can be at stake that contribute a more-than-rational dimension to disagreement about contested materials.

Concerned with the problem of public involvement in technoscientific controversies, Marres (2007) argues that the inability of formal procedures and institutions to contain the overflowing effects of technoscientific objects makes their democratic accommodation necessary. Central to her argument is the notion of issue which she develops from her reading of the American pragmatist tradition of democratic theory. In this tradition, the formation of democratic publics is intimately linked to the emergence of problems which affect actors who are not responsible for but jointly implicated in the problem. Marres reads this model of public formation through an object-oriented lens. In this view, the material entities produced by the technosciences emerge as relational and multivalent matters of concern (cf. Latour, 2005) to which different actors bring different problematisations and ways of being affected. These problematisations need to be actively articulated with material entities, leading her to speak of issues, rather than problems, which spark the organisation of democratic publics to the extent that "existing institutions cannot settle" (Marres, 2007: 770) their controversial effects. To be sure, Marres is chiefly concerned with the proof that a democratic politics of public involvement is warranted by the very materiality of technoscientific controversies rather than a normative commitment to broadening inclusivity and civic participation. However, her analysis of the dynamic by which issues overflowing institutional containment spark democratic publics into being can be read alongside Barry's concern with the manner in which political devices process controversy into order. Exceeding the institutional containment of the proliferating relations of materials, then, the moment of issue articulation which Marres takes to index the formation of democratic publics could under certain conditions occasion the articulation of dissensus which Barry takes to index the domain of the political.

These conditions have to do with the practices through which public involvement is enacted. Here, political devices organising the procedures of conflict and consensus come into play. Yet they also have to do with the nature of issues. Issues are "entanglements of actor's attachments" (Marres, 2007: 775), that is, issues incorporate different relations between human and nonhuman entities. The specific quality of these relations can be a source of conflict because "actors are jointly and antagonistically implicated in issues" (Marres, 2007: 773). That is to say, publics form not necessarily as a community of identically affected actors but their formation may bring into relief the way in which "partly *exclusive* (my emphasis) associations are entangled in issues" (Marres, 2007: 773). These associations exceed the different knowledges brought to objects, extending to "material, physical, and technical associations" (Marres, 2007: 773) which might be mutually exclusive between different groups of actors. It is precisely in this mutual exclusivity of material ties entangled in issues where potentials for the political in the sense of antagonistic articulations lie. The antagonism inherent to the formation of collectivity, which Mouffe takes to be the dimension of the political, and which Barry locates in knowledge controversies about materials, might also be found in attachments to materials playing out on the plane of divergent ways of being with materials in addition to different ways of knowing them.

In her critique of rationalist models of democratic deliberation, Mouffe (2000) similarly gestures at a more-than-rational dimension of political controversy: enlisting Wittgensteinian philosophy, she argues that "types of practices" rather than "forms of argumentation" are the connective tissue of political association, posing an ontological rather than epistemic limit to the possibility of rational consensus

(Mouffe, 2000: 11). Whereas her argument concerns whether agreement is grounded in reason or shared forms of life, it also suggests attending to the inextricable entanglement of practices and knowledges sparking the articulation of antagonistic ways of being with materials rather than material politics playing out on a primarily epistemic plane. In chapter seven, I will explore how such an approach to the materiality of politics might help examine an episode of fisheries policy-making as a way of querying the anti-political dimension of computational policy optimisation.

Chapter 3 **Methodology**

"How do you make sure that your own presence doesn't bias your observation?" This question was put to me by an ecological modeller at the end of a lab talk about my doctoral research. I had been invited to give this talk to a group of scientists at a marine research centre in Southern California. In the preceding weeks, the group had allowed me to observe their work and interview lab members. In return they wished to hear more about my research. Answering the ecologist's question in any detail would have meant explicitly questioning its underlying epistemological assumptions. However, it was late on a Friday afternoon and the lab members in the audience were already shuffling around in their seats in anticipation of a well-deserved weekend. Running out of time, I made a joke about the methodological importance of being nice to the people one encounters in the field and then briefly shared a few more serious thoughts about reflexivity in ethnography. Judging from the look on the face of the ecologist, it would be fair to assume that I did not leave him with the impression that my research could produce anything more valuable than a series of anecdotes.

His question deserves a proper answer. A specific constructivist tradition in social studies of science and technology would engage this question by emphasising the manner in which an observer's practices are not independent from, but rather in manifold ways entangled with, if not co-constitutive of, the phenomena being represented. This focus on the ontological productivity of scientific knowledge practices is one of the features which distinguish this tradition from a social constructivism after the semiotic turn that would engage primarily with the epistemic, reducing problems of knowledge to questions of discourse and having little to say about the material worlds which discursive practices help to perform (Latour, 1993). I wish to broadly situate my study within this tradition. Moving from representation towards performance entails empirically tracing the material and epistemic practices through which knowledge objects are enacted (Barad, 2003). Laboratory studies in STS have produced praxeographies of the ways in which the natural sciences co-perform nonhuman entities as technoscientific objects which come alive as active participants in social processes (Latour, 1987, 2005b). As the joints by which nature might be carved are not prior to but rather the results of differently configured epistemic practices, the multiplicity of possible ontologies demands active coordination and negotiation between different ways of figuring and performing the world (Mol, 2002). In these negotiations, pretensions to objectivity would obscure the partiality of any knowledge claim on account of its situatedness in historically contingent social and material relations (Haraway, 1988). Methods geared towards identifying clearly delineated sets of determinate processes might render inaccessible a world of elusive realities, distributed phenomena, heterogeneity and variation (Law, 2004: 6). Finally, the question as to how ways of knowing affect the world thus rendered knowable is posed with particular poignancy in relation to social research. Representational devices asserting specific social realities can begin to circulate and orient the actions and self-understandings of social actors, requiring particular care on the part of researchers towards the differences their accounts might make to the realities they co-constitute in and through their investigations (de la Bellacasa, 2012; Law, 2009).

A brief but forthright answer to the ecologist's question, then, might be formulated as such: I doubt that bias is a helpful category because all knowledge is made by someone, from somewhere, and with particular means. Rendering the position from where I produce knowledge explicit by carefully giving an account not only of what I observed but also of the social and material relations that allowed me to observe it, I open my knowledge production up to critical interrogation and to being called to account for the partiality of my claims about the world. The following chapter works towards detailing a more elaborate answer and drawing out its methodological implications. If the object of this study is best conceived of as knowledge-making in a performative rather than representational sense, then it would befit this chapter to demonstrate methodological reflection on the research process as generative, contingent, and relational rather than documenting an exercise in representational distancing and algorithmic rule execution. No longer can the object of research be imagined as existing independently from the theories and methods brought to bear on it. Indeed, neat distinctions between a passive field which discloses its inherent truths to the analytic activities of a researcher are rendered problematic by taking into account the multiple productive associations forged between researcher and the researched, as well as the objects, tools, methods and theories mobilised whilst engaging in research.

3.1 Problematising simulation

The generativity of productive associations between researcher and field was certainly on display when the formulation of the research problem for this study underwent some changes in response to initial exploratory engagements with the field in which I was interested. This had consequences both for the development of the research questions and the selection of the eventual case study. I shall discuss these in turn.

Initially I started out with a problem formulation grounded in the literature on the performativity of knowledge practices and, more specifically, the performativity of economic modelling (Callon, 2007; Mackenzie, 2006). Empirically I was interested in a relatively novel form of computational simulation, namely agent-based modelling. This substantive interest developed from my previous master's research on the biopolitics of artificial life and complex systems simulations (Peters, 2012) and was further driven by the increased attention agent-based modelling received at the time in the scientific literature, some of which had been authored by researchers at my home institution who were developing large-scale agent-based models of American and European markets (CRISIS, 2014). Hence my initial problem formulation can be summarised thus: since there are well-documented cases of the performativity of mainstream economic models in the literature, to what extent could agent-based modelling be said to perform different economies? Moreover, I wished to focus on agent-based modelling of socio-ecological systems, departing from the established literature on the performativity of economic models by explicitly considering the manner in which the more-than-human world comes to be represented, and perhaps shaped, through modelling practices. Attending to questions of nonhuman agency, I was interested in studying how lively materialities shape both digital modelling practices themselves (Knuuttila, 2005; Landström et al., 2013) and might also possibly affect the efficacy of socio-ecological modellers to perform their knowledge objects.

These seemed to be exciting questions, however the search for an apposite setting and case to study them raised two issues. Firstly, models take considerable time to construct and circulate. Studying the performativity of agent-based modelling in the strict sense (of a successful perlocutionary utterance, see MacKenzie, 2006) would have entailed either pursuing a historiographical study which turned out to be limited by the relative novelty of agent-based modelling and a relative scarcity of ABM that are operational in applied management. On the other hand, interviewing modellers drawn from a number of different agent-based modelling projects would certainly have limited the extent to which I could have gained more sustained access for observing the material practice of modelling. Another possibility still would have been a longitudinal ethnographic study which, however, was limited by the three-year funding period of my doctoral grant. Secondly, when I started scoping for candidate cases by engaging in exploratory conversations with agent-based modellers, I realised that my interlocutors were rarely the kinds of academic economists in whom the performativity literature in economic sociology seemed chiefly interested. Rather than that, my interlocutors tended to be trained in other scientific disciplines such as physics, ecology or computer science and, while often confidently conversant in economic theory, were located outside of university economics departments, frequently taking issue with the doxa of mainstream academic economics. In short, they were doing heterodox economics. Often pursuing applied research projects in some form of collaboration with partners in the worlds they modelled, these heterodox economists differed from the economists I had encountered in the literature and their practices raised different theoretical and substantive questions. These questions exceeded my initial interest in the pragmatics of computational modelling, extending to issues of inter- and transdisciplinary collaboration and the politics of computational methods in the context of environmental governance.

These two issues encountered in the exploratory phase of my research became consequential for the formulation of my research problem. Rather than imposing my theory-informed problematisation on a field which turned out to have more things going on than I had initially thought (Lykke, Markussen, & Olesen, 2000), I opted to let the empirical richness and contingency which I encountered in these initial conversations with modellers affect and modify my research questions and categories as well as the subsequent selection of my case. As a result, I reformulated my research objectives from understanding how agent-based modelling performs different economies in the strict and narrow sense towards a more open-ended exploration of the manner in which heterodox economic modelling takes hold in environmental management practices, the ways in which the materiality of computation might affect both the interdisciplinary work of modelling and efforts to embed computational models into incumbent environmental knowledge infrastructures, and the difference heterodox economic modelling might make for the production of socio-natures in practices of environmental governance.

3.2 The case of agent-based modelling for fisheries management

After surveying a number of candidate cases, eventually I selected the case of an international consortium formed by researchers from several universities in Britain and the United States and a major US-based marine conservation nonprofit. The consortium had been formed at the time to apply for a multi-year grant from a British university-based funding body which had called for proposals addressing global commons problems. As part of a broader project proposal problematising marine resources as global commons, the consortium was responsible for delivering a work package on agent-based socio-ecological modelling and computational policy optimisation for the management of global fisheries. I discuss the formation of the consortium and its specific problematisation of marine resource governance in greater detail in the first empirical chapter.

The case fulfilled a number of both practical and methodologically important criteria. In practical terms, access could be relatively easily facilitated by my supervisors who introduced me to the principal investigator of the consortium. At that time the consortium was in an initial project stage which allowed me to observe, rather than having to reconstruct, how early decisions were made that shaped the development of the project. The language spoken in the consortium was English, as was the language in the project area, the groundfish fisheries of the California Current at the American West Coast, that the consortium would be focussing on in its early modelling work. Access, time frame, and language being important criteria for making the case study practically feasible, the consortium case also fulfilled a number of criteria which made it relevant in relation to conceptual problems of natural resource management and scientific modelling. Expecting the case of the consortium to offer particularly rich detail, I followed an information-oriented case selection strategy that chooses for increasing the utility of the information gained from a single case, e.g. by selecting a case that deviates from the exemplar cases established in a field of research (Flyvbjerg, 2006). Characterisable as a deviant case, agent-based modelling for fisheries management is unusual with respect to the established literatures to which my research objectives speak: because it involves a transdisciplinary research design and heterodox economic modelling, the case is unusual with respect to the established literature on the performativity of economic modelling; because of its strong focus on computational social science methods, it differs from the cases usually considered in the STS and geography literature on modelling and environmental governance. Finally, engaging from a constructivist perspective with the way a widely recognised global environmental problem such as overfishing comes to be computationally known and governed would add empirical relevance to the case in the context of an increasing digitisation of environmental science and governance (cf. Adams, 2018).

Fisheries management, of course, is a case of natural resource management and as such heavily reliant on economic theory and modelling. In fact, historically it was in relation to problems of fisheries management that economic theory such as the tragedy of the commons (Hardin, 1968) and methods such as bioeconomic modelling, which later came to be paradigmatic for other domains of natural resource management, had been first developed (Hubbard, 2014). I elaborate this particular point in chapter four. However, scientific management of fisheries has seen repeated failures to fulfil its promises with overfishing being widely regarded as a global environmental problem (Global Ocean Commission, 2014). The case of fisheries management has been previously studied as an exemplar of economic performativity particularly with respect to the way market-based environmental governance formats human-environment relations. These studies have documented the performance of maritime resource economies through socio-technical assemblages of mainstream economic theories and calculative devices for enacting private property in fisheries resources (Hébert, 2014; Holm & Nielsen, 2007). Investigating the performativity of mainstream economics for natural resource economics, these studies are in line with the series of exemplar case studies which together comprise the performativity programme in economic sociology (Callon, 2007; Muniesa et al., 2007).

The case of the consortium, however, presents a deviation from these exemplars, offering a richly detailed empirical setting in which to query some of the tenets of the performativity programme. The project which the consortium pursued falls into the domain of heterodox economics, assembling actors from outside of the economics discipline to construct an economic model. This configuration of actors, knowledges and techniques has so far been understudied in the performativity programme in economic sociology and cognate studies in geography which typically start from academic economics proper and then follow their theory production downstream to empirical markets or, alternatively, start in medias res of empirical market economies, tracing the assemblages that make them work (Pellandini-Simányi, 2016). In addition to its heterodoxy and interdisciplinarity, the consortium is also transdisciplinary in the sense that consortium members themselves wished to move beyond the confines of scientific representation, liasing instead with the conservation nonprofit and other partners to embed the model into a decision-support tool for natural resource managers to apply for the governance of those empirical resource economies which the modellers claimed to represent. Especially in environmental research, this style of research design is becoming more frequent and raises questions about the pragmatics and politics of transdisciplinary collaboration (Landström, 2017). Particularly with respect to modelling, it raises further questions about the construction of models in relation to their contexts of use in decision-making (Svetlova & Dirksen, 2014). A further criterion for the selection of this case was the ability to empirically observe the production of software code for the model.

Computational models run on software which in scientific contexts might be purpose-built for specific modelling projects. However in social studies of scientific modelling the production of software typically remains blackboxed (for a rare exception see Gramelsberger, 2006). I further elaborate on this point in chapter five. Bringing the production of software into focus, the case would allow me to test the purchase of pragmatic theories of scientific representation on the specific case of computational science and to query how the materiality of computation might affect relations between scientific and policy actors in the context of constructing environmental knowledge infrastructures.

3.3 Ethnographic reflections

In an important because generative sense I had already engaged with the field during the exploratory stage in spring and summer 2015 which led me to revisit the initial formulation of my research problem and to the eventual selection of the consortium as the setting for my case study. Engaging in those consequential conversations with modellers meant already entering the field. Massey (2003) argues for an understanding of fieldwork that does not situate the field as separate from the researcher, passively awaiting his or her inscriptions and validating his or her truth claims, but rather as a process of co-generating research materials. Thinking in terms of relationality and process helps avoiding a spatio-temporal imaginary of the field as something out there, over yonder, frequently also backwards; an imaginary authorising distancing moves which entrench a hierarchical relation between the researcher and the researched (Haraway, 1988). In addition to being normatively questionable, such an imaginary is particularly difficult to uphold when studying the world of technoscience (Forsythe, 2001). Geographically and culturally close to the lifeworld of the ethnographer, technoscientific field sites merge with the home of the researcher and fieldwork is no longer as strictly temporally bounded. Attention to relationality and process, moreover, implies conceptualising the field as linking different places, scales and points in time as it unfolds in the research process of tracing networks of associations (Whatmore 2003: 93). Rather than assuming phenomena to possess qualitatively different characteristics at micro/meso/macro-scales, such a research strategy traces the associations linking entities across scales and locations, and seeks to foreground "the vehicle, the movements, the shifts and the translation between loci rather than the loci themselves" (Latour 2005: 196). Hence, tracing modelling-in-action meant adopting a multi-sited research strategy of "follow(ing) the thing" (Marcus 1995: 106) as the model took shape within the various relations it became embedded in at different places and points in time.

A form of multi-sited ethnography combining participatory observation with qualitative interviews and document analysis seemed best suited for investigating the work modelling does as it connects multiple sites, actors, objects, and practices (Hess, 2007; Hine, 2007; Marcus, 1995). Hinting at the performativity of mapping connections between disparate locations, Marcus suggests that the "chains, paths, threads, conjunctures, or juxtapositions of locations" (1995: 105) established through the very act of conducting a multi-sited ethnography in fact define its argument that a coherent phenomenon traversing multiple locations and scales does indeed exist; an argument resonating with Latour's (2005) description of the process of tracing an actor-network as a form of co-performation. During my fieldwork, the choices which associations to trace and places to go were shaped by practical contingencies such as access, time and travel funds, the research participant's own account of the importance of that association or place to their work, and my theory-informed expectations that something empirically rich as well as analytically generative might be found following a particular actor. The methodological injunction of actor-network theory to "follow the actor“ (Latour, 2005b) tends to translate into a snowball sampling strategy with which researchers explore a social network through referral. However, in this case particular care has to be taken to avoid exclusive focus on human actors, which would contradict the methodological principle of general symmetry (Callon, 1986). Moreover, in tracing a socio-technical network, decisions about in- and exclusion are necessarily involved, calling for ethico-political reflection on the part of researchers in order to avoid the privileging of managerial accounts (McLean & Hassard, 2004; Strathern, 1996). I discuss an occasion where the latter consideration became particularly salient further below. In the following section I will first give a chronological account of my multi-sited ethnography of technoscience, detailing how specific engagements generated research materials (Whatmore, 2003). Then I will proceed to reflect more in-depth on specific dimensions of ethnography in the world of technoscience with respect to the generativity of role negotiations, questions of expertise and learning in participant observation, and the digital mediation of presence in fieldwork.

In the spring of 2015 one of my doctoral supervisors introduced me to the principal investigator of the consortium based at a major research university in England. A physical geographer, he agreed to sponsor my access to the consortium and introduced me via email to the rest of the team he was working with. At that time, the consortium was in the process of applying for a major grant. Some preparatory meetings had resulted in a series of white papers detailing the motivation for the consortium project and the team was now in the middle of finalising the grant proposal for the submission process. In the following months I met the principal investigator several times for hour-long in-depth interviews during which I interviewed him about his perspective on the motivations, objectives, work plans, and the structure of the consortium. As they took place during the process of acquiring project funding, these interviews often turned into me acting as a sounding board for the principal investigator who seemed happy to treat the interview situations partly as rehearsals for the persuasive strategies needed to gain project funding. As frequently happens during interviews with academic elites, the interview situation at times took on a tutorial character during which the interviewee sees it necessary to impart specialised technical knowledge on the interviewer (Stephens, 2007). While this tutorial character made it easier to frame the research relationship in terms familiar to both interviewer and interviewee, it also meant that at times I had to expend some effort to refocus the interviews on the questions I was interested in.

As with all of the in-depth interviews I conducted during my research, these interviews were semi-structured, allowing interviewees to unfold an open-ended narrative which I occasionally steered back towards my research questions with the aid of a list of interview topics prepared in advance of each meeting (Ayres, 2008). I recorded and transcribed interviews whenever possible. A full list of interviews can be found in the appendix. Together with white papers and versions of the grant proposal, these transcripts of my interviews with the principal investigator provided the core materials to which I returned when writing about imagining and infrastructuring human dimensions in fisheries management in chapter four. Notes from these interviews, particularly about comments of the principal investigator regarding which actors he considered to be important to enlist for his project, also provided guidance as to which associations to follow and explore in later stages of my fieldwork. In addition to these interviews I also participated in meetings with American counterparts and phone conferences with prospective project partners.

Beginning in October 2015, the first hire joined the consortium. A postdoctoral research assistant tasked with developing the software base of the model, he should become my primary interlocutor for the following months when we met weekly for hour-long in-depth interviews during which he explained his coding work to me in addition to occasional work shadowing. I reflect in more depth on role negotiations and the relational construction of code literacy in an environment of performing highly specialised technical skill below. At the time, the postdoc was the sole project member apart from the principal investigator on the British side of the consortium and seemed keen to find in me an interlocutor with whom to share not only the results of his work but who also took an interest in the details of the process with which he developed those results. He often updated me on new developments within the consortium and facilitated my access to important materials such as the code base of the model and internal project documents. His main collaborators at the time were located in California and much of the collaborative work he engaged in took place in computer-mediated communication environments. I reflect below on the specificity of doing fieldwork in such digitally mediated settings. The research materials my engagements during this time generated were traces of this collaborative work in the form of screenshots from groupware conversations within the team, code excerpts, and transcripts of interviews with the postdoc. These materials provided the empirical grounds on which I develop my argument on interdisciplinarity and abstraction work in chapter five.

In March 2016 I set off to visit several sites in the United States. I conducted fieldwork at sites of environmental management, starting with my participation in a week-long meeting of the Pacific Fisheries Management Council (PFMC) in Sacramento, California. The PFMC had been pointed out to me throughout interviews with the principal investigator and other consortium members as one of the organisations they wished to target as prospective users of their decision-support tool. I prepared my visit through several emails and phone interviews with PFMC staff and decided to track an agenda item on the regulation of trawl gear. I selected this agenda item partly on the recommendation of a PFMC staff member, who characterised it as an exemplary case of PFMC procedure, and partly because gear regulation had been one of the policy scenarios previously modelled by the consortium. In addition to participating in the meetings of scientific as well as industry advisory committees and the Council itself I conducted several in-depth interviews with science advisors and policymakers as well as having background conversations with representatives of conservation organisations and the fishing industry. I also collected agendas, handouts, and Council documents, took photographs, and obtained audio recordings of the entire Council meeting from a staff member, thereby complementing the recordings of advisory body meetings and interviews which I produced myself.

At the Pacific Fishery Managament Council, a curious methodological dilemma presented itself. The consortium primarily concerned itself with modelling fishing behaviour. I expected the consortium scientists to engage in some form – perhaps through interviews or experiments – with the fishers whose behaviour they aimed to model. Repeated questioning of consortium members to this effect, however, implied that they were happy to postpone this empirical part of their research in favour of theory-driven behavioural algorithms for the time being. In chapter six, I discuss an episode in which consortium members deliberate about theory-driven behavioural modelling. Moreover, as I discuss in chapter four, fishers were not considered by the consortium members I interviewed to be actors with much capacity to affect the success of their project. Hence the dilemma: the methodological principle of following the actors, to me and in this case, seemed to suggest not following the association between the modellers and the fishers that, however, seemed obvious in a project about modelling the behaviour of fishers. The important actors mentioned to me during interviews with consortium members were instead the science advisers and resource managers at the PFMC whom the modellers envisioned as users of their work product and considered critical to their project's success (and who I duly interviewed).

I found it challenging to reconcile this absence of fisher's voices in my case study with a methodological sensibility cognizant of the critique of early actor-network theory's tendency towards privileging heroic or managerial accounts of technoscientific orderings that leave exclusions, invisibilities, and the differential distribution of resources for affecting techno-scientific projects unadressed (McLean & Hassard, 2004). The decision presented itself where to "cut" the network (Strathern, 1996): judging from the accounts of the consortium scientists, the fishers whose behaviour they modelled were assumed to possess little agentic capacities within the socio-technical network of fisheries management. That is to say, at the sites of consortium modelling, fishers were implicated but absent actors (cf. Clarke & Star, 2008). However, at the PFMC these same fishers were evidently present during, and actively challenged, the kind of science-based policy-making to which the consortium wished to contribute. Not satisfied with this dilemma, and since I was already there in the presence of the people whose behaviours the consortium's model presumably concerned, I decided to leave the confines of Latour's methodological prescriptions and venture into talking with fishers themselves.

This turned out to be difficult. At the PFMC, it quickly became clear, fishers and scientists do not necessarily see eye to eye. Presumably because as a university researcher I came from a similar professional background as the Council scientists, the fishers I introduced myself to apparently saw little reason to trust me, left emails and calls unanswered or remained rather tight-lipped when I approached them in person. Given the short time that I had in the United States, I found myself unable to satisfyingly resolve the difficulties of gaining the trust of fishers and enlisting them as participants in my research. Small exceptions to that experience seemed like big achievements, as when I had the opportunity to informally talk with fishers about their experience of the PFMC meeting during smoking breaks. A fishing industry lobbyist was willing to facilitate access to a tour of a fishing port in Oregon she helped set up as an occasion were fishers, science advisors, and regulators could meet outside of the formal environment of a Council meeting. Trying to confirm details about place and time a few days before, I was suddenly disinvited by the fisher who would host the tour. This surprised the lobbyist who eventually speculated that the Council would consider the presence of outsiders not conducive to such a meeting. Eventually I had to resort to my participation in the fishing industry advisory committee meeting, which was open to the public, to hear the voices of fishers. If there appears to be in my account some of that same tendency towards managerial accounts for which earlier studies of technoscience informed by actor-network theory have been criticised, it may perhaps be explained with these difficulties of gaining access rather than an unreflexive tracing of successful techno-scientific ordering practices.

After Sacramento, I travelled to Southern California in order to visit the main scientific collaborators on the American side of the consortium at the marine science institute of a public research university in California. I spent a week with the group, observed their work, and conducted several hour-long in-depth interviews with scientists working on the consortium project. At the end of my visit I was invited to give the presentation about my research which occasioned the audience question that opens this chapter. My interviews at this site focussed on the specific problematisations which the Californian research group brought to the consortium as well as their side of the experience of interdisciplinary collaboration which I detail in chapter five. In April 2016 I visited a fisheries science centre of the National Oceanic and Atmospheric Administration (NOAA) in Seattle, Washington, tasked with producing scientific evidence involved in the decision-making processes of the PFMC. This site had been brought to my attention during interviews with PFMC participants as an important source of data and models informing decision-making in fisheries management. In Seattle, I participated in the annual fisheries science symposium of the centre and had the opportunity to engage in background conversations with several federal scientists.

From Seattle I travelled to New Orleans, Louisiana, to participate in a week-long meeting where all consortium members from both the British and American side were present to discuss first results and plan the work of the project. These meetings were held twice per year. On this occasion I was also invited to contribute to the group discussion. In addition to transcribing parts of the group discussion my participant observation in this meeting also comprised background conversations which provided valuable contextual information e.g. on substantive differences between members of the consortium. Next to recordings and field notes I collected further documents such as the meeting agenda and various handouts. The research materials generated during this week of meetings informed my work in chapters five and six. In the following section I will discuss two occasions during this meeting in New Orleans that prompted me to reflect in more depth on my relations to research participants and which each in its own way eventually proved analytically generative.

3.3.1 Studying up in technoscience I: role negotiations as generative moments

It is by now well established that ethnographic study of the worlds of technoscience confounds traditional narratives about ethnographic fieldwork by blurring the distinctions which had organised the relations between fieldworker and field, the studier and the studied. The anthropologist Diana Forsythe (2001) notes how in research situations of "studying up" in the worlds of technoscience there may exist considerable overlap between the lifeworlds, knowledges, and skills of ethnographer and research participants. As a result, traditional role distinctions between fieldworker and informant collapse into more fluid and shifting roles which are performed situationally and place different demands on negotiating relationships in the field. In my own fieldwork with the consortium of modellers, this blurring of distinctions between the roles of participant observer and colleague placed specific demands on my attempts at maintaining ongoing relationships with research participants.

However, these role shifts and negotiations also proved analytically generative at critical junctures. At times research participants would cross the boundary between providing data for my interpretive constructions and offering interpretations themselves. For instance, one of the American consortium members working in an administrative role had just completed a doctoral thesis in human geography, asked pointed and well informed questions about the theoretical framework of my research, and was indeed quite familiar with the published work of one of my thesis advisors. Whispering in a conspiratorial tone during a team meeting in New Orleans, she once alerted me to something she felt should be relevant to my research interest in expert practices and ontological politics, namely that only one team member, a marine biologist, would consistently refer to fish as animals whereas the modellers on the team would call them "the resource" or "the biology". While I did not pursue this specific observation any further, her interpretation of the meeting certainly sharpened my attention to the disciplinary differences within the team which eventually informed my discussion of how different ways of figuring and formalising the fisher agent are normatively inflected (see chapter six).

At other times research participants would call upon me as a colleague because they assumed that I possessed skills or knowledge valuable to their work. A team member in England, with whom I had spent some time observing the interdisciplinary production of software code (see chapter five), asked me whether I would be willing to read and suggest edits for a paper draft he had co-authored for submission to a peer-reviewed journal. Eager to be useful for once to someone who generously had made time for me over several months, I happily agreed, cautioning however that I had little of substance to add to a quite technical paper. My concern turned out not to matter for his request. Aiming for publication in a journal read by scientists not necessarily familiar with his modelling technique, he expected from me to receive suggestions for edits for clarity from someone who is not working in his field but nevertheless familiar with the protocols of academic writing.

While such occurences allowed me to maintain productive relationships with research participants by situationally shifting between the roles of colleague and ethnographer, at other times they proved more directly generative for my own analysis. This was particularly the case in those moments when my enrolment as participant in the consortium team failed, forcing me to reflect on the reasons for this failure (Jemielniak & Kostera, 2010). In chapter seven, I explicitly treat such an instance of ethnographic failure as diagnostic: during a team meeting, I had been called upon as a social scientist who just had spent time researching the workings of an environmental governance organisation which the modellers wished to integrate into their simulation as a "policy agent". As a consequence the principal investigator asked me to report how the organisation worked. My account of the vagaries and vicissitudes of policy-making in practice that I witnessed in that organisation, however, was dismissed as merely amounting to "noise" – a dismissal which led me to interrogate how different conceptions of noise, namely as an index of mediation or a disturbance to be reduced, might disclose different ways of understanding and doing environmental politics. This failed enrolment of myself as a social researcher into a project of social simulation led by physical scientists also disclosed divergent notions of the social: the modellers expected the social to be a formalisable set of determinate and distinct processes, however I took interest in the messiness and ambiguity of social practices (cf. Law, 2004). In this ethnographic moment, my inability to successfully perform the role of colleague brought into sharp relief the different epistemological and ontological commitments of modellers and ethnographer: whereas the modellers were interested in deriving general formal rules from empirically observable regularities of policy-making, I understood those regularities to be provisional achievements that have something to tell us about the simultaneously political and interpretive work necessary to create order from the rich ambiguity of policy-making in practice; work that is common to both the studier and the studied.

3.3.2 Studying up in technoscience II: code literacy and co-literacy

Studying the worlds of technoscience can also involve some overlap between the skills of researcher and the researched. In such a case participation can become more substantive with the positive effect that a "deeper understanding of complex social and technical processes“ can provide "a more solid basis for critique“ (Forsythe, 2001: 124). With some modifications, this effect proved salient in my praxeography of interdisciplinary modelling work (see chapter five). In order to observe how scientists with different disciplinary backgrounds collaborate for the production of software code, I had to acquire at least a modicum of literacy in the basics of agent-based modelling, object-oriented software development, and the Java programming language. Informed by previous work on human-computer interaction highlighting the material affordances of computational work environments (Mackenzie, 2006;

Suchman, 2000, 2007; Suchman & Trigg, 1996), I prepared myself for this part of my fieldwork by attending a training course on agent-based modelling provided by the IT services department of my home institution, participating in massive open online courses on object-oriented programming with Java as well as an introductory course on complex systems science, and occasional self-directed study of further online resources about Java programming.

In addition, I studied computer science textbooks on object-oriented modelling and agent computing (Booch et al., 2007; Russell & Norvig, 2010). These textbooks had been recommended to me by the primary interlocutor at this site of my fieldwork, an England-based postdoctoral research assistant hired by the consortium to write the software code for the model. Generously agreeing to meet over several months in weekly intervals for roughly hour-long in-depth interviews and to letting me observe his work with his colleagues, this postdoc facilitated my access to observing a crucial part of the technical work of constructing a software-based computational model. He granted me access to the code repository and the internal groupware platform of the project, helped me with the first steps of navigating the code base of the model, and introduced me to aspects of coding which had so far remained esoteric to me. Whereas I can by no means claim to have acquired the same level of skill as my interlocutor with respect to code literacy, it was certainly a more modest form of co-literacy which I developed with the aid of his patient explanations. Over the course of my work with the postdoc, this co-literacy solidified into something resembling the "interactional expertise" which Collins and Evans (2002: 254) classify as "enough expertise to interact interestingly with participants and carry out a sociological analysis". Eventually the acquisition of this interactional expertise in software development allowed me to pursue my research questions about the materiality of software work and to relate them to problems of interdisciplinarity in modelling (see chapter five).

I would like to think that at least some mutual learning facilitated by situational role switching between colleague and ethnographer took place in this process of developing co-literacy. When asked, I would share with the postdoc the theoretical issues which informed the questions I put to him in our interviews. At times I would also remark on something in his coding practice that, while being a merely technical issue for him, raised broader questions for me. For instance, the question of delineating the boundaries of an actor and locating agency, while remaining a live issue in social theory, seemed to me to have been answered in the modular, object-oriented design of artificial agents that bore conspicuous resemblance to the distributed and decentred concept of agency in actor-network theory. While I cannot speak to the extent to which these conversations had any effect on his coding work, they certainly occasioned opportunities for negotiating our different ways of being interested in modelling and our asymmetries in knowledge and skill.

3.3.3 Ethnographic co-presence: taking digital mediation seriously

Researching computational modelling by necessity involves considering digital devices such as software applications, code repositories, groupware and so forth as equipping the practices encountered during fieldwork. No longer confined to laboratory or field, contemporary scientific practice increasingly takes place "across networks, within distributed databases and via information infrastructures" (Hine 2007a: 619). In the case of the consortium, digital devices also played an important role for mediating the geographical distance between the American and British sites of participating institutions. Indeed, much of the ongoing collaborative work between consortium members at different locations involved various digital communication technologies rather than face-to-face meetings. This geographically dispersed and digitally mediated character of the modelling project necessitated adapting ethnographic research strategies to include participant observation in computer-mediated communication environments.

However, rather than orienting ethnography towards an immaterial virtual scape, computer-mediated communication is better understood as a local achievement realised in situated practices. Following the actors, then, necessitated "moving between online and offline as users of computer-mediated communication do" (Hine 2007a: 619). As a consequence, my in situ fieldwork in England and California was accompanied by ongoing participation in computer-mediated communication environments. Doing fieldwork, then, could mean sitting at my desk and checking for updates in the code repository or reading up on new conversations on the groupware platform which the team used. Later I would follow up on these updates and conversations during face-to-face meetings and with in-depth interviews. Shuttling back and forth between engagement with digital devices and artefacts and participant observation during moments of physical co-location, this kind of fieldwork can be characterised as establishing a form of "co-presence" (Beaulieu, 2010) which reconfigures ethnographic research in a way that decentralises physical co-location and face-to-face interaction, thus allowing for tracing technoscientific "streams of practices that are mediated by information and communication technologies" (Beaulieu, 2010: 456). Taking digitally mediated settings seriously, this mode of ethnography enabled me to render more symmetrical praxeographic accounts of the manner in which practices of inscription in computational modelling involve digitally equipped forms of skill and expertise which differ between sites and disciplines – an argument which I develop in chapter five on the collaborative achievement of model abstraction.

3.4 Data analysis

The preceding discussion should have rendered data something of a misnomer. The various research materials my engagement with the field generated were certainly not given up by a passive world to my research activities. Instead they were co-generated in eventful encounters in which neat separations between data collection and analysis were complicated through a process of displacements, e.g. from question sheet to interview situation to transcript or from observation to field note to software code excerpt, in which decisions about what counts as significant were at stake throughout (Whatmore, 2003). I collated the various materials generated throughout my fieldwork to organise an archive comprising interview transcripts and gathered documents as well as excerpts of online conversations complemented by field notes, software code snippets, and photographs. Interviews were transcribed and thematically coded with the aid of NVivo software. A sample interview transcript is included in the appendix. Coding the transcripts followed a principally inductive strategy for identifying themes which, however, remained cognizant of the necessary shaping of significant themes and categories by the theoretical predispositions and methodological sensibilities I brought these materials in conversation with.

For instance, investigating modelling as a performative practice entails a particular focus on the materialities involved and thus calls for analysing accounts of practice with a view towards their pragmatic dimension rather than exclusively reading them as evidence of meaning-making. This analytical focus brings into view the movements with which human and nonhuman elements come to be assembled by foregrounding relations, linkages, and mediating operations, but also discontinuities and ruptures (Fox & Alldred 2014: 11). This was achieved through a reading of interview transcripts, field notes and other materials as evidencing situatedness in socio-material networks complemented by the observation and description of material practices in situ. This analytical strategy can be illustrated with the following excerpt from a transcript of an interview with a software modeller who talked about an object-oriented method for simulating gear-habitat interactions:

> This was particularly complicated because it required a few things. It required habitat, but then it also required gear which looks at the habitat, and its catchability depends on it. And then I had to create a factory so that when I create a map I can tell it to be rocky. It was these three objects that had to be created at once in order to get this done. But once that's done, the rest of the model interacts nicely with it, and that is how we eventually end up with fishing the rocky line.

Analysing this interview transcript while being cognizant of the methodological injunction to treat as symmetrical human and nonhuman actants (Callon, 1986), the interviewees claim that something was "particularly complicated" to do can then be read as indicating embeddedness in a socio-technical network which shaped a particular course of action. Such a reading would direct further analysis towards the specific configuration of agencies in that network which can be described with the aid of observational data and further interviews. In chapter five, I conduct such an analysis of the agentic capacities assembled in interdisciplinary software modelling. A different analytical strategy, perhaps informed by a more anthropocentric notion of subject-object relations, might have stopped at treating the interviewees' claim as indicating satisfaction with the successful mastery of a technical challenge.

Similar decisions shaped the analysis of documents such as white papers and grant proposals of the consortium or the reports of advisory committes of the PFMC. Disregarding their quality as artefacts, such documents can be analysed with a view to the discursive strategies they bear as in my discussion of the work metaphor does in rendering a particular problematisation of marine resource governance plausible (see chapter four). However documents can also be read as material artefacts stabilising social relations and inscribing acts which orient the actions of others (Asdal, Borch, & Moser, 2008). In chapter seven, I read an advisory bodies' production of reports as the processing of deliberations into authority achieved through effacing the noisy conditions of production of those documents. Such a strategy of reading the documents ubiquitously found in policy settings as devices with an operational and pragmatic dimension contributes to an understanding of the materiality of politics which can complement an interpretive analysis of the meanings and framings of policy (Braun & Whatmore, 2010).

3.5 Research ethics

Ethics clearance where human participants were involved has been obtained in compliance with CUREC protocol before embarking on fieldwork. Participants have have been given, and signed, a consent form which I constructed based on examples provided at a departmental research methods training for doctoral students. The consent form is included in the appendix. Names and other identifying information of research participants have been anonymised. I also anonymised the organisations participating in the consortium. As the PFMC meeting is a public event and PFMC staff produce extensive publicly available documentation of its proceedings, I have chosen not to anonymise this organisation. However I do anonymise the identities of my interlocutors at the PFMC.

3.6 Conclusion

To recapitulate, my decision to pursue a multi-sited ethnography of the development of a model for fisheries management had the advantage of tracing the relational materiality of modelling: contingent on different sites and practices of development and use, the model gave rise to specific capacities for differently situated actors which I discuss in the chapters below. An early decision to spend significant time with a software modeller and acquire the interactional expertise to more fully engage with his modelling work allowed me to contribute a detailed description of the practice of computational simulation to the praxeological literature on scientific representation. The decision for participant observation in the consortium meant that I was privy to disputes within the consortium that allowed me to observe the normative questions and political strategems heterodox economic modellers grapple with. Being able to contrast work done on and with models at different sites, such as the consortium and the PFMC, allowed me to identify infrastructural relations limiting the embedding of socio-technical imaginaries in the material world of fisheries management and to bring into relief how the material politics of policy-making trouble projects of computational policy optimisation.

While this multi-sited strategy proved advantageous with respect to the questions above, it also limited my research in some aspects. Most importantly, I had to trade off time spent doing participant observation and interviewing consortium members against other possible research participants from the world of fisheries management. This limited the extent to which I could gain trust and build rapport with the latter, which became particularly salient on the occasions where I did not manage to negotiate access to fishers at the American West Coast. As a result, my study could have had a stronger focus on the role of fishers in fisheries management had I been able to spend more time evolving my ethnographic participation in the PFMC from relatively detached observer to a more fully participant role. In hindsight, the decision to approach the PFMC by negotiating access through a gatekeeper such as the staff member might have contributed to my identification (Buch & Staller, 2011) with the powerful camps of regulators and science advisors in the eyes of fishers and thereby hindered my ability to gain the latter's trust. In future research, a methodology and research design more explicitly geared towards the co-performative role of research into local economies (e.g. Gibson-Graham, 2008) might help to develop a richer account of the varied agencies assembled in representing, as well as the normative stakes involved in performing, diverse natural resource economies.

Chapter 4 Contested future natures: embedding agent-based modelling into the knowledge infrastructure of fisheries management

> Have you heard of the dog and the frisbee?
>
> *Yes, there is a simple rule. The dog just runs...*
>
> Same angle. Maintains a constant angle that catches the frisbee. As opposed to solving second order differential equations that describe the same system in a much more complicated way. We want the frisbee rules for the fishery as well rather than the many equations rules.

In December 2015 I found myself talking about a dog running after a frisbee while sitting in the office of the principal investigator of the international research consortium. The way a dog presumably catches a frisbee – following a simple heuristic rather than trying to predict the state of a system – served as an analogy for what the scientists on the consortium tried to achieve, imagining a different way altogether of doing fisheries management: faster, cheaper, more adaptive; better suited to a world they considered to be more and more complex because of multiple perturbations stemming from climate change, technological advances, and increasing human activity in the oceans. What is more, the scientists' envisioning of different ways of knowing and governing maritime human-environment relations was invested in devising new techniques of calculation departing from orthodox economics. I had indeed heard of the dog and the frisbee because of a lecture of the same title by Andrew Haldane (Haldane & Madouros, 2012), chief economist of the Bank of England, which was referenced throughout the consortium's writings. Opening his lecture with the frisbee analogy, Haldane proceeds to envision the international financial system as a complex environment in which heuristic decision-making, i.e. based on simple decision rules, may perform more robustly than attempting to probabilistically calculate future outturns as suggested by rational expectations theory. Joining research into heuristic decision-making from behavioural psychology with the physics of complex adaptive systems, both Haldane's and the consortium's arguments resonate with a reformist project in economics which advocates replacing mainstream economic models with agent-based modelling (Cooper, 2011; Arthur, 2013; Bier & Schinkel, 2016).

Departing from the notion of models as representations, the performativity programme in economic sociology has identified economic modelling as part of the practices through which specific economies are enacted (Mackenzie, 2006; Muniesa et al., 2007). Studies in this idiom tend to investigate the ways in which economic models are involved in bringing about the worlds they purportedly represent by becoming embedded into the infrastructure of markets through various material mediators. As I discuss in chapter two, work on modelling in science and technology studies further draws attention to the entwinement of practices of model construction and model use in the context of policy-making, suggesting that scientific features of models may be derived from the policy contexts in which models are put to work (Svetlova & Dirksen, 2014). In this chapter I wish to consider models as part of the scientific knowledge infrastructure rendering economic activity in fisheries knowable and governable in the United States. In American fisheries management, modelling work is infrastructural work: model results produced by scientists are meant to support the decisions made by environmental managers. For the most part, the work of modelling remains invisible to the various publics participating in fisheries management organisations, and technical questions about model choice, parameterisation, validation and so forth are hidden away in the research centres and scientific advisory bodies producing the "best available science" upon which American law mandates fisheries management shall be based.[4] Insofar as modelling work is infrastructural work, I wish to practice a form of infrastructural inversion (Star & Bowker, 1999), attending to the sites and occasions where choices about the tools equipping the knowledge practices of fisheries management are being made.

The empirical story I will tell concerns an attempt by the international consortium of scientists and conservationists to embed their agent-based model of human dimensions of ecosystems into the knowledge infrastructure of American fisheries management. Human dimensions, here, concern the behaviour of fishers in relation to environmental, economic, and policy change. A by now well established literature in fisheries science flags up human dimensions as a key source of management uncertainty and identifies the insufficient capacities of management tools to take behavioural change into account as one of the causes of the many failures of science-based management of global fisheries (cf. Fulton, Smith, Smith, & Van Putten, 2011). Envisioning future fisheries managed sustainably with the aid of computational techniques, the consortium takes an approach to modelling human dimensions strongly influenced by heterodox economics. Rather than modelling the dependency between fish population dynamics and a single representative economic agent as in the bioeconomic models currently established in fisheries management, the consortium promotes agent-based modelling in order to simulate the self-organisation of a multitude of more-than-rational agents making heuristic decisions

[4] The work of science advice in an American fisheries management organisation will be discussed in greater detail in chapter seven.

within a coupled socio-ecological system.[5] The question of how to formalise human dimensions, however, comes charged with normative commitments, imaginaries of threatening and desirable futures, envisonings of political relations, and metaphorical trafficking animating a particular understanding of human dimensions in environmental management. Moreover, rather than seamlessly integrating into the array of knowledge practices with which environmental management is being performed, new modelling techniques and the imaginaries rendering them meaningful come up against the inertia of incumbent ways of constituting human-environment relations and their futures.

As a result, the scientists of the consortium have to simultaneously construct social and technical relations, enlisting multiple actors at multiple sites into their project to bring their imagined modelling infrastructure about. After developing the analytical lenses of imaginaries and infrastructures, the empirical part of this chapter will document, first, the ways in which a new knowledge infrastructure is being envisioned, and second, the work of constructing the model in such a way that it can be embedded into the infrastructural relation between modelling and decision-making. As a consequence, the empirical part of this chapter is organised into two sections. The first section traces how a series of white papers lays out an ambitious vision for fisheries management significantly departing from the currently established Maximum Sustainable Yield (MSY) approach. Preparing a funding bid by a consortium of British and American research scientists and conservationists, these white papers draw on heterodox economic theory to imagine problems of fisheries

[5] How the artificial economic agent in agent-based modelling is discursively and materially constructed as a more-than-rational decision-maker will be discussed in chapter six.

management as analogous to problems of financial governance and argue that similar modelling and management methods can be deployed in both fields. The eventual grant proposal responded to a funding call on global commons problems, and as a consequence, a concern with the management of global commons had to be translated into a concern with human behaviour as a barrier to effective fisheries policy implementation. This translation also displaced the consortium's original vision of overcoming the Maximum Sustainable Yield approach towards a concern with operationalising human dimensions in Ecosystems-Based Fisheries Management (EBFM). Based on ethnographic work in an American fisheries management organisation, the second section traces how the infrastructure for knowing and managing fisheries already in place along the California Current offered a certain resistance to the ways in which the consortium envisioned doing fisheries management differently. For an infrastructural relation between science and governance to be established and maintained, models need to have specific material affordances accommodating the local and contingent conventions of science-based policy-making. As a result, the consortium simultaneously altered the technical structure of their model and its intended use in order to increase the chance of successfully embedding their device into the infrastructural relation between modelling and decision-making as it obtains in fisheries management on the West Coast of the United States. The chapter demonstrates how STS work on socio-technical imaginaries and infrastructures helps theorising the practices by which model construction and use become entwined and concludes with querying the (anti)political dimension of this imagining and infrastructuring of future fisheries.

4.1 How futures take hold: socio-technical imaginaries and infrastructures

It can be considered a particularity of the temporal order of capitalism, Beckert (2016) argues, that actors are compelled to orient themselves towards an open future filled with risks and opportunities, deploying a number of practices and devices in attempts to render the future knowable in such a way as to guide actions in the present. These techniques include both calculation and narrative as complementary means for creating imagined futures which, while fictitious, shape expectations, justify decisions, and coordinate social action. As decisions anchored in credible narratives about the future might have distributional effects, the means with which futures are imagined frequently become loci for power contests which restrict the range of credible future envisionings (Beckert, 2016: 85). In the case of evidence-based policy making, the futures imagined and made calculable with the help of predictive techniques may be further constrained by the practicalities and objectives of the very management practices future knowledges are supposed to support as evidence (Lane et al., 2011).

Science and technology studies have turned towards studying the ways in which the technosciences imagine futures towards which present actions are directed (McNeil, Arribas-Ayllon, Haran, Mackenzie, & Tutton, 2017). Fujimura (2003) understands scientific imaginaries as results of social practices enacted across a network of heterogenous actors and forming an important part of scientists' work as they attempt to marshal resources, create demand, and fashion communities receptive for and actively involved in turning their future visions into present projects. The rhetorics of persuasion and hyperbole are necessarily part of these imaginings as they turn on future possibilities which people need to be convinced are both desirable and attainable. Moreover, in order to gain broader purchase these scientific imaginings engage with, and latch on to, other cultural discourses which necessitates understanding their historical and cultural situatedness.

Suchman (2012) argues on behalf of configuration as a concept and a method for studying how technologies conjoin material and semiotic relations. Invested in understanding the rhetorics animating technoscientific projects, Suchman proposes attending more closely to their always incomplete and contingent articulation with technical devices which "materialise cultural imaginaries, just as imaginaries narrate the significance of technical artefacts“ (Suchman, 2012: 48). Configuration seeks to understand technical artefacts as embodied instances of broader rhetorical figurations coming up against practical realities. The analysis of configuration extends broadens the scope beyond a singular technical artefact in order to include its imaginative anteriority and the specific way its materialisation is shaped by diverse settings of practical use.

Whereas Suchman suggests studying the imaginative work preceding the construction and use of the technical artefacts equipping the present, Jasanoff (2015) proposes the study of imaginaries for investigating the processes by which future envisionings are embedded into material infrastructures. In the latter project, socio-technical imaginaries are defined as

> collectively held, institutionally stabilised, and publicly performed visions of desirable futures, animated by shared understandings of social life and social order attainable through, and supportive of, advances in science and technology (Jasanoff, 2015: 4).

Attending to metaphor and analogy matters in this analytic for understanding both the ways these visions travel and come up against frictions in different locales as well as the rhetorics drawing legitimacy from more established spheres for imaginings of future possibilities (Jasanoff, 2015b: 325). Bridging cultural theory on the construction of collective imaginaries and an STS concern with the construction of technological systems, Jasanoff's work on sociotechnical imaginaries proposes a process model of the manner in which normatively inflected ideas about socio-technical futures circulate, extend beyond their original formulation, are resisted and adapted, and take hold through embedding in material infrastructures. With its focus on the making and circulation of meaning, this research programme suggests studying texts and their modalities of circulation as indexing collectively held beliefs about technoscientific futures. Although Jasanoff (2015a: 327) gestures at the performance of imaginaries as a hybridisation of ideas and infrastructures, the particular practices by which future envisionings take hold in material worlds receive comparably less attention. To redress this imbalance, I suggest that readings of imaginaries might be fruitfully complemented with a praxeographic attention to the work of infrastructuring.

Recent research into infrastructures resonates with a concern with technoscientific world-making practices as it figures infrastructures as relational, enacted through practices, and productive of particular forms of life. Inverting a figure/ground relation, the analysis of infrastructure attends to the work and materials supporting and enabling some other activity: artefacts, institutional arrangements, and their attendant labours that on account of their frictionless functioning usually remain invisible and need not be considered when carrying out said activity (Slota & Bowker, 2017). Arguing that "an infrastructure occurs when local practices are afforded by a large-scale technology," Star and Ruhleder (1996: 114) develop a number of dimensions obtaining in infrastructure: these include embeddedness, being learned as part of membership, links with conventions of practice, and becoming visible upon breakdown. These dimensions aid an analysis of the moments in which infrastructural relations shift as complex entanglements of people, practices, and artefacts change the very activities they support. Heterogeneous bundles of human labour, organisations, and artefacts constitute infrastructures not in essence, but rather in relation to something else at specific points in time. This relationality is central to the analytical purchase of the infrastructure concept. In their socio-material heterogeneity, infrastructures may well be characterised as assemblages (Bennett, 2010: 24). Extending beyond mapping the agentic effects of heterogeneous assemblages, however, an analysis of infrastructures would attend more closely to the situated moves by which some groupings of human labour and material forces are rendered invisible and unproblematically supportive in relation to something else (Slota & Bowker, 2017: 531).

Building on this theorisation, recent research has turned to the ways in which plural natures (Bingham & Hinchcliffe, 2008) are conjured up through infrastructuring practices (Blok et al., 2016). Analysing the means with which environments come to be known and governed, this research links STS work on the construction of information infrastructures with analyses of environmental governance as playing out in heterogeneous, contested, and situated settings linking several scales (Blok et al., 2016; Lippert et al., 2015). Bringing to the fore the sites and moments where decisions about the design of environmental knowledge infrastructures are made, this research stresses the performative effects of the operations of material means for knowing environments as they shape the way relations to environments are enacted. These operations, however, take work and may be subject to contestation and negotiation as well as being regionally divergent, implying an ontological politics of multiple natures with attendant modalities of ordering and governing being performed through heterogeneously deployed knowledge infrastructures. In the following two sections I wish to work these theorisations of socio-technical imaginaries and knowledge infrastructures through two subsequent episodes of the envisioning and embedding of a heterodox economic model for fisheries management.

4.2 Heterodox envisionings of fisheries and finance

Throughout a series of internal white papers, written between February 2014 and October 2015, a consortium of British and American scientists and a major conservation organisation developed an ambitious vision for reforming the management of global fisheries. With titles such as "Re-inventing Commercial Fishing“ or "Re-imagining Fisheries Management“ the white papers are explicit about their inventive and imaginative purpose, criticising the established metrologies and policy tools of fisheries management as too complex, data-intensive, slow, and altogether inadequate for a marine environment figured as "ever more uncertain in its patterns and rhythms“ as a result of climate change and increased human activity in maritime space.

The main target of their criticism is the array of calculative and policy techniques producing Maximum Sustainable Yield (MSY) as the "currently dominant fishery management model.“ Calculated for a stock of a single species of fish in a fishery, MSY turns on setting a seasonal harvest quota which is meant to optimise for both aggregate profitability and surplus production of fish populations based on calculations incorporating data-intensive stock assessments and population forecasting models. Historically the Maximum Sustainable Yield approach to fisheries management had been promoted by the U.S. Department of State in the context of the Cold War wherein scientific resource management was enrolled into the promotion of international treaties which closed American territorial waters for Soviet fishing fleets while keeping global oceans open for American fleets (Finley, 2011). Maximum Sustainable Yield incorporates the microfoundational assumptions about rational action and attendant modelling techniques of mainstream economics. Its intellectual origins reach back to 1950s bioeconomics, specifically the foundational Gordon-Schaefer model which defines MSY as an equilibrium point on a function between resource exploitation and population growth (Cardwell, 2014). Historian of science Jennifer Hubbard (2014) regards MSY as an incursion of economics into marine biology, emphasising the reframing of overfishing as a problem of reduced profitability rather than the health of fish stocks by economists such as H. Scott Gordon whose work on fisheries as common-property resources would become seminal for resource economics. In venues such as United Nations Food and Agriculture Organisation conferences, economists argued for a utilitarian approach to fisheries that would foreground human needs which were formalised by treating fishers as rational investors maximising a profit function (Hubbard, 2014: 377). Throughout the 1970s the expertise and models of economists eclipsed those of marine biologists in the making of fisheries policy and subsequently justified a number of privatisation programmes carving up marine commons into tradeable catch shares.[6]

The consortium wishes to move away from the Maximum Sustainable Yield approach for a number of reasons. Figuring ocean ecology as a complex system incorporating uncertainties only exacerbated through climate change and increased fishing pressure, the consortium criticises MSY as "deeply flawed“ because of the slowness with which it can be implemented considering that it is predicated on conducting detailed stock assessments needing expensive and laborious data collection. Moreover, the consortium takes issue with the reductive assumptions underwriting MSY calculations:

> It wrongly infers system health from single species health, ignores most interaction between species, and ignores reasonably well expected changes in future environmental conditions, such as warming waters. Furthermore, it assumes that the equilibrium growth rate is fixed, a dangerous assumption in such a complex, dynamic system.

Arguing that "the more uncertain and complex the system, the more careful we have to be with using complex governance rules“, the consortium wishes to "simplify and streamline“ fisheries policy-making through envisioning the development of "small sets of decision rules“ for managing fisheries held to trump their complicated alternatives by being quicker to adapt to changing conditions. These are the heuristics or "frisbee rules“ for the fishery mentioned in the epigraph to this chapter.

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[6] As I discuss in chapter two, studies informed by the performativity programme in economic sociology have described the various market devices, such as Individual Transferable Quotas, with the help of which neoclassical economist’s theories and models are performed in the construction of resource markets for fisheries (Holm & Nielsen, 2007; Johnsen, Holm, Sinclair, & Bavington, 2009; Hébert, 2014).

Bolstering their claim that such a new approach might be feasible, the consortium finds an unlikely ally in the theory of macroprudential financial regulation. In the white papers, they sketch out a vision to "use the complex systems analytic established in the economic realm to develop a new set of systems rules (heuristics) for commercial fishery management." Drawing an analogy to the inroads heterodox economics made into financial regulation theory after the financial crisis of 2008, the project wishes to do for the ocean economy what complexity science and behavioural economics have done for the macroprudential regulatory architecture of financial markets (cf. Cooper, 2011). The internal project literature is littered with analogies to the financial crisis, and the perceived shortcomings of neoclassical economics are frequently brought up in my conversations with consortium members. The white papers prominently refer to the work of Andrew Haldane, chief economist of the Bank of England, to argue for understanding the dynamics of marine human-environment relations as analogous to the dynamics observed during the subprime housing crash triggering the financial crisis:

> The problem of modelling booms and busts in housing or other markets may not be that different from modelling booms and busts in fish stocks. The thesis of the project is that similar analytical approaches can be used to understand them. In both cases, millions of agents, interacting in complex ways create a system that is prone to cycles; that exhibits "herding" behavior most, but not all, of the time; that is regulated; and that features an "extractive" layer (bankers or fishermen) and an "extracted" resource (householders or fish) with nonlinear feedbacks between the two. Naturally there are many important differences between such systems, but the key point is that the same methodologies can yield insights in both systems. Just as with the general equilibrium models in economics, MSY-based approaches fall short because networks/relationships as well as heterogeneity are largely ignored and the system is treated as uniform and predictable.

Drawing an analogy with financial systems, MSY is criticised as neglecting relationships between fish species and the dynamics of networks of more-than-rational fisher agents with decision strategies departing from rational profit maximisation. However, this trafficking of analogies runs both ways. After the crash of 2008 called into question certain tenets of orthodox economics as to the self-equilibrating nature of markets and the rational behaviour of economic agents, Haldane produced a number of interventions promoting heterodox thinking in the theory of financial regulation. Speaking to international central bank audiences and co-authoring high-impact articles, Haldane argued that economics should learn from the natural sciences, in particular the life sciences, to understand and manage markets as complex adaptive systems (Haldane, 2009; Haldane & Madouros, 2012; Haldane & May, 2011). Refuting central banks' dominant equilibrium models, Haldane instead urges economics to become more interdisciplinary, arguing on behalf of work in ecology as providing new models and metaphors for understanding systemic risk in financial markets. Providing an analogue to the failure of financial regulation, the collapse of fish stocks and the associated failure of single-species management techniques play an important roles in Haldane's argument. Haldane (2009: 26) understands the failure of the global regulatory regime to prevent the events of 2008 as analogous to the failure of scientific fisheries management to prevent the worldwide collapse of fish stocks from the 1970s onwards:

> Existing regulatory rules for financial institutions have echoes of fisheries management in the 1970s. Risk quotas are calibrated and applied node by node, species by species. This approach takes no account of individual nodes' system-wide importance – for example, arising from their connectivity to other nodes in the network or their scale of operations.

Haldane's argument tacks back and forth between fisheries and finance: informed by ecological theory, fisheries management shifted towards the management of a broad set of indicators for the overall robustness of marine ecological networks rather than individual species abundance estimates. However, financial regulators failed to heed the same lesson, continuing to appraise risk portfolios of individual financial actors rather than the systemic risk arising from the specific network topologies of their interconnection. Referencing the work of Jane Lubchenco, a marine ecologist and former head of the National Atmospheric and Oceanic Administration during the Obama administration, Haldane (2009: 18) gestures at the principles underlying ecosystem-based fisheries management (EBFM) as a model to emulate for financial regulation. Just as EBFM attempts to manage vital dependencies across an entire fishery rather than a series of individual species, macroprudential regulation should concern itself with mapping the financial sector as a network of actors whose interactions give rise to systemic vulnerability rather than a series of autonomous banks holding calculable risk.

If economic theory is to learn from other sciences and appreciate the dynamics of complex systems, then it needs new techniques to model economies. In a lecture, Haldane (2016) contrasts agent-based modelling with standard economic models which assume a single, representative, rationally optimising economic agent. Lamenting the slow adoption of agent-based modelling in the economics discipline, Haldane praises ABM because it provides a way of relaxing the microfoundational assumptions of mainstream economic models. Agent-based models consist of a network of many individual, interacting artificial agents (Bonabeau, 2002; Gilbert, 2008). The behaviour of an individual artificial agent is determined by an algorithm formalising a set of behavioural rules. These rules can be defined by the modeller: agents could rationally optimise gain in the same way as the microfoundations of mainstream economic models assume, but they could also follow heuristics, i.e. simple rules of thumb such as in the dog-and-frisbee example opening this chapter, or follow any rule arbitrarily defined by the modeller. The behaviour of the overall system follows from the dynamic interaction of a multitude of agents. That means that system behaviour emerges endogenously rather than resulting from exogenous shocks, giving rise to hard-to-predict, nonlinear dynamics. As I discuss in chapter one, agent-based modelling is gaining currency in the environmental sciences, aiding socio-ecological research into the management of common-pool resources (Janssen & Ostrom, 2006; Poteete et al., 2010). In the wake of the financial crisis, scientists are calling for agent-based modelling to complement, if not substitute for, the suite of mainstream models in economics and finance (e.g. Farmer & Foley, 2009).

Within the consortium, fairly idiosyncratic institutional and biographical characteristics account for the prominence of the finance analogy and the attendant preference for agent-based modelling. The CEO of the conservation nonprofit instrumental in setting up the consortium previously had a professional career in finance and holds an advanced degree in finance from Harvard Business School. As one of the American fisheries scientists remembers, this professional and educational background informed an early choice to focus on agent-based modelling:

> My understanding is that the CEO has a business background and has a lot of friends in finance. And the big thing in finance right now is agent-based modelling ... so, this is something he kept hearing from his friends in finance. For example, the head of research at Goldman Sachs is on the board of directors of the nonprofit. I think he was one of the people who were sort of saying, you know, ABM is this really hot new thing.

Agent-based modelling had been listed as one among many techniques in an early survey of marine management and modelling methods commissioned by the nonprofit from the scientist's research group. The finance analogy eventually provided the rationale for choosing ABM as the modelling method to focus on:

> In the fisheries world, the models are behind on the social side. We have some pretty great models of the biophysics and biogeochemistry of the oceans. We have some pretty decent models of the ecology of the oceans. But we don't

> really have any good models of the humans ... and this agent-based model was something that was very quickly emerging in finance as, you know, the next big thing. So the CEO's idea was to, okay, let's see if we can bring in ABM to solve this modelling gap in the oceans.

Moreover, the principal investigator on the British side of the consortium is a physicist with an affiliation to a leading heterodox economics think tank founded in the wake of the financial crisis. His conversations with the executive director of the think tank, a former McKinsey consultant who authored a trade book on complexity economics, got him interested in problems around economic modelling. The work of the think tank modelling American and European economies with the help of ABMs is referenced several times throughout the white papers.

Tacking back and forth between economics and ecology, complexity provides the main metaphor both for Haldane's project of "rethinking the financial network" (Haldane, 2009) and the consortium's project of "reimagining fisheries management".[7] In both their writings, complexity refers to the interaction of more-than-rational agents, each adapting to their changing environment, and thus giving rise to emergent systemic behaviour. Just as Haldane (2009: 2) is highly critical of the informational assumptions - zero cost of information and cognitive capacities sufficient to probabilistically weight all future outcomes - which undergird traditional equilibrium models in finance, the consortium argues for modelling fishers as more-

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[7] For a nontechnical overview of complexity science see Mitchell (2009) and for complexity in economics see Beinhocker (2007). Whether complexity qualifies as a metaphor is a question of what metaphors do. Following Lakoff and Johnson's (2003) definition of metaphor as rendering abstract matters knowable by reference to embodied experience, complexity would not qualify. However we might consider complexity as a metaphor in a different sense, namely as a nomadic term transferring meaning among scientific discourses (Proctor & Larson, 2005).

than-rational, heuristic decision-makers.[8] The aggregate actions of fishers as they respond to environmental and social change are held to generate emergent patterns exceeding the predictive capacities of traditional models; actions which are to be brought into the remit of marine governance through formalising insights of behavioural economics in a predictive computer simulation. Thus financial regulation theory in the wake of the 2008 crash serves as a template for what the consortium wishes to achieve for the management of global oceans. Fisheries are imagined as complex systems characterised by emergent effects of more-than-rational interacting agents, susceptible to sudden shifts, and prone to endogenously emerging crises.

However, metaphors and analogies also do epistemic and political work in science (Proctor & Larson, 2005). Nomadic terms such as complexity connect the disparate discourses of fisheries and finance, performing a mutually authorising function for the introduction of new theories and methods: if it works in fisheries, Haldane claims, it should work in finance; conversely, if it works in finance, the consortium argues, it should work for fisheries. Complexity, here, has a heuristic role gesturing at the as-yet-unknown in both disciplinary fields, issuing a promissory note for future technoscientific possibilities of knowing and controlling social and ecological systems. Referring to Susan Leigh Star's work on the conditions under which scientists declare observations from different domains to be evidence of the same phenomenon, Bowker (1993) analyses such equivalence claims as rhetorical moves with which a researcher gains legitimacy for novel epistemic claims by pointing to another field which in turn references the field of the researcher. Such circular moves

[8] On the history of formalising rationality in the human sciences see Erickson et al. (2013) and on the history of the economic agent see Foley (2004). Economic rationality and agency will be discussed in greater detail in chapter six.

had been common, Bowker argues, to establish cyberneticians' claims as to the universal purchase of cybernetics as a shared explanatory framework for highly heterogeneous phenomena. Echoing the ambitions for a universal science of post-war cybernetics, this recourse to complexity posits a single cause for the simultaneous crises of finance and fisheries with fresh memories of an economic crash providing the prominent cultural context within which the metaphor of complexity can prevail.[9]

In order to be realised, the ambitious vision of the future of fisheries management articulated in the white papers needed to marshal resources and enlist actors outside of the consortium. The consortium had been set up as part of an effort to win a seven-figure grant in response to a funding call on the theme of "global commons, collective responsibilities and market failures“ issued by a privately funded research and policy unit at a major British university with the stated aim of "tackling complex global issues.“ In order to qualify, the proposals had to demonstrate that their research was of "global scale and future significance“ as well as interdisciplinary, using innovative methodologies, and strongly oriented towards impact outside of academia. In addition, the funding strategy of the research and policy unit emphasises fund matching through partnerships with third-party organisations such as businesses and foundations. The funding call explicitly mentions "global commons problems with regard to the management of the oceans and their resources“ as a potential field of interest. Figuring the management of marine resources as a commons problem is a staple of resource economics. Indeed, as Hubbard (2014) points out, the work of economist H. Gordon Scott on fisheries as common-pool resources prefigured and

[9] As a successor paradigm to cybernetics, complexity science retained much of its universalist ambition. Figured as chaos, complexity's main trope of nonlinearity gained broader cultural significance from the late 1970s onwards (Hayles, 1990, 1999).

inspired the influential argument about a "tragedy of the commons“ (Hardin, 1968). These arguments assume rational, self-interested, and autonomous individuals trapped in a social dilemma: as every individual attempts to maximise his or her own profits by making use of an open-access common-pool resource, through over-use the resource rent begins to dissipate for everyone. As actors within the system are assumed to be unable to resolve this dilemma through communication, an external imposition of either governmental ownership of the resource or the institution of private property rights become necessary to prevent resource rent dissipation. The tragedy of the commons model and its assumptions, although influential for the design of market-based environmental policies, has seen repeated challenges based on historical and empirical research into the diverse ways commons have been and are being managed (for the case of fisheries see e.g. Feeny, Hanna, & McEvoy, 1996). Perhaps most prominently, Nobel economist Elinor Ostrom (2010) refutes the assumption of rational individuals trapped in a social dilemma as empirically unsubstantiated and calls on resource economists to improve their theoretical understanding of human behaviour in relation to common-pool resource problems.

Responding to the funding call's problematisation of maritime resources as a commons problem, the consortium's grant proposal translates (Latour, 1983) the problem of managing marine commons into a problem of simulating more-than-rational behaviour and computationally optimising policies. However, this translation, whereby solving the problem of global commons is displaced into the simulation apparatus to be developed by the consortium, is enveloped and rendered meaningful by a broader envisioning of a future nature shaped by technoscience. Before turning to the translation of a commons problem into a problem of simulating behaviour, I wish to attend to the way this imaginary envisions a watershed moment between a catastrophic and a desirable future nature. In their grant proposal, the consortium paints a gloomy picture of looming environmental catastrophe. Marine environments figure as being on a "trajectory of significant degradation“ because

> increasing human population and per-capita demand, coupled with the most recent global financial crisis, are driving a new agenda of "blue growth“, which along with coinciding technological advances, are threatening a new era of industrialisation of the oceans.

The ocean is problematised as a global common-pool resource under threat from climate change and human activity such as deep sea mining, pollution, and overfishing, leading to a great deal of uncertainty about the way the ocean system will react to further stresses from environmental change and increased resource exploitation. A future world in which food crises are linked to irreversible marine ecosystem shifts stands out as the main threat scenario: the provision of an important protein source by the ocean to two billion people is threatened by over half of global fisheries being depleted. Industrial fishing has led to overexploitation with knock-on effects on habitat, and the reorganisation of trophic systems by fishing down the food web causes algae and jellyfish bloom. The resulting "loss of ecosystem services, impacting food security“ is figured as the "Marine Resources Problem“ strategically linking into the funding bodies’ call for research which aims to tackle commons problems of global significance. This particular vision of a possible future to be avoided partakes of the genre of future writing which Urry (2016) terms "new catastrophism,“ problematising the resource base of contemporary societies in deliberations about systemic risk and future collapse.

This catastrophist discourse comes with its own temporality: situating the present at a critical junction, it allows for a positive future envisioning to be reasonably entertained under the condition that certain paths be pursued in the present. Referencing a report by the Global Ocean Commission (2014), the grant proposal stresses the timeliness of the consortium's project, calling for urgent research and action to avoid in marine environments the same scale of habitat and biodiversity loss observed on land, arguing that "we have a narrow window of opportunity to change the trajectory of marine ecosystems from one of decline to recovery." The desirable future the consortium wishes to advance towards is firmly lodged within a discourse of ecological modernization (Mol, Sonnenfeld, & Spaargaren, 2009): advances in science and technology are to reconcile industrialised commercial-scale fishing with the recovery of marine biodiversity on a global scale. Science and technology figure in the ambivalent role familiar from contempary cultural discourses in Western societies: they are simultaneously imagined as a cause of a host of risks and the prospective means for resolving them in the future (Beck, 2009). If this is a story of ecological modernisation fairly familiar from a number of environmentalist discourses, its specific epochalism latches onto themes of instability, crisis and technoscientific salvation typical for complexity science. As Isabelle Stengers (Stengers, 1997: 4) notes, complexity scientists tend to promote these themes to underscore the need for an epistemic break and a new rationality to ward off catastrophe and bring an unstable world back under control. Complexity, here, is both a cause for concern because of the threat of human activities cascading uncontrollably across environmental systems, and a reason for hope, since the computational tools of complexity science promise to render these socio-ecological interdependencies legible and controllable.

The stated interest of the funding body in addressing global commons problems with respect to the ocean commons had to be translated into the consortium's interest in reforming fisheries management through agent-based modelling. Promising to solve an actor's problem through science, translation enlists this actor's concern with the problem into the epistemic project of scientists (Latour, 1983). This act of translation displaces that actor's concern into a situated scientific practice, such as a laboratory, rendered equivalent to the concern it is meant to address. In their grant proposal, the consortium attempts a translation of global commons into agent-based modelling, rendering this displacement plausible by emphasising the behavioural, human dimension of resource management. The threats posed by the industrialisation of the oceans are to be mitigated and brought under control through the development of novel computational techniques for knowing and governing human behaviour in marine environments:

> New modelling approaches, enabled by advances in computing, allow management of fisheries that not only takes into account catch levels but can also incorporate information on geographic patterns of activity, economics and social factors including human behaviour. This not only allows determination of sustainable catch levels but the best approaches to ensuring compliance among fishers.

In the first version of the grant proposal, predictability is presented as the main scientific challenge to overcome for the achievement of a desirable future reconciling marine biodiversity with industrial-scale fishing. Predicting how the ocean system, imagined as coupled social-biophysical system, will behave under a number of scenarios is the task of agent-based modelling. Agent-based modelling, then, promises to make futures calculable, rendering a realm of non-knowledge legible to governance institutions. This promise latches onto a still powerful Classical modernist discourse interpreting the unknown, here: more-than-rational behaviour in fisheries, as a temporary deficiency to be overcome through science, transforming non-knowledge into governable and optimisable quantities (U. Beck & Wehling, 2012). In the grant proposal, the use of numerical data and references to the scientific literature on overfishing and ecosystem decline mark out the space of certain knowledge. In contrast, terms such as volatility, complexity, and heterogeneity mark human behaviour as a space of non-knowledge, elusiveness, and the absence of control which needs to be rendered legible and predictable to solve the commons problem.

Arguing that "there are currently no tools available that adequately represent the complexity of fisheries," the consortium puts forward an operationalisation of human dimensions informed by behavioural economics and complexity science. The complex adaptive systems perspective on human dimensions understands the behaviour of fishing fleets as emergent macro-effects of micro-interactions modelled at the level of individual fisher agents. Importantly, these agents incorporate more-than-rational decision strategies departing from the microfoundations of mainstream economics:

> Traditional models of the behaviour of natural resource extractors typically treat individual agents as black boxes, optimising for relatively simple utility functions, given constraints such as price and extraction cost. We ... propose to inform our model of individual resource extractors (fishers) on a more psychologically realistic description of decision-makers, informed by insights from behavioural economics and cognitive psychology.

Claiming that the bioeconomic and ecosystems models currently in use in fisheries management cannot formalise this more-than-rational behaviour of agents, let alone the dynamics of their interaction, the consortium promises to model "realistic emergent group behaviour." Indeed, understanding how fishers respond collectively in an emergent way to marine management policies is presented as a central challenge to master for the problem of overfishing to be solved. As a result, the promise to finally make human dimensions legible for the knowledge instruments of ocean management translates an interest into global oceans commons into an interest in agent-based modelling of fisheries.

However, this translation did not proceed entirely uni-directional in favour of the consortium's interest in modelling fisheries in analogy to financial modelling. During the grant review process, the original proposal had to be modified. The funding body voiced concerns about project impact which entailed refocussing the project on engaging with the policy-making process of applied fisheries management. The grant proposal had been reviewed by two anonymous external reviewers and, as a result of their comments, the consortium re-submitted a revised version with extensive changes. The first reviewer spoke of the proposal in glowing terms, highlighting the fit of the project with the funding bodies' mission and strategy:

> It seems to me to be exactly the sort of project that your funder had in mind. It is an ambitious "big picture" project which has the potential to address an issue of vital global importance ... I think it highly likely that a number of major US as well as European donors will be willing to contribute to this project if the University provides the level of funding which is requested.

The second reviewer was more sceptical. While agreeing with the methodological approach combining agent-based modelling with computational policy optimisation, the reviewer found fault with the problematisation of non-knowledge about fishing behaviour as the key challenge to sustainable fisheries management, arguing that "the problems are more political than scientific in most cases."[10] Pointing out a lack of experience with applied fisheries management within the consortium, the reviewer criticised a certain naiveté as to the relation between scientific evidence and policy-making:

[10] This comment proved prescient. The material politics of fisheries management will be examined in chapter seven.

> There is a presumption that showing optimal solutions will be persuasive in a policy environment. Or put another way, while the focus of the work is that fisher's behavior is the key factor, in my experience it is the political process. While I think modeling fisher's behavior is interesting and useful, I wish there was a greater effort to understand what happens in the policy process, and perhaps even model that behavior.

As a result of this criticism, significant changes had been made in the revised version of the proposal. The project was now presented as re-focused on aiding policy-development and -implementation, stressing the "ease with which the model can be used by others." Reacting to the reviewer's comments, human behaviour was now re-framed as a barrier for policy implementation in applied management, emphasising the

> difficulties in developing and then implementing relevant policies ... complicated by the 'behavioural filter' of those doing the harvesting – typically a highly complex and heterogeneous body of fishers, who are themselves responding as individuals and as a group to a range of social, environmental and economic factors.

Furthermore, the revised proposal newly included a Policy Impact Strategy. This section identified the difficulties of operationalising human dimensions for ecosystem-based fisheries management and integrated ecosystem assessments as technical challenges for applied fisheries management. The consortium would now aim to provide a solution for these challenges, arguing that "uncertainty exists over how to operationalize ecosystem-based approaches to optimizing yield" with the result that formalizing human dimensions of ecosystems through agent-based modeling would serve an important practical need of fisheries managers. As part of this strategy, key influential actors in American fisheries science and governance were identified and listed as prospective partners in coordination with whom this practical problem of fisheries management would be addressed. After resubmitting the revised proposal, the consortium project was eventually funded.

Motivated by analogy to the inroads heterodox economic modelling has made into financial regulation, the imaginary spelled out in the grant proposal translates "global commons“ into the "Marine Resources Problem“ as a scientific and technical challenge. This challenge includes the re-invention of methods for modelling, predicting, and managing fishing behaviour as emergent aggregate effect of the more-than-rational decision strategies of individual fishers. A future is envisioned in which a marine resource ontology can be held on to and reconciled with marine biodiversity by formalising human dimensions, which so far have eluded the knowledge techniques of marine governance, in a way that caters to the assumed practical needs of fisheries managers. In so doing, the future envisioned in the pages of the grant proposal translates the funding bodies' problematisation of global commons into a problem of simulating human behaviour with agent-based modelling, claiming that preserving marine biodiversity is primarily a problem of managing emergent collective behaviour in complex systems. Prominent cultural discourses of technological risk and the temporality of non-knowing are mobilised to render more persuasive an envisioned future of sustainable marine resource exploitation as desirable and attainable. The following section will examine how the construction of the artefact which this imaginary renders meaningful, namely and agent-based model, is entwined with its integration into the knowledge infrastructure of fisheries management at the American West Coast.

4.3 "Socialising the model" as infrastructuring work

Promoting their future vision of sustainable oceans, the consortium successfully enlisted an important institutional funder and marshaled the financial resources necessary for launching their agent-based modelling project. However, in order to reform fisheries management practices, their decision-support tool had to be developed in such a way that the tool, and the imaginary rendering it meaningful to the consortium and its funders, could be embedded into existing environmental knowledge infrastructures. Ideas have to latch onto things in order to circulate and gain some traction outside of the communities in which they have been formulated; following Sheila Jasanoff (2015a: 327) we can understand embedding in this sense as a co-production or hybridization of ideas and material infrastructures. The epochalist drama, with its linear conception of time in which technoscientific progress overcomes catastrophic threat, would have the new replacing the old. However an infrastructural analytical lens affords an understanding of how envisioned futures come up against recalcitrant socio-materialities wherein imaginaries do not seamlessly mesh with infrastructures, but instead future natures are contested and modified in the more quotidian and messy settings of environmental management in action (Blok et al., 2016: 7, 13). In what follows I wish to illustrate the labour of infrastructuring with the example of a decision the consortium made about model coupling.

As a result of their Policy Impact Strategy, leading members of the consortium contacted high-level scientists and policy-makers working with NOAA Fisheries, the federal agency tasked with fisheries management. Early on, the consortium demonstrated to these high-level actors the novel technological and managerial possibilities promised by agent-based modelling. In their internal communications the consortium members call this work of enlisting influential actors "socialising the model.“ This certainly is one of those moments in an ethnography of technoscience where epistemic distance between ethnographer and interlocutor seems to collapse in a terminology that might well be shared among modellers and STS researchers (cf. Blok et al., 2016: 12). Science and technology studies have long stressed the co-production of social order and technoscientific artefacts, emphasising the necessity for engineers and scientists to simultaneously construct material and social relations for their projects to be successful (cf. Callon, 1986; Jasanoff, 2004; Pinch & Bijker, 1984). This simultaneous construction of the model as a material artefact and the social relations through which the model is embedded into the infrastructure of fisheries management, however, privileges some actors over others. Asked about the grounds on which the decision had been made to "socialise the model“ with high-level scientists and policy-makers rather than the fishers whose behaviour is being modelled, the principal investigator laid out a rationale shaped both by the funding arrangement of the project and a specific envisioning of the power relations in fisheries management. The principal investigator explicitly did not rule out speaking with fishers directly, but explained to me the need to speak first with key NOAA officials at this vital early stage of the project:

> There is another good reason why we're starting sort of at the top of the hierarchy if you imagine it as fishers at the bottom and NOAA at the top. Ultimately we want to talk to everyone, and get everyone's opinion, and everyone's feed into it, and we want everyone to be aware of it. So there is no sort of, uh, there is no strategy to exclude anyone, we definitely want to be as incl- ... and that's not just because we think that's the right thing to do but it is just purely pragmatic. The reason why we started with people at the top is because that is important to demonstrate to the people we want to get more funding from. That we are interacting with the people who are setting the policy. It is a very easy sell to say, look at this list of people that we are already talking to and who are taking this seriously ... There is a prioritisation of the people at the top at the moment because it is strategically good for our project, for the fundraising.

This presumed pragmatic need shaping who gets to have a say in the way the model is being designed at its earliest stage of development, however, is complemented with an envisioning of the power relations between fishers, scientists, and policy-makers stabilised with the help of the consortium's eventual work product:

> This is a tool that will guide a certain set of people, certain class of people. The people who actually decide policy. Of course it is them we have to socialise it to. Because ultimately it won't make any difference to the people doing the fishing whether their policy is generated by a human being or a Bayesian optimiser or an agent-based model or whatever, they'll just be confronted with a set of rules. So we work within the confines of what the rule makers will allow. That is why we are talking to them.

Envisioning users and use scenarios of the decision-support tool entails assuming specific power relations within fisheries management and asserting for their work product a specific role within these power relations. In this interview conducted at an early stage of model development, the principal investigator of the consortium assumed that resource managers have the power to set policy. Resource users, i.e. fishers, are imagined as lacking the power to contest the way those rules are being set for them. As a consequence, the decision-support tool is constructed to support the rule-setting work of resource managers.[11] Imagined as having little agency, the fishers whose behaviour is being modelled and whose work the tool is supposed to help govern are positioned as less important for the success of the consortium.

This orientation towards supporting the needs of resource managers informed decisions about the material design of the model. The consortium is aware of the necessity to modify their technical practice of designing the model in relation to the settings in which their model has to become a taken-for-granted, ready-to-hand tool for producing decision-supporting science. Their work of "socialising the model" with influential actors elicits design proposals in such a way that the consortium's work

[11] This managerial orientation of the project also proved consequential for the manner in which the consortium debated the design of the more-than-rational fisher agent at the core of the model. I will discuss this issue in chapter six.

product ties into the work practices, norms, and conventions existing in American fisheries managment. A major decision which resulted from this work concerned model coupling. Initially the consortium had planned to couple their ABM of human behaviour with an ecosystem model called ATLANTIS which had been developed by the Australian national research agency. In the original grant application, ATLANTIS figured prominently as "state-of-the-art ocean ecology model“ which would complement the consortium’s "most sophisticated fisheries ABM yet constructed“ in a rhetorics of innovation promising a "step change in the level of model sophistication, the use of models to assess desired system states, and the methods of analysis for developing new policy approaches.” However, as a result of their conversations with NOAA Fisheries the consortium decided not to couple their model with ATLANTIS after all. Instead they moved to a more modular approach where their agent-based model of human behaviour could be flexibly coupled with the range of biotic models already in use in the current infrastructure of fisheries management in the United States, namely single-species models or models of intermediate complexity. This decision was a major one since model coupling demands considerable investments of time and work for developing interfaces allowing for the interoperability of models and resolving the data frictions arising from such attempts to integrate different technical systems (Edwards, 2010). To account for this decision it is necessary to look at the fisheries management infrastructure in the United States as it spans across legal frameworks, organisational arrangements, and the norms and conventions governing the day-to-day practices of science advice for policy-making.

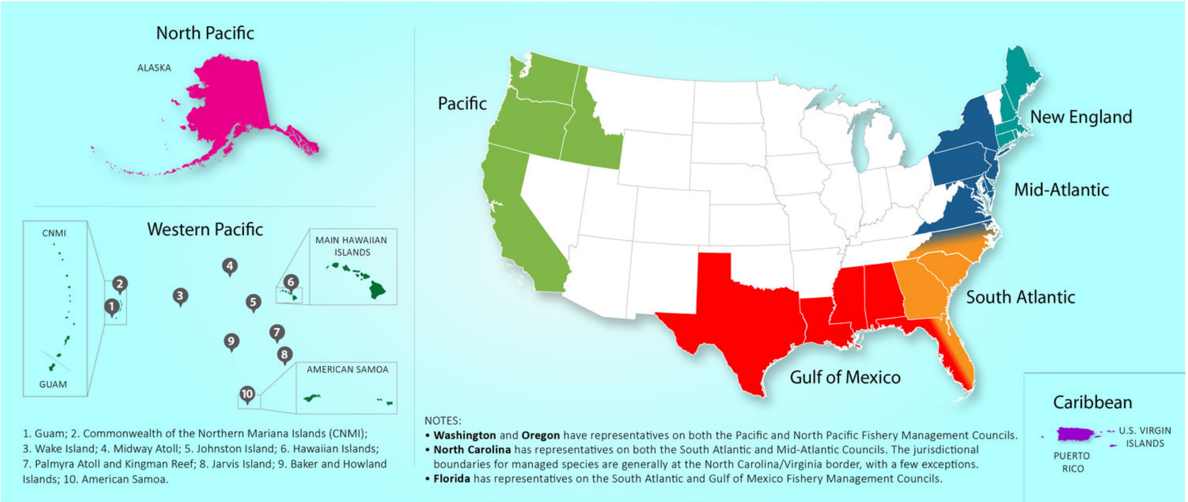

Fig. 1 Regional fishery management councils in the United States (Screenshot taken from http://www.fisherycouncils.org/ accessed 14 June 2018)

The legal framework for marine management is set out in the Magnuson-Stevens Fishery Conservation and Management Act. Reauthorised by Congress in 2007, the law requires that American fisheries be managed according to fisheries management plans prepared by regional fisheries management councils of which there exist eight across the United States (Fig. 1). The councils have to establish scientific advisory committees as well as ensuring the consultation of affected parties such as industry, consumer, and environmental groups. The key metric guiding the work of the regional fisheries management councils is Maximum Sustainable Yield (MSY) which defines the total amount of fish that can be harvested over a given time period. As stipulated in the legislation, operationalising and implementing the MSY metric is the core task around which work in the councils is organised. However, the Magnuson-Stevens Act also provides for the further exploration of ecosystem principles in management. The MSY metric is calculated by stock assessment scientists working at NOAA's regional fisheries science centers using sampling data fed into population abundance forecasting models. Their calculations are reviewed by the scientific advisory committee which will prepare an MSY recommendation presented to, and finally decided upon by, the Council. Under the National Environmental Policy Act, NOAA Fisheries also has to produce environmental impact statements detailing the expected impacts of proposed policy actions which council members will receive as decision-supporting information.

In the day-to-day practices of fisheries management, the incumbent MSY regime persists in the face of challenges by some actors to move towards an ecosystem-based approach. Different future natures are at stake in this challenge: namely, nature as a series of distinct resource stocks or nature as an ecosystem. In March 2016 I travelled to Sacramento, California to observe a meeting of the Pacific Fishery Management Council (PFMC) and conduct interviews with participants of the council process. Although I am repeatedly told by various interlocutors from the worlds of science and policy that the PFMC would be one of the more "progressive" councils because Ecosystem-Based Fishery Management is at least an established topic of conversation, the implementation of EBFM principles is flagged as a contested issue. At stake in this contest over the integration of EBFM principles and their attendant techniques into the decision-making process is the envisioning of multiple future natures in the California Current.

The knowledge infrastructure supporting the MSY management regime enacts marine nature as a series of distinct single-species fish stocks calculated in relation to efficient resource use by a representative economic agent. In contrast, EBFM figures nature as an interdependent ecosystem with a variety of relations between human and nonhuman elements. Here, the calculation of overall ecosystem health, e.g. through indicator species, troubles the single-species resource ontology of fish by embedding fish in webs of multiple ecological relationships. These different management regimes and their attendant calculations of plausible futures guide and justify decisions in the present with consequences for the distribution of prospective financial gain from a natural resource. At the time of my visit, the management process remained organised around single species or groups of related species such as groundfish. However, several conservation lobbyists relate to me that they are pushing for ecosystem indicators to figure more prominently in the Council's fishery management plan. So far they had mixed success because industry representatives contest the integration of EBFM principles into the process for harvest allocations. One of the lobbyists dismisses as "short-termism" the concerns on the part of the fishing industry that an ecosystem approach would lead to more conservative harvest quotas. A scientific work group established to develop the annual ecosystem report presents, in the words of a senior science advisor, "solutions in search of a problem," struggling to make their work relevant to members of the Council who decide primarily about harvest rules which are still set according to MSY principles. In the thicket of applied management, scientific questions take on a decidedly political tone when technical language about "integrating indicator species into the focal topic process" for establishing a "cross-FMP[12] framework" becomes a way of articulating divergent envisionings of future natures in the California Current.

As a result of these contests at the PFMC, the current settlement between different means of envisioning and calculating future natures constrains the suite of credible models. Arising from this settlement, the local norms governing the practical work of fisheries management eventually shaped the model coupling decision by the

[12] FMP stands as an acronym for Fishery Management Plan. The central work product of the Council, this regularly reviewed document details how a specific fishery is governed.

consortium. The work product of the PFMC, its scientific advisory committee, and associated science centers comprises a number of metrics and documents. In the vernacular of a member of a scientific advisory committee, their work falls into two main categories. Firstly "technical“ management, i.e. defining in regular time periods how much fish of a given species or species group can be sustainably harvested as legislated under the Magnuson-Stevens Act. Secondly, "strategic“ management which evaluates the possible ecosystem outcomes of policy changes including cumulative effects of policies as legislated under the National Environmental Policy Act. In Sacramento, I meet a long-serving member of the scientific advisory committee who had been listed as a key actor in the consortium’s impact strategy. The statistician-turned-marine scientist explains to me how frequent challenges issued by members of the Council to the knowledge claims of science advisors led him to appreciate particular types of models. These models, he believes, are better suited for producing a decision-supporting science capable of standing up to political scrutiny:

> Ecosystem models in particular are extraordinarily complicated. Even people like me, who have developed them, really struggle to fully understand how they behave on some occasions. In many, several places it may be better to use a simpler solution that people can understand, that they are able to understand the problem without getting into enormous complexity. (...) That does not mean that the simple model is right. It is certainly better when you stand up in front of decision-makers to be able to explain that you know why the result is as it is. If you just say, well, I applied the model and I got the answer, your chance of being accepted is not very high. Modellers do need to recognise that what we do is, we simplify ecosystems in huge ways. And not being able to even understand what we are doing, you know, you just have no credibility.

What is being articulated here is a form of boundary work that is to be expected in an organisation institutionalising science-based policy-making (Gieryn, 1995; Jasanoff, 1987). In these settings, boundaries between science and politics have to be negotiated between scientists and policy-makers who develop local and contingent norms governing the distribution between epistemic and political authority in their collaborative work. Noteworthy, however, is the way in which the frequent challenges to which the authority of scientific knowledge claims are exposed in the specific setting of the PFMC generated a local and contingent convention for delineating credible scientific knowledge (and its underlying modelling practices) based on the intellectual tractability of models and model results for both scientists *and* policy-makers. To adopt a distinction made by Jasanoff and Wynne (1998): in the world of science, models may well work as research heuristics, but for model results to cross over into the world of politics and both anchor the epistemic authority of credible knowledge about the future and justify political decisions in the present, models have to work more akin to unambiguous and fully tractable truth machines. Their use in fateful decision situations places specific demands for justification and legitimation on models which in turn shapes the modelling choices of scientists (Svetlova & Dirksen, 2014). Local and contingent conventions about permissible models establish a nexus between the predictive practices of science and the practices of deciding and justifying policy which constrains with the techniques for envisioning credible futures also the range of future natures that orient present decisions in the management process (Lane et al., 2011). Because they have to render their model results analytically tractable to policy-makers, science advisors developed a norm by which they permit only those kinds of models which are more likely to afford them epistemic authority in relation to the policy process.

Having been made aware of this local convention, the consortium resolves to change their strategy for model coupling. The state-of-the-art model ATLANTIS is sidelined in favour of a modular approach. Relating what he learned from demonstrating the modeling approach of the consortium to senior NOAA figures, the principal investigator of the consortium explains to me his rationale for the new modular model design:

> They use ATLANTIS to start the conversation, to get intuitions. But when it comes to the crunch and they actually want to hammer the table and say, right, you really must change because of this, then they use a much more simplified model where you can see, if this one goes up, that one goes down. It is really conceptually simple, but also quite robust. That tends to work much better. The conclusion we have come to is that we need to have both. Our model needs to be a module that can bolt onto ATLANTIS and that can also bolt onto an intermediate complexity model and it can also bolt onto something that is very, very simple (…) We have got this strategy now that we are building an adapter that allows us to plug into different things.

Intellectual tractability for policy actors emerges as a key affordance which the model needs to offer in order to be successfully embedded into the work practices by which scientists produce decision-supporting evidence. Different modelling practices of intuition and persuasion are contingent on the material affordances which different types of models offer different actors and their practices (Landström, Whatmore, & Lane, 2011; Merz, 1999b). These material affordances are consequential for the decision of how to couple the agent-based model with the environmental models already part of the knowledge infrastructure. The decision for modularity, i.e. designing an adapter for coupling the agent-based model to a range of biotic models, means that the ABM could in principle afford both intuition and persuasion. Moreover, the meetings with NOAA also recovered hitherto unmet requirements of prospective users, that is, ways in which the consortium's model might become a useful addition to the work practices of fisheries management. Under the National Environmental Policy Act the environmental effects of policy changes have to be evaluated in advance. The senior member of the scientific advisory committee I spoke with flags recurrent problems of evaluating cumulative impacts with available models. The ramifying effects of fishers' adaptations to policy change are difficult to establish with models of human behaviour derived from past behaviour under different regulatory conditions:

> Under a National Environmental Policy Act evaluation, which is part of the law that we work under, one has to look at cumulative impacts. To some extent that is exactly what you were referring to when you mentioned feedback effects. Having said that, some of those feedbacks are extraordinarily difficult to actually quantify. You can talk about, you know, if you put this regulation in, you would expect people to react to it and that would have some flow-on effects. But to actually document them is less trivial.

This difficulty of formalising and predicting the adaptations of human actors to policy change and their cumulative environmental impacts is indeed what the consortium has identified as "a service we are trying to provide, to key directly into their impact assessment for different policies," as the principal investigator puts it to me. However, providing this service for impact assessments shifts the prospective use scenario of the agent-based model from "technical" management replacing MSY, as originally envisioned by the consortium in its series of white papers, to "strategic" management removed from the seasonal setting of harvest rules. As a result, the imaginary of a future nature formulated in the white papers of the consortium encounters obstacles to its enactment. Attempts to embed the agent-based model, and the future nature it promises, into the knowledge infrastructure of fisheries management play out in a contested field where multiple envisionings of future natures vie for credibility.

Given these contests, attempts at successfully integrating the consortium's model have to engage with the relationality of infrastructure (Star & Ruhleder, 1996). As consortium members "socialise" the model, they elicit the conventions of practice organising the relations obtaining in the knowledge infrastructure of fisheries management. In turn these conventions then inform design decisions about the model in order for it to become embedded into the array of social and material relations between fisheries science centers, scientific advisory bodies, and the Council where implicit, local, and contingent norms about permissible modelling approaches producing credible evidence exist. For the model to become infrastructural, it has to conform to the local norms of the PFMC which ensure that some practices calculating future natures can support decision-making in a routinised way that preempts potential challenges to the credibility of the futures so envisioned. To the extent that the model-based knowledge practices at the NOAA fisheries science centres remain unproblematic and routinised both for the evaluation work of the scientific advisory committee *and* the decision-making of policy-makers in the PFMC, an infrastructural relation between modelling and policy-making can be established. In this relation, modelling supports policy-making with the former remaining largely hidden from the public performance of science-based decision-making in the Council. Socialising the model, as the consortium learned, entailed a number of choices affecting simultaneously the material design of software interfaces, the enlisting of prospective users, and the envisioning of use scenarios. These choices played out in a contested setting where an infrastructural relation between modelling and policy-making constrains with the suite of permissible models also the range of credible future natures.

4.4 Conclusion

The consortium envisions future oceans in which modelling the more-than-rational behaviour of fishers supports sustainable fisheries management. The imaginative anteriority of their agent-based model is organised by metaphorical trafficking between macroprudential regulation theory and ecology, mutually lending plausibility to heterodox projects of reforming the governance of both fisheries and finance. This analogy between fisheries and finance places the responsibility for the depletion of fisheries squarely on the behaviour of fishers, hitching a vision of global ocean futures to a narrative of crisis and control in another powerful sphere, namely global finance.

However, the embedding of this imaginary into the knowledge infrastructure of fisheries management plays out in a contested arena of situated environmental management. As a result, the future envisioned by the consortium does not seamlessly mesh with the socio-material world of American fisheries management, but instead encounters resistances issuing from an infrastructural relation between modelling and policy-making. Here, evidence is prone to public challenges which in turn shapes the material affordances of models considered useful and credible by scientists and policy-makers. The fatefulness of decisons in fisheries management places demands for legitimation and justification on model-produced evidence which inform the design choices of modellers, demonstrating the "real entwinement" of model construction and use (Svetlova & Dirksen, 2014). In this local arena of environmental management, knowledge claims about futures provide loci for ongoing contests between actors from industry, conservation, science, and politics. These contests are articulated with techniques for calculating future natures: both the established array of techniques calculating MSY based on forecasts which underwrite harvest quota allocations, and the array of techniques operationalising EBFM, of which the agent-based model is to become a part, are meant to orient and coordinate present action by justifying policy decisions. As these different techniques for constituting future natures are held by actors from industry and conservation to have distributional consequences, they become sites of contests over the credibility of future envisionings (Beckert, 2016: 85). The provisional settlement resulting from these contests leads to local and contingent norms governing the range of models permissible as evidence in the policy-making process. The "worldly encounters“ (Tsing, 2005) of the global socio-environmental future envisioned in the socio-technical imaginary of the consortium with the infrastructural work of modelling for environmental management at the American West Coast generate frictions which the consortium had to accommodate by simultaneously altering the design of their model and the scenarios of its intended use. The consortium's work of "socialising the model", then, is a practice of infrastructuring by which the model is embedded into a relation of routinised support to policy-making.

This particular way of equipping evidence-based policy-making opens into the "integrally material and political" (Slota & Bowker, 2017: 534) dimensions of environmental knowledge infrastructures. Regimes of measurement and technical regulation can have an anti-political effect of (provisionally) placing the objects of measurement and calculation outside of the space of contestation (Barry, 2002). In the case of calculating future natures, however, an infrastructural analytical lens alerts us to the moments when calculative practices themselves are moved in- or outside of contestation. Embedded into larger-scale organisational arrangements between fisheries science centres and management councils which are governed by conventions of practice learned by members of these organisations, infrastructural knowledge practices provisionally constrain the space of dissensus by allowing for the routinised production of regulation. The local and contingent norms and conventions of science-based policy-making developed in the arena of fisheries management, in conjunction with the material affordances of computational modelling techniques, constrain the kinds of future-oriented knowledge practices that can enter into an unproblematically supportive relation to decision-making. To the extent that science remains supportive of the smooth operation of policy-making without opening a space in which contests can be articulated, an anti-political and infrastructural relation between modelling and management will be maintained. The sites and occasions of infrastructuring work, then, emerge as sites of potential politics articulating different future natures. That is to say, outside of their normal functioning these sites and occasions of infrastructuring are characterised by practices through which different imaginaries vie for embedding into and shaping the knowledge infrastructure for producing credible future natures that order human-environment relations by orienting present regulatory action. To the question of who gets to imagine futures (Jasanoff, 2015a; Urry, 2016) we might then add the question of how these futures come to be realised, fail to do so, and are being modified in the local settings of infrastructuring work.

Different environmental knowledge infrastructures may conjure up multiple natures. This raises the question which kinds of future natures are at stake in this case of infrastructuring (Blok et al., 2016). While ecosystem-based management and its models may gesture at human-environment entanglements proliferating across a multitude of relations, the legal framework and the local conventions of fisheries management at the West Coast of the United States still hold an MSY-based resource ontology (cf. Richardson & Weszkalnys, 2014) in place where a single, rational economic agent exploits a singular, bounded resource. The consortium's design decision for model modularity, making the agent-based model interoperable with the biotic models currently in use, leaves this resource ontology of fish intact. However, replacing the representative rational agent with a multitude of more-than-rational agents, the model infuses human dimensions with animal spirits.[13] The following chapters will explore in-depth the practical performances and politics of this computational technique.

[13] In its perhaps most famous use by John Maynard Keynes, animal spirits denote the more-than-rational dimensions of economic agents.

Chapter 5 **Agile abstraction: circulating reference in computer simulation**

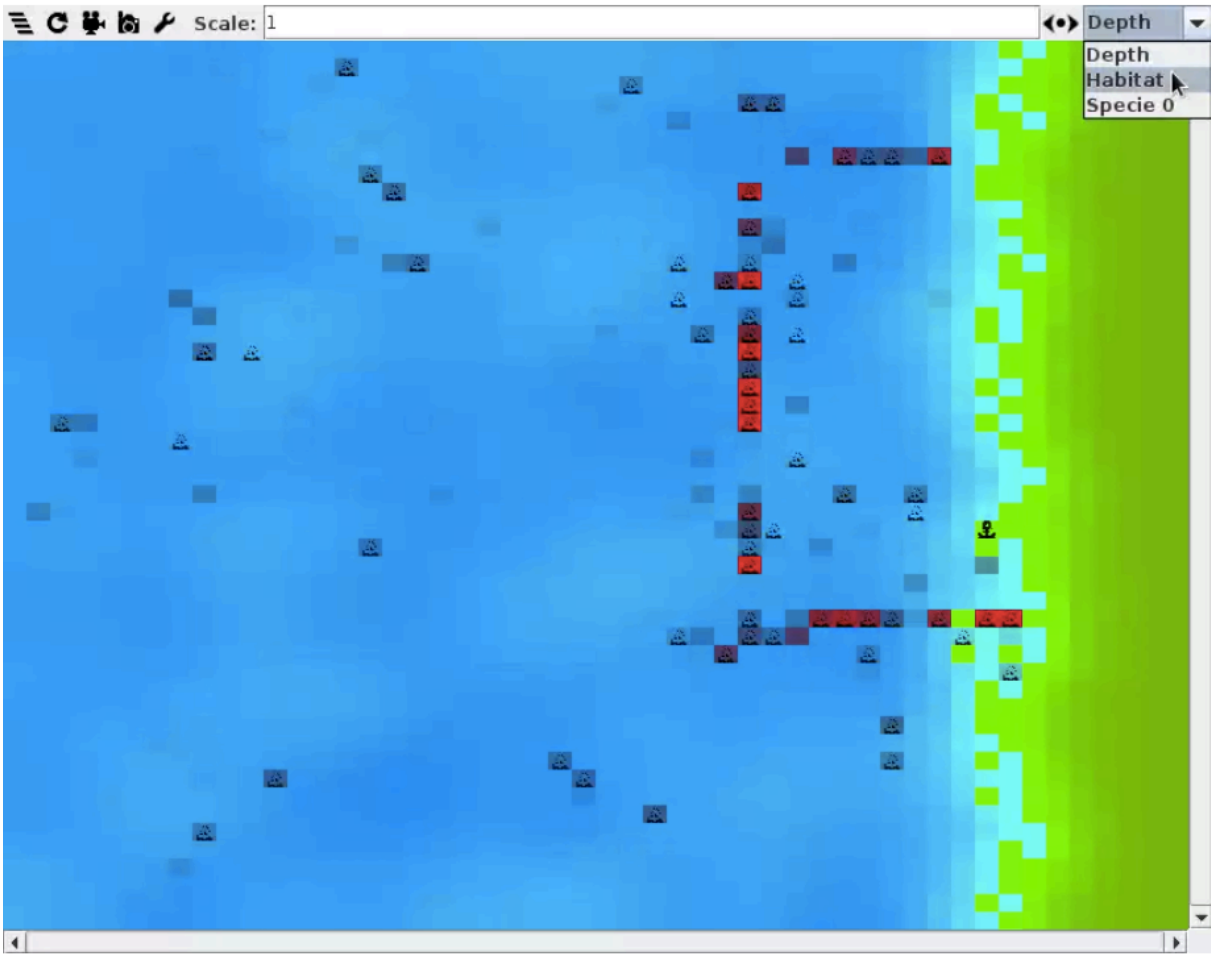

Fig. 2 Screenshot of a visualisation of an agent-based fisheries model. The coastline is on the right hand side with the square icons representing fishing boats self-organising into a horseshoe pattern during the simulation run.

A swarm of little oblong blocks swirls across the screen. We are in a university office in England, looking at a computer visualisation of an agent-based model simulating a commercial fishery. In a rectangular window there is a two-dimensional map with a stretch of green coastline bordering a blue ocean. An anchor symbol on the coast represents a port from which dozens of oblong blocks representing fishing boats depart, whiz out to sea, return to port, and depart again. As time passes the blocks/boats arrange into a pattern on the ocean grid that looks a little bit like a horseshoe (Fig. 2). A click on the reset button restarts the simulation. This time, the blocks/boats initially find different paths, the first few moments of the visualisation seeming like a chaotic swarming without discernible order. Yet after a while the symbols again arrange themselves into the horseshoe pattern. What I am watching unfold, I am told, is emergent behaviour in a fishery. The fishing boats, modelled each as autonomous agents making individual decisions, learn from one another over time that fishing at a particular place is more profitable. As a result of their individual decisions and interactions, a larger structure emerges: the horseshoe pattern.

The principal investigator of the research project explains to me the significance of what I see unfolding on the screen:

> As a group, they learn how to respond to things beautifully ... if one of them is earning more by randomly fishing in a place that is better, then they all learn that very quickly. The group learning is very, very effective. But it is very inefficient. Because it takes a few of them to find the solution randomly, and then for the networks to pick it up, and all of them to find ... so they do actually find the optimal response. Which is really pleasing. You can throw anything at them in the model, any sort of policy, and within a few time steps they all start responding beautifully to it.

On another occasion I sit with the postdoc in the team who implemented the model in code. We talk about what he had to do to produce the simulation generating the horseshoe pattern. He remembers:

> This was particularly complicated because it required a few things. It required habitat, but then it also required gear which looks at the habitat, and its catchability depends on it. And then I had to create a factory so that when I create a map I can tell it to be rocky. It was these three objects that had to be created at once in order to get this done. But once that's done, the rest of the model interacts nicely with it, and that is how we eventually end up with fishing the rocky line.

Here are two ways of talking about models and modelling. One way of talking about modelling is concerned with the generative properties of the model. The model responds in a particular way if you "throw" things at it. It generates questions about self-organised emergence, efficiency, optimality, learning, and the diffusion of information through networks. The other way is concerned with the architecture of the model. The model is an artefact to be constructed in such a way that it refers to something in the world. Modelling poses problems of software engineering: multiple elements of code are functionally interdependent and their interaction has to be taken into account when adding new code to the program.

The literature on modelling in science and technology studies distinguishes between different modes of modelling and their respective objects. In chapter two I discuss how science and technology studies argue for understanding models as multivalent objects which, relative to practices of authorship and use in which they are involved, appear as either epistemic objects whose open-endedness offers capacities for generating new knowledge or as technological things incorporating taken-for-granted knowledge (Merz, 1999). In a similar vein, geographers identify different modes of modelling relative to the expert practices which models equip, emphasising the socio-material relations and attendant knowledge making practices of modelling which together constitute distinct kinds of environmental expertise (Landström & Whatmore, 2014). Modelling involves different practices, socio-material relations, and object conceptions. Relative to their contexts of either construction or use, models appear as generative epistemic objects, open to interrogation and modification, or as black-boxed technical objects respectively. While my ethnographic encounter with fisheries modelling was limited to studying the construction of an agent-based model prototype and did not include its eventual use in fisheries policy-making, different practices, settings, and object conceptions were nevertheless present simultaneously, but distributed among the different members of the modelling team and their specific relations to the model they developed together. These different sites, practices, and by extension, conceptions, had to be aligned and coordinated for the model to be produced as a shared artefact. Moreover, the specific interests and practices did not line up neatly along divisions of authorship and use: different scientists participated at different stages in the authoring of elements of the model in coordinated ways.

This chapter documents how this coordination was achieved simultaneously with the representational work of rendering elements of the target domain of the model in software code. Modellers call this part of their work abstraction. Drawing on STS work on scientific representation (Latour, 1999c) and collaboration without consensus (Star & Griesemer, 1989), I wish to argue on behalf of understanding these interdisciplinary abstraction practices in modelling as creating coherence between disparate elements in at least two senses: first, the work of abstraction circulates reference, facilitating passage between different sites and materials. Second, at the same time abstraction holds together differently equipped knowledge practices in the making of a shared artefact. Rather than a reductive removal from the world, then, abstraction in modelling may be thought of as generating new socio-material realities (McCormack, 2012).

5.1 Simulation as practice: collaborating, coding, circulating

Modelling necessitates resolving problems of collaboration between heterogeneous actors. Groups of scientists with different practical skills, disciplinary knowledges and techniques have to arrive at a shared modus operandi that is both flexible enough to accommodate those differences and coherent enough to allow for the coordination of their activities. Decentering the rational mind, actor-network theory has developed the conceptual vocabulary of interessement, enrolment and translation to theorise the ways in which scientists achieve knowledge-making projects through a series of practical negotiations with heterogenous human and nonhuman counterparts (Callon, 1986). While this conceptual vocabulary facilitates a symmetrical analysis of the social processes involved in a collective epistemic quest, the agonistic and uni-directional rendering of translation in Callon (1986) needs to be complemented by an analytical vocabulary that accounts for the multi-directionality, provisionality, and ambiguity obtaining in heterogeneous, collaborative work arrangements. Moreover, the original model of translation stresses stratagems of interessement and enrolment that hold less purchase in an empirical situation of collaborative model construction where, other heterogeneities notwithstanding, a shared commitment to a common project can be presupposed.

As a consequence I wish to argue for a modified reading of the concept boundary object (Star, 2010; Star & Griesemer, 1989) as better suited to theorising the ways in which the heterogeneous team of modellers develops a mutual modus operandi in order to produce a common artefact. The concept boundary object, as originally developed by Star & Griesemer (1989), attempts to explain work arrangements of ongoing collaboration in the absence of consensus. Residing in a liminal space between actors with each different knowledges, the boundary object remains relatively ill-defined, i.e. open to differing interpretations, yet simultaneously provides a shared structure to be worked on collaboratively. Occasionally, its interpretive flexibility will be reduced when the boundary object is worked on in a specific setting with a greater coherence of interpretation. This movement back and forth between ill-defined and locally tailored object states, as well as interdisciplinary and disciplinary work settings, respectively, constitutes the particular dynamic of the collaborative work process facilitated by the boundary object.

The concept boundary object had been presented as a corrective to the unidirectionality of the translation model of actor-network theory (Star & Griesemer, 1989) and would on a superficial reading seem to emphasise the material mediation of social action. However, its provenance in symbolic interaction theory (Star, 2010) suggests subject/object and meaning/matter dualisms that call for some modification of the concept in order to account for the relationality and materiality of scientific work as it plays out in the collaborative situation of interest here. In symbolic interaction theory, an object is the result of an indication by which an individual renders phenomena perceived in its environment meaningful to itself, drawing for this interpretive act on a symbolic repertoire learned from interactions with other people (Blumer, 1962). This emphasis on human meaning-making as antecedent to engagements with materialities, wherein the symbolic is held separate from and comes to determine the material, is retained in the boundary object analytic as it stresses the mediating work between different disciplinary knowledges furnishing different interpretations of the same object. While influential in studies of interdisciplinarity, this focus on the symbolic dimension of interpretation rarely explicitly addresses the role which the specific material practices forming part of disciplinary expertise might play in the need to coordinate different ways of knowledge-making (Landström & Whatmore, 2014; see also Mol, 2002). As a consequence, I wish to modify the boundary object analytic with the aid of an anthropology of affordances that locates meaning neither as inhering in an essential quality of objects nor exclusively in cognition, but rather in the processual in-between of active practices enacted along and through multiple relations with objects (Ingold, 2011). In this reading, the interpretive flexibility and coordinating capacity of a boundary object is as much contingent on heterogeneous disciplinary knowledges as it is on the affordances it offers in relation to the heterogeneously equipped material practices with which disciplines enact their orderings in specific settings.

Coding as a material practice equipped with software engineering tools is a constitutive element of the heterogeneous expert practices that need to be coordinated in the collaborative authoring of the model. With some exceptions (e.g. Gramelsberger, 2006), studies of simulation modelling practices have yet to pay close attention to the production of software code. However philosophy of science has flagged the opacity of software code and computational processes as a problem for scientific authority claims in simulation modelling (Humphreys, 2009). Software may seem an abstract and immaterial thing. Yet software has to be written as lines of code, by someone, at some place, under certain conditions, using specific devices. Software studies have highlighted the materiality of code through advancing a relational analytic of software where what comes to matter are the lively conjunctions of code with what lies outside of it (Fuller, 2008). Folding the outside into code, programming mixes the strict orderings of computation with the unruly materialities it formalises. As the result of a "process of engagement between thinking with and working on materials" (Fuller, 2008: 10), programming as a material practice encounters material agencies operative across multiple scales including programming languages and other interfaces with computational equipment.

Yet computer simulation at first glance appears as a site bewilderingly devoid of the panoply of materials, instruments, and fixtures foregrounded in many ethnographic accounts of scientific work (Helmreich, 1998: 31). The absence of field and laboratory in simulation might tempt an imagination of coding work as centred around solitary human programmers designing effortlessly malleable virtual worlds. While research at the sites to which computationally generated knowledge travels certainly remains important for understanding how models come to matter, programming and its sites would seem to be particularly salient loci for praxeographic investigations of science at a moment when scientific forms of representation are increasingly produced by means of simulation. In chapter two I discuss how praxeographies of scientific modelling draw out its more-than-rational dimensions, focussing on the materially mediated practices with which models are constructed. Following Latour's injunction that the ethnographer of science shall not "grant to the scientific mind what should be granted to the hands, to the eyes and to the signs" (Latour, 1990: 52), simulation practice, too, may be described as being constituted through socio-material relations, relying on as well as being shaped by material means such as programming languages and development environments. Latour (1999) theorises scientific representation as a practical achievement of circulating reference through a series of material transformations and spatial displacements. The provenance and durability of particular model parameters has been investigated in a similar fashion (Whatmore & Landström, 2011). Closely attending to coding as a socio-material practice, I wish to bring into relief the ways in which abstraction work in computer simulation, too, circulates reference through concatenations of objects, symbols, and practices where the software-generated visualisations on a computer screen sit at the end of "a whole process of mobilisation" (Latour, 1986: 16).

In order to understand model abstraction as a materially mediated practice it is necessary to account for the agentic contribution of the objects equipping the production of simulation software. Attempts at theorising the agentic contributions of materiality in computational modelling turn on the generative potential of affordances. Knuuttila (2005) operationalises these affordances as materially embodied constraints shaping the course of modelling work by enabling specific perceptions and actions. Landström, Whatmore, and Lane (2013) conceive of material affordances in modelling as productive obstacles encountered in attempts at manipulating models as obdurate technical artefacts incorporating interdependent, concatenated elements where changes proliferate throughout the network of relations. While these literatures emphasise the generative role of affordances in shaping the direction of modelling practices, they address practices that are different from the abstraction work that is of interest here: Landström, Whatmore and Lane (2013) are primarily interested in how modellers learn about the environment through improvised negotiations of affordances and obstacles in modelling. While Knuuttila (2005) is interested in the question of representation, affordances matter only in relation to the model as a "material sign-vehicle" rather than in relation to all of the materially mediated practices which have to be coordinated in the process of abstraction. Yet a framework capable of accounting for abstraction as the collaborative work of representation would also need to account for the multiple, layered affordances generated by an interdisciplinary setting characterised by differently equipped expert practices.

I wish to argue on behalf of work in new media studies on media ecologies as a framework for understanding the materiality of abstraction work. Proposed by Fuller

(2005: 2) as part of a materialist theory of media, the concept media ecology attempts to capture a sense of the "dynamic interrelation of processes and objects, beings and things, patterns and matter" obtaining in informational environments. Set against notions of informational environments as immaterial scapes, work on media ecologies foregrounds questions of materiality and agency by deploying a relational theory of affordances in order to draw attention to "capacities of activity, thought, sensation and affect" (Fuller, 2005: 174) arising from the composition of media objects and practices. While similar to the work on affordances in modelling discussed above, work on media ecologies particularly emphasises the compositional and dynamic character of the layered affordances of multiple media objects crafted together through some practice or act of performance. Rather than analysing affordances of objects in isolation, this media ecological perspective focusses on "the ways in which medial dynamics in combination generate behaviours, qualities, and openings that are more than the sum of their constituent, codified paths" (Fuller, 2005: 24). This compositonal and dynamic notion of media ecologies offers greater purchase on the collaborative and multidirectional character of abstraction work: shuttling back and forth between situations of shared interdisciplinary work and local disciplinary settings, abstraction work is characterised by dynamic connections between different yet partly overlapping practices and media objects. From this relational and materialist perspective, abstraction work plays out within a media ecology of multiply layered affordances generating situations of lively contingency where the achievement of software code formalisation is a temporary settlement between heterogeneous agentic capacities. In the remainder of the chapter I will trace the process of abstraction which circulates reference through the media ecology of computer simulation.

5.2 Prototyping the toy model

At the early stage of their research project when I had the opportunity to observe their work, the scientists qualify their model as a prototype or, in their own vernacular, as a "toy model." Developed in a collaborative effort within the research group, the prototype is meant to demonstrate that the simulation methodology the group chose to work with shows some promise before the work of integrating data-derived representations of the oceanographic, marine biological, and human features of the target domain can begin. Before embarking on the laborious task of negotiating access to the required data sets for the fully-fledged model, the group produces, discusses, and showcases within the team and to prospective funders and collaborators a stripped-down "toy model" as a proof of concept of their chosen simulation methodology. Prototyping is a common practice in technology design. Grounded in sociological research on technology design as the processual alignment of social and material relations, Suchman, Trigg and Blomberg (2002) argue for understanding prototypes as artefacts constructed in ongoing interactions between designers and prospective users of technologies. Rather than implementing user needs assumed to be preexisting and stable in a technological artefact, prototyping practice instead "simultaneously recovers and invents work requirements and technological possibilities that each make sense in relation to the other" (Suchman, Trigg, & Blomberg, 2002: 166). The prototype as a device partially aligns heterogeneous knowledges, work practices, interests, and sites into a coherent assemblage through a series of demonstrations of a workable device that orient diverse actors towards a common object and occasion conversations about just what it is that the design project wishes to achieve.

What further motivates the collaborative work on the prototype is the team's concern with the validation of their model. As the team members strive to construct a computer simulation which faithfully represents its target domain, they try to recreate in the model significant phenomena observed in the target domain and, by constructing their model in such a way, are enabled to claim with some confidence that the simulation will have predictive power when manipulated in hitherto unobserved ways. As a participating marine scientist explains to me,

> I think that on the level where we are building the toy model, when we validate it, we need some test case that we know a lot about empirically and where there is interesting behavioural change on the human side.

The claim to eventual predictiveness, here, hinges on the successful mimesis in the model of selected phenomena observed in the past that the participating marine scientists take to be well-supported by empirical evidence in their domain of expertise. Fisheries scientists on the team contributed a list of policy scenarios which the prototype is meant to recreate and circulated brief scenario descriptions within the team. These scenarios describe existing marine management policies such as individual transferable quotas, marine protected areas, total allowable catch, gear restrictions and their expected outcomes in terms of fleet behaviour and ocean ecology. One of the marine scientists explained to me how he assembled the list of scenarios with a view to the eventual validity of the toy model:

> We are sort of simulating a simple system to see if we get the qualitative behaviours that we know and have seen in these fisheries. In the prototype model we had a small set of policies that we would have on/off switches for. What they asked me to do at that stage was, can you give me empirically well-validated hypotheses that are like, if I do policy x, biomass goes in direction y, or number of boats goes in direction z. That is where that list came from. The example I gave earlier was, in every fishery that has seen catch shares, the number of boats goes down. (laughs) So that better happen in the model we build!

The perceived need for testing whether the prototype can successfully recreate these well-described scenarios issues from the novelty of the simulation methodology, agent-based modelling, which aims to simulate the phenomena of interest as emergent global properties resulting from the micro-interactions of artificial software agents with their environment. It is a peculiarity of this methodology frequently emphasised in my conversations with the scientists and modellers that the system-level, aggregate behaviour shall be emergent, that is, generated "from the bottom-up" rather than "hard-coded" into the model. In order to avoid what one scientist calls "circularity", they cannot explicitly program the agents in the model with a decision rule that would produce the expected outcome of a specific policy scenario. Rather than that the outcome has to result from feedbacks between policy regimes, static agent decision rules, and the ecosystem conditions in which both play out:

> With an ABM you can try out any combination of policies x, y and z that you want. You just make a button in the interface, you don't have to change anything about how the agents work, it's just sort of a rule, it is like an externally imposed rule that they have to follow. And then the consequences of those policies become emergent. And so you can create this very flexible platform for testing a huge range of policies.

The marine scientists consider the fishing-the-line phenomenon discussed in the introduction as a particularly suitable test case as it had been well documented by a former graduate student in their research group and involves a number of interactions between different policies, fisher's decision-making, and ocean ecology. The work of that graduate student on marine protected areas (MPA) and catch quotas (ITQ) on the Pacific Coast showed that, whereas bycatch-protecting MPAs would generate strong fishing-the-line behaviour because fish move across MPA boundaries, the addition of ITQs for bycatch would have the adverse affect of fishers trying to avoid catching costly bycatch around MPAs:

> That is a very powerful test for the model because of different combinations of policies: turn on just MPAs and [fishing-the-line] should go up, turn on ITQs it should be lower than it was in the first place without changing the fisher decision rule. That is a really powerful test case!

Hence the manifest function of the prototype as expressed by the scientists themselves is to demonstrate that well-known policies and their expected outcomes can indeed be recognisably simulated using the agent-based approach while at the same time indicating technical and epistemic possibilities of testing, predicting, and optimising policy outcomes not yet available with existing analytical modelling techniques. At the same time as producing a working prototype for showcasing to governmental agencies and scientific collaborators, the prototyping process creates a shared understanding of the purpose of the project, its specific interest in and problematisation of marine management, and the novel technological possibilities afforded by agent-based modelling within the team itself. Just as importantly, however, the process allows for the coordination of practices across a diverse ecology of media with which programming the model is realised.

5.3 A media ecology of modelling

An incomplete list of the elements obtaining in the media ecology of modelling work could begin with the Java programming language, object orientation as a programming paradigm, the integrated development environment IntelliJ IDEA, the online code repository Github, the groupware platform Asana, agile story cards, the Google search machine, and not end with numerous scientific papers about fisheries ecology as well as data sets and reports of regulatory agencies. Such an enumeration, Fuller (2005: 15) argues, hints at the potential agentic capacities arising from a media ecology when its heterogeneous elements are assembled through some practice or performance. Before turning to an ethnographic episode describing such a practice of crafting together heterogeneous elements in the next section, I wish to firstly turn towards some of these elements in greater detail in order to render a more richly textured account of the affordances they might offer in composition.

5.3.1 Object orientation

The work of the postdoctoral research assistant tasked with developing the software for the prototype model, whom I will call Emilio, is characterised by the need for working across disciplinary difference and geographical distance between him and his collaborators. Based at a research university in England, Emilio is an economist with extensive graduate training in software engineering for computational social science methods. While he has developed a number of agent-based models for a range of domains, he tells me that he has never worked on an environmental or marine-related project before and knows very little about fisheries science. Emilio's expertise instead lies in developing the software code for agent-based models. His work process is equipped with a number of software applications and development methodologies facilitating what he is at pains to emphasise is an object-oriented approach to software development. Object-oriented programming designs software systems as sets of interacting objects each of which represent an instance of a class (C. Crutzen & Kotkamp, 2008). A class describes a generic kind of object, and an object is a specific instantiation of a class. Objects have states and behaviours, and a key principle of object oriented programming is encapsulation: the inner mechanisms of an object giving rise to its behaviour and altering its state are hidden from other objects. Objects interact by passing messages between them when an object "calls" another object through an operation allowed by its interface. Encapsulation introduces a distinction between the observable behaviour of an object and the mechanisms giving rise to this behaviour, and allows programmers to change the implementation of individual objects without disturbing the functionality of the overall program.

As a paradigm for designing software systems, object orientation significantly departs from earlier ways of creating software. Specifically, it affords a shift away from the physical computing machine and towards the problem the computation is supposed to solve (Booch et al., 2007: 29). On the level of machine languages, programming a computer proceeds by giving an electronic machine a linear sequence of binary instructions. Higher-level programming languages, while closer to the semantics of human language than binary, still demand such a linear, stepwise coding of a sequence of instructions. While procedural programming introduced functions that organise the code into groups of repeated routines referenced by name, thus allowing for a more efficient economy of coding by eliminating redundancies, procedural programming still designs software systems as a linear sequence of master instructions executing subroutines. Object orientation breaks with this style of software design as the coding of a linear sequence of instructions to a machine by encapsulating the instructions inside of interacting software objects (Alt, 2011). Object orientation affords a shift in the way developers perceive and act with software while writing code: rather than decomposing a system into algorithms, i.e. the stepwise flow of a linear process, object oriented programming "sees the world as a set of autonomous agents that collaborate to perform some higher-level behaviour" (Booch et al., 2007: 17). Instead of a linear sequence of instructions for a computer processor, object oriented programming configures the software system as distributed interaction of networked computing units linked in ad-hoc loops of message-passing.

A recent textbook on agent-based modelling claims that most agent-based models are realised using an object-oriented design approach and programming language (Gilbert, 2008: 22). The genealogy of object orientation can be traced back to the development of systems theory and accompanying practical problems of systems simulation in the 1960s. The SIMULA programming language, developed by Ole-Johan Dahl and Kristen Nygaard between 1962 and 1967 at the Norwegian Computing Centre in Oslo, is credited with gesturing for the first time at basic concepts of object orientation such as classes, objects, encapsulation, and inheritance (Black, 2013; Holmevik, 1994). Having a background in computer-aided systems simulation, the Norwegian scientists were concerned with formalising complex, heterogeneous real-world systems in standardised ways so as to make procedures for systems description more easily amenable to computer processing. Representation and coding were entangled from the outset in the development of SIMULA as "simultaneously a systems description and a programming language [requiring] both systems reasoning and programming skills" (Holmevik, 1994: 27). Drawing on a series of case studies, including airport departure systems and epidemiology, the researchers developed a generic systems description predicated on capturing "joint activity within the system itself" and implemented in code as a "series of interacting quasiparallel processes" rather than "described as a general mathematical structure" (Holmevik, 1994: 32). The basic element of a system, then, was a process, in later terminology called object, and systems were to be simultaneously understood and simulated as concatenations or networks of interacting objects.

In the late 1960s SIMULA had found its way to the United States where a graduate student at the University of Utah College of Engineering, Alan Kay, had been tasked by his supervisor with reading the technical documentation of the programming language. His undergraduate degree in biology furnished Kay with a corporeal metaphor for recognising the class/object structure as an analogue to developmental processes in the organism: both morphogenesis and the semantics of SIMULA would build up complex structures from the interaction of relatively simple, versatile components (Kay, 1993). However whereas SIMULA had been developed in the world of mainframe computing for large-scale industrial and defense applications, Kay was interested in the fledgling technocultural discourse of personal computing that developed at the time around American technology research institutions such as Xerox PARC in Palo Alto (Turner, 2006). After Kay moved to Palo Alto, his involvement in the project of wresting computing from institutional settings and bringing it into everyday lifeworlds led him to believe that programming languages needed to be extensible beyond specialised applications and predictable use scenarios. A versatile approach to programming was needed that allowed non-specialists to simulate any system on a computer, and that could deal with the contingencies brought to IT applications by users not trained in computer science. To Kay, the object metaphor gleaned from SIMULA provided just that. Having this metaphor at its core, the first dedicated object-oriented programming language SMALLTALK which Kay developed at Xerox PARC embodied his belief that

> everything we can describe can be represented by the recursive composition of a single kind of behavioral building block that hides its combination of state and process inside itself and can be dealt with only through the exchange of messages (Kay, 1993: 3).

As a recursion on the notion of the computer itself, object-oriented programming was to be understood as the design of software systems comprising a network of message-exchanging computers running on a computer, and the human user was fashioned as yet another object with state and behaviour linked to the machine via concurrently developed interactive devices such as the computer mouse and graphical user interfaces. Kay condenses this approach to programming in the principle that "everything is an object" (Kay, 1993: 19). Object orientation has subsequently informed the development of dedicated programming languages such as Java and has been adopted as the dominant design methodology across a wide range of computer applications including agent-based modelling.

5.3.2 Integrated Development Environment

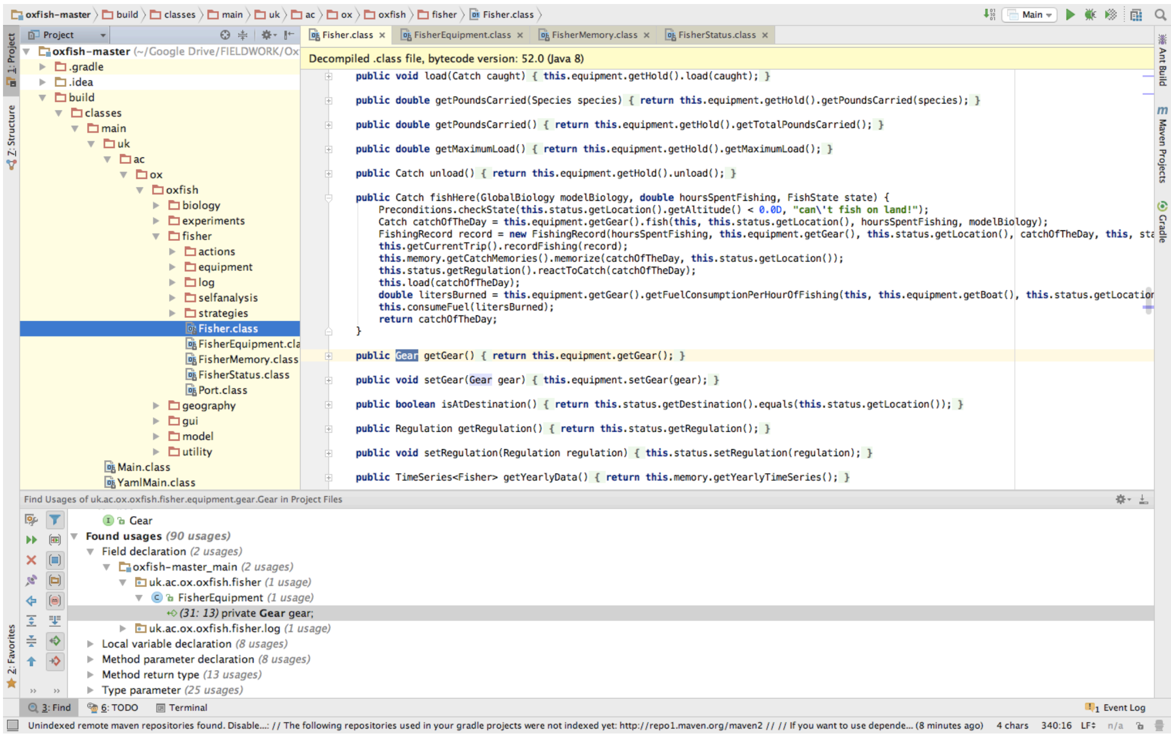

Fig. 3 The graphical user interface of the integrated development environment (IDE) showing how the class `Gear` is linked across the software system.

As I spend more time observing Emilio's work, I notice a key device equipping his programming work: the Integrated Development Environment or IDE (Fig. 3). When I ask Emilio during some of our meetings to explain the code to me, he opens on his ThinkPad laptop the application IntelliJ IDEA, an IDE developed specifically for object-oriented development in the Java programming language. A turbulent journey along hyperlinked, clickable chunks of code ensues with Emilio providing running commentary on the operations of various lines of code; a staccato of elliptic everyday language conjoined with code speak that makes my head spin:

> New tile habitat ... given the hardPercentage here was ... just put it equal/= ... and here it is the same, this.proportionFixed = proportionFixed ... if you ever have to make a copy just call the constructor again, very simple.

Over and again I have to ask him to slow down, go back another step, repeat what he just said. Emilio's own navigation within the development environment is skilled to a degree that its various digital objects are ready to hand, their affordances smoothing into an uninterrupted flow of perceptions and actions along the edges linking software objects across the program (Ingold, 2011: 83). Lacking Emilio's skill of perceiving with code, I immersed myself within this media ecology, installing the IDE application on my own MacBook and retrieving the code from Github in order to painstakingly retrace our journeys through code from my recordings of those meetings.

In appearance resembling a word processor combined with a file manager, an IDE is a program with a graphical user interface allowing code to be written in a nonlinear way. The IDE helps to organise the software system into distinct chunks of code which are stored, classified, and accessed through a file browser as components of a larger system. Much of the time of programming is actually devoted to inspecting existing code using IDE functions: browsing and searching for classes, analysing dependencies, keeping track of the hyperlink trails crisscrossing the code along which data flow when the program is executed. Through its hypertextual explorability of the software system the IDE invites perceiving the model as a network of concatenated yet distinct software objects that refer to abstractions of the target domain.

5.3.3 Groupware

Fig. 4 A corridor of the marine research facility in California.

Emilio's collaborators work in an interdisciplinary fisheries science research group comprising biologists, ecologists, and economists in the department of marine science of a public research university in southern California (Fig. 4). The department sits atop a hill overlooking a lagoon adjacent to a major marine protected area; indeed, when visiting during my fieldwork I was assigned a desk with a view on the Pacific ocean, and my host proudly pointed at the window suggesting that sometimes whales and dolphins could be seen from where I sat. This proximity to, and intimate familiarity with, all things maritime was emphasised not only through the starfish ornaments adorning the building itself, but also in the self-presentations of several of the marine scientists on the departmental website as their portrait photographs showed them scuba diving, holding a fishing rod, or perched on a boat gleefully presenting marine organisms to the camera. The scientists of the Californian research group are trained in and have published on a number of mathematical modelling techniques including bioeconomic modelling, ecosystem modelling, and population modelling for stock assessment. However while acknowledging the expected benefits of an agent-based modelling approach, few of them have worked with this modelling methodology before, and none holds expertise in object-oriented programming or is familiar with Java, the programming language with which the prototype is implemented. Although they could technically access the code repository of the prototype model, none of them have actually done so; instead the Californian team members focus on formulating research hypotheses and assisting with substantive questions arising in the process of assembling the prototype.

The team bridges the geographical distance between them with the help of week-long biannual meetings held in places like Washington, Seattle, or New Orleans as well as regular telephone conferences, frequent emails, and an online project management platform which they use to communicate via message boards, assign tasks to each other, and exchange files. Rather than receding into the background as an informational infrastructure (Star & Ruhleder, 1996), this online groupware application itself frequently becomes foregrounded as the object of attention: principal investigators and project managers exhort team members to use the message board and task assignment functions more consistently, addressing latent insecurities about proper conduct regarding hierarchy and role distribution within the team which might obstruct the integration of the groupware into the daily work practices of the group. Emilio explains to me that the achievement of the episode of work discussed in this chapter relied to a large extent on the team actively working with and resolving a problem using the groupware. About this he expresses a satisfaction that I share with him since the digital traces the team left behind aid my task of documenting their collaborative abstraction work.

5.3.4 Agile programming

Emilio describes the Californian fisheries scientists as his "clients" to whom he has to hold his work product accountable. Importantly, it is the clients who both initialise an episode of programming work through providing a "user story" which describes in narrative form a scenario to be simulated, and who eventually confirm whether Emilio has succeeded at the task of recreating the phenomenon in a way they consider as valid. This distribution of roles also distributes expertise along lines both disciplinary and pragmatic: the Californian fisheries scientists double as "domain experts," holding substantive expertise about the fisheries to be modelled, and as proxies for the eventual users of the decision-support tool that the model will form part of. Emilio, on the other hand, somewhat modestly considers himself as "mostly the coder" with the technical proficiency and responsibility to implement in code the user stories formulated by his clients.

However this boundary and its implied distribution of roles remains subject to ongoing negotiations as it is not always immediately obvious which questions arising in the process of prototyping are strictly of software engineering and which of scientific nature. In one instance Emilio intended to couple the agent-based model with an oceanographic model developed by another research group and encountered a mismatch between the spatial orderings of the two models which worked with cells and polygons respectively. This unruliness of system interoperability and the lack thereof, and the labours necessary to resolve it, constitute a case of what Edwards (2010) recognises as "friction" in model development and scientific collaboration more generally. Several methods of coupling cells with polygons were technically feasible in this case, but they would each produce different model outputs. Emilio understood it as his responsibility to present these different technical possibilities to his scientific collaborators and leave to them the choice between the options and their different outcomes. Here it is the software engineer who explores and renders explicit material affordances and presents them as technological possibilities generating different epistemic effects to the scientists to choose from. Differently put, the situations of ambiguity sparked by the friction between software systems, and the way they are resolved by negotiating specific responsibilities for their resolution, occasion boundary work between the role and remit of scientist and engineer, or client and coder, within the team while moving the project forward.

The term "client" betrays the origins of this way of structuring the software development process in commercial software engineering methodologies. Emilio explains that his work process is inspired by agile programming. Agile or lean software engineering methodologies were developed beginning in the 1980s as a response to structured software engineering methods that relied on detailed planning and management, extensively analysing and documenting system requirements in the form of a contract between developer and user at the beginning of the project and then coding functions as "downstream" implementation. In contrast to this top-heavy forward-planning approach, agile denotes a software design approach that "seeks to organise the gamut of software development in loops or iterations" (Mackenzie & Monk, 2004: 101) which place at their centre the "ad hoc craft practices" (Mackenzie & Monk, 2004: 93) of writing and testing code rather than relegating the production of code to the execution step of a process dominated by comprehensive planning of the entire software system.

Agile methodologies deploy a number of techniques meant to facilitate a close and continuous collaboration between developers and users, encouraging the iterative production of usable pieces of software in a quick succession of workable demonstrations. Agile software is produced in shorter iterations and with a principle of simplicity in mind: developers are encouraged to frequently showcase demos to users, soliciting feedback and requests for modifications, while at the same time attempting to design and code those and only those functions needed to fulfil the client requirement in the simplest possible way. This close and frequent collaboration between developers and users necessitates finding ways of structuring the ongoing cooperation between actors situated at different sites, in different material environments, and approaching software development with heterogeneous skills, knowledges, and interests.

An important device with which agile programming organises this cooperation is the story card which explicates those functions of the system the client demands. As the programming proceeds, story cards are transformed into tasks to be implemented in a cyclical process that iterates through narrative articulation, task clarification, code implementation, and unit testing. Tying together "in a rule-governed process a very disparate set of work processes and relations involving management, 'the customer' or client and all the members of the software development team," Mackenzie & Monk (2004: 114) argue, the story cards index progressively developed shared understandings of the system and temporally structure the work process in iterative loops. From the incremental addition of relatively simple functions eventually a complicated software system grows simultaneously with a shared understanding of its meaning and significance without the entire team collaborating on the system needing to understand the technical details of each implementation. Emilio has adapted a version of agile programming to suit his needs and shows me on the screen of his ThinkPad laptop how he shuffles story cards between columns from initial formulation to eventual implementation:

> What happens is that we write a short, little story of what the policy is supposed to do or what it is expected to do. And that is a user story. What the policy is, what we think should occur. We start coding the policy until I can show it to the domain expert who created the user story and say, look, do you think this result, this simulation run, makes any sense? And he could say yes or no. He could say he wants to check another parameter, another hypothesis. And so I keep working until he's satisfied. (...) And then I pick another user story and keep doing it. It is basically a continuous cycle of taking a little story, coding it, getting feedback, then testing it, and then it's done. And that's really the process I go through. The code just grows like this. Little story by little story.

The provisional moment of closure towards which each episode of the agile programming process is oriented is the "demo," an executable program which demonstrates by means of an interactive, two-dimensional computer graphics visualisation that the simulation successfully represents the scenario in question. Posting download links on the groupware platform, Emilio regularly circulates demos within the group. Each demo program is bundled with an accompanying simple HTML page that includes short videos of simulation runs, a brief description verbally framing the scenario and explaining the results, and open questions and suggestions for future work. The demonstration occasions further conversations within the team beyond those held between Emilio and his immediate collaborators on a specific user story. Other team members are invited to comment on the demo which they frequently do on the groupware message board, variously voicing their assent to the results of the simulation, signalling possible directions for further hypotheses to be tested and scenarios to be simulated, asking for clarifications, suggesting changes and so forth. The series of demos circulated through the groupware platform prototype the model by each working as "developing description" and "provisional proposal" (Suchman et al., 2002: 171). Through a series of iterations, the demos document the specific ways in which the research group is interested in fisheries management by recreating in software the scenarios selected by the fisheries scientists, and embody the new possibilities of devising, evaluating, and optimising management interventions afforded by agent-based modelling.

5.4 Operations of agile abstraction

At the same time as maintaining coherence and cooperation within the team, the agile process also facilitates the work of abstraction. For modellers, abstraction means defining the entities and relations to include in the model. Story cards indicate these entities and relations and occasion team conversations where interpretive work is done simultaneously with a sequence of operations rendering stories into stylised scenarios and formalisms that can be displaced from the target domain and further transformed into the software objects of the model domain. These operations include *defining* the user story as a narrative, *decomposing* the narrative into a scenario with a finite set of distinct entities and relations, *classifying* these entities and relations, and *inscribing* them into code as software objects. Linking the diverse elements of the media ecology of coding, these operations compose heterogeneous agentic capacities in a process folding the world into model code. The remainder of the chapter will document how the agile process proceeds within an ecology of affordances by relating an ethnographic episode of abstraction work.

5.4.1 Defining the user story

Sitting in his office in England on a rainy autumn afternoon, Emilio tells me about an episode of work involving the implementation of a user story and the circulation of a demo to his collaborators in California. The user story in question came out of a discussion at a meeting of the research group in Washington, DC several weeks earlier where two marine scientists from California presented a number of candidate user stories to be implemented in the prototype model. As Emilio remembers, one of the stories concerned the spatial effects of a policy regulating fishing gear:

> California did this thing where this rule was imposed where they had to limit the size of the rope of the net, if I remember correctly. The idea was that you need a very long rope when you are fishing over rocky areas while you don't need a very long rope when you are doing it on sandy areas. The idea was, change the gear in such a way that you cannot fish in rocky areas. But the way it was initially described was "Oh, they tried this thing and it worked," and so we had to get to what exactly happens when you change the gear. So the user story is, if I change the gear so that rocky areas aren't fishable, what happens?

As one of the marine scientists explains to me during a conversation later in California, the rationale and specific interest behind their user story was a variation on the fishing-the-line test case discussed above. Only specially configured gear can harvest fish living on rocky seafloor, a distinct habitat where certain species of fish tend to be more abundant. Regulatory restrictions on such gear configurations create an unfishable zone coextensive with the rocky habitat which in turn can lead fishers to target the outmigrating fish along the boundaries of that zone. The marine scientists recognise this spatial pattern as similar to the fishing-the-line harvesting behaviour observed along the boundaries of dedicated marine protected areas. If this fairly elaborate interaction between policy, habitat, and fleet behaviour could be recreated in the model prototype, it would not only demonstrate the model's validity but also its capacity, and thus political utility, for predicting unintended consequences of management interventions resulting from dynamic feedbacks between policy, agents, and environment. Yet in order to achieve this demonstration the story about "fishing the line" has to be mobilised and made to travel. Along its way it will undergo a series of spatial displacements and material transformations: a narrative about fishing off the American Pacific coast related during a meeting in Washington, DC will be transformed with the help of an online message board discussion into a stylised scenario transported to a university office in England where it can be inscribed into a set of software objects written in Java code.

5.4.2 Decomposing the user story

For Emilio, a major challenge in programming work is to decompose a user story into what he calls "actionable" elements. As he explains, actionability turns on the sequentiality of tasks; a story becomes actionable insofar as it permits him to organise his work into a sequence of code-writing tasks with clearly delineated temporal boundaries adequate to the iterative logic of agile programming. Emilio concedes that this decomposition rarely proceeds in a strictly rule-based fashion.

Instead it involves a great deal of ad-hoc improvisation grounded in his skill and experience as a software developer and the materials available to him. As Emilio is presented with the user story, he has to problematise it in a way that allows him to identify and isolate relevant distinct entities and their relations in the textual narrative which he can then translate into the syntax and semantics of the Java programming language.

In the computer science literature on modelling, this decomposition work is called abstraction (Booch et al., 2007: 41). Before entities and relations can be inscribed in Java code, a decision has to be made about which entities of interest are actually held to exist in the domain to be modelled. The literature concedes that this abstraction work is difficult, should be understood as a craft rather than as rule execution, and depends on the positionality and problem definition of the involved developers and domain experts (Booch et al., 2007: 158-159). Developers have to consult with domain experts for the collaborative creation of generic scenarios which describe entities with "crisply defined boundaries" (Booch et al., 2007: 83) participating in the problem domain. While the literature exhorts developers that these abstracted entities should "directly parallel the vocabulary of a given problem domain" (Booch et al., 2007: 43), their creation is the result of the collaborative work of negotiating and aligning the layered material affordances of programming with the narrative descriptions of the domain experts, a practice in which the very boundaries of the entities in the problem domain are at stake.

The emphasis on vocabulary highlights that natural language with its polysemic ambiguities has to be worked on in such a way as to prepare it for the "notational formatting" (Goffey & Fuller, 2012: 151) of coding. Emilio has to carefully align the affordances of object orientation with the clients' initial articulation of the story and its subsequent collaborative elaboration as a stylised scenario in order to establish some correspondence between his rendering of narrative in code with the way his clients, who do not work with the code base itself, conceive of the sense and substance of their narrative. Following up on the user story presented at the team meeting, Emilio posts a request on the groupware message board:

> **Help me out define 'habitats'**
> I am planning on simulating the effects of forcing fishers to switch to gear that doesn't work (or anyway is risky to use) on rocky soil, much like the example you mentioned at the DC meeting. To start I need to understand how to define a habitat as a separate object from just a sea patch. Right now the world is divided into "patches" or "tiles" of sea; each tile has its own biomass, carrying-capacity, malthusian steepness and migration rate. This way we can create patches that are richer in fish or potentially so. Would a habitat just be a set of patches (a region of the sea) that share similar biology and terrain? Is terrain-type the only thing missing? If so, what kind of terrains do I need, just "rocky" and "sandy" or more?

One of the Californian collaborators responds to Emilio's question:

> Great Emilio! Yeah, you can just assign a habitat attribute to each tile i, i.e. Hi = {h1, h2, h3...} where h's are the type of habitat. If a tile has 50% rocky substrate and 50% sandy substrate, the habitat attribute would be Hi = {0.5, 0.5, 0...}. The best basis for the habitat attributes that we will be considering is the shapefiles/available data. In the Channel Islands, I just used rocky and sand as there are no higher resolution data available that extends (sic!) throughout the Islands.

To which Emilio replies:

> Alright! I will try just adding a sandy-rocky variable to each tile and see what we can get out of it.

Emilio's collaborator suggests specifying habitat as a set of sea patches with the shared property of a specific terrain. This is not how the system eventually came to be designed. Instead, Emilio specified habitat to suit his local practice of writing code in alignment with the layered affordances of the agile process and the object-oriented programming environment. However, before turning to that specification, I wish to attend closely to the practices with which the user story is transformed and made to circulate. The abstraction work here commences by stripping the earlier story of those references that situated the narrative temporally (some time in the past) and spatially (in California) as well as erasing the political process necessary for enacting the policy of gear restrictions. What remains, and is highlighted as significant, are the entities fishers, gear, and habitat as well as their relations, namely "use" and "not working on." In so doing, Emilio transforms a tale of a situated occurrence into a stylised scenario. Scenarios are common devices in modelling "crafted to pose just and only those problems that the scientist is, a priori, committed to solve" (Suchman & Trigg, 1996: 151). Only those elements of the original story which are of interest to the research group in their quest to simulate an observed fishing behaviour as the emergent effect of an interaction between fishers, gear, and habitat are selected, isolated, and rendered significant in the scenario. Stripped of any markers of spatio-temporal situatedness or historico-political contingency, the scenario, and the world it contains, can be displaced to a university office in England without losing its coherence. Although the narrative form somewhat sets it apart from those inscriptions usually held to form the set of objects Latour (1990) calls immutable mobiles, the scenario device realises similar effects of mobility, immutability, simplicity, and combinability (see also Suchman & Trigg, 1996). Highlighting only those elements relevant to the operations the modellers wish to perform, the scenario provides a simplified inscription that subsequently becomes combinable with the preexisting inscriptions in the code base of the software system.

5.4.3 Classifying habitat

Working on the scenario, the team's abstraction work proceeds by delineating the boundaries of distinct entities in the domain. The team discusses how to abstract "habitat". The logical problem at stake here is whether terrain-type is a predicate to the subject patch of sea or whether habitat is a subject in its own right with a number of predicates including terrain-type. Emilio suggests the former, and in their reactions, his collaborators seem to agree. Terrain-type now focusses the attention and the actions of the group. The formalism Hi = {h1, h2, h3...} offered by one of the Californian fisheries scientists accelerates the displacement of "habitat" from the Pacific coast to England without losing its coherence, and renders it combinable with already existing inscriptions in the code base (cf. Latour, 1986: 21). The formal notation of habitat as the set Hi = {h1, h2, h3...} renders a part of the world familiar to the Californian fisheries scientists as a set of elements which Emilio, who has to implement habitat in code without being able to draw on comparable marine science expertise, can nevertheless recognise as computable variables standing as proxies for terrain-type and possibly a range of further habitat attributes which need not be further specified for the software design task to become actionable.

However, a complication presents itself when another fisheries scientist on the team joins the online discussion by suggesting that, in addition to the topography of the seafloor, habitat also comprises kelp canopy, bathymetry, and several other attributes. Destabilising the abstraction of habitat as terrain-type alone, the fisheries scientist points to a report on "Groundfish Essential Fish Habitat" prepared by the National Marine Fisheries Service (NMFS) for reference. Responding to that comment, another Californian scientist proposes to focus on the "most important habitat attributes that we think will affect the behavior of the fishers and the fishes." While habitat constitutes a shared object that the fisheries scientists on the team and Emilio work on collaboratively, the array of relations it comprises is all but stable, confounding the actionability of the programming task.

Is habitat to be operationalised as a set of sea patches with the shared property of terrain-type? Which other predicates play a role for defining this set? The questions the team works on point to abstraction as classification work. As a way of ordering the world, Bowker and Star (1999) argue, classification is by necessity fraught with a practical politics of invisibility as decisions about the design of schemata are affected by questions of "workability," the advantages of specific "cuts" within the system, and the "ordinary biases" (Star & Bowker, 1999: 44) of those making these decisions. The work of classifying habitat plays out in a liminal space between fisheries scientists and software engineering: as long as habitat dwells in the shared space of the online discussion between different team members, it remains relatively ill-structured and its meaning contingent upon its relation to the different interests, knowledges, and practices of different team members. In the groupware conversation different versions of habitat are in play, each relating to questions of workability and the effects of particular ontological cuts: the environment fish populations inhabit comprising a number of topographic, biotic and other features; a policy question relating to fishing behaviour; and a formalism that can be rendered in code. In this instance, habitat acts as a boundary object in the sense of "something people ... act towards and with" (Star, 2010: 603), facilitating the team's collaboration even in the absence of consensus by orienting their perceptions and actions.

When the classificatory work moves from the collaborative situation into the local situation of Emilio's programming work, habitat becomes tailored in a work process enacting ontological cuts that remain invisible to the rest of the team. This local specification of habitat and its translation into lines of code, however, is contingent not so much on a specific disciplinarily inflected interpretation Emilio brings to habitat, but rather on the situated and contingent convergence of affordances in the media ecology of modelling work suggesting a particular rendering of habitat as a set of software objects. It is to this crafting together of socio-material relations in programming practice that the next section turns.

5.4.4 Coding habitat

Reflecting on the team discussion, Emilio consults the NMFS report containing data on fish habitat which had been suggested by one of his American collaborators. As it turns out the report only contains data on hard, soft, and mixed seafloor terrain. And what about kelp canopy, I ask? "Kelp is something alive so probably we would have to model it somehow. Is kelp alive?" The ethnographer ashamedly admits his ignorance. Emilio resorts to Google instead: "Okay, it is an algae. But anyway, I do not need it right now. It is not hard to add kelp if we really need to." Hence a decision can be made. The layered affordances of having only terrain data available in the report, and being able to add another predicate in later iterations, shape the classificatory cut that stabilises habitat: algae do not matter for now. What matters is hard, soft, and mixed terrain for which parameters exist in the NMFS report on Emilio's screen. Thus the boundary object habitat is specified and rendered meaningful in relation to the local affordances of coding work. The task is actionable. Emilio can type the following lines of code into his integrated development environment (Fig. 5):

```java
public class TileHabitat
{
    /**
     * in % how much of the sea tile has a hard substrate
     */
    private final double hardPercentage;

    public TileHabitat(double hardPercentage) {
        this.hardPercentage = hardPercentage;
    }

    public double getHardPercentage() {
        return hardPercentage;
    }
}
```

Fig. 5 The TileHabitat class

However, this specific rendering does not directly follow from the classificatory work done on habitat by the team. The team agreed that habitat is a set of sea patches defined by their shared terrain-type property and may include a number of other as yet unspecified predicates. In this case, the object orientation principle of encapsulation would suggest abstracting terrain-type as a new method of the existing object abstracting sea patch. Instead these few lines of Java code create an entirely new class of software objects named `TileHabitat` whose state represents an unchanging, hence `final`, seafloor composition characterised by its amount of hard, rocky substrate. If called by the object abstracting sea patch upon runtime, the habitat object will return the decimal value `hardPercentage` falling somewhere between 0.0 and 1.0 for soft and hard substrate respectively. Habitat is thus transformed into the class `TileHabitat` and "terrain-type" into the method `getHardPercentage` performed on the data type `double hardPercentage` which is gleaned from the NMFS report. Upon runtime the simulation program would create an entire set of `TileHabitat` objects belonging to this class to populate the ocean grid. Objects have states and behaviours: the state of the `TileHabitat` object is topographical texture, whereas its (fairly simple) behaviour is to select and return a decimal value when called to do so; a so-called getter function.

As a result, the initial user story has been inscribed into the code base in the form of a software object that can be combined with previous inscriptions for ocean grid, fishing gear, and agents by invoking the method of this object upon running the simulation. The terrain parameter will be passed on to, and serve as input for, a further software object operationalising fishing gear in order to simulate the relation between habitat and fishing gear described in the scenario. If the value for `hardPercentage` is high, then the software object for fishing gear will compute a lower catch value. The catch value is processed by the artificial agent's decision algorithm, leading the agent to either explore other tiles on the ocean grid, exploit the same tiles, or imitate other agents with higher catch values, gradually letting the majority of agents converge on tiles with high yield: hence the emerging horseshoe pattern described in the introduction of this chapter. Through this specific data flow architecture, the artificial agent does not "know" whether it is fishing on rocky or sandy ground. In this way the aggregate fishing behaviour hypothesised in the initial scenario as resulting from the dynamic interaction between gear restriction policy, fishers, and environment can indeed emerge as an effect of feedbacks rather than being hard-coded into the decision-making algorithm of the fisher agent: a novel knowledge claim has been supported.

This specific implementation of the fisheries scientists' user story was a compositional effect of multiple affordances assembled in the practice of programming. In keeping with the agile programming methodology, Emilio focussed on coding only the bare minimum needed to quickly produce a workable demo: terrain-type emerged as the minimally sufficient abstraction. However, Emilio decided not to follow the suggestions of his collaborators to assign terrain-type as a predicate to the existing class sea tile, but rather created a new class for the habitat abstraction that could, in principle, contain various predicates and would be called by the sea tile class upon runtime. When I ask him about this decision, Emilio explains that his experience with previous coding projects taught him a certain frugal discipline when deciding whether to implement every detail of his client's requests, given that the code base will be modularly extended with further functions at a later iteration. This frugality and modularity characterises "good" agile programming, Emilio suggests. Agile's frugality and iteration principles converged with the encapsulation affordance of object orientation and the data availability of the NMFS report in the eventual abstraction of the user story as the new object `TileHabitat` with its `hardPercentage` value and the modification of the gear object taking into account the probability to catch at a patch of sea given its specific topography.

Whereas habitat acted as a boundary object facilitating collaborative work in the team, the classificatory "cut" enacted in Emilio's implementation in code was affected by the media ecology of computational modelling in his local work setting. Within this ecology, the availability of certain data, the affordance of working by modular addition, a principle of quick and iterative implementation, the shared substantive goal of simulating the scenario as emergent behaviour, and the affordance of object orientation encouraging the encapsulation of behaviour converged in a temporary settlement which folded the ambiguous, messy object habitat into a set of unambiguous, formal declarations to a computing machine.

5.5 Conclusion

In the collaborative production of the model prototype the team had to solve two interrelated problems. Firstly, the team had to create representations of phenomena in the problem domain: the scenarios selected and verbally described by the fisheries scientists had to be rendered digitally, that is, translated into software code in a way that conforms to the strictures of the programming environment, satisfies the logic of emergence of agent-based modelling, and is finally recognisable to the marine scientists when they examine the model output. Secondly, the group had to achieve this work of abstracting and coding collaboratively while managing the differences within the team. In this chapter, I have identified and described a process I am calling agile abstraction that allowed modellers to solve both problems simultaneously. Agile abstraction iteratively generates conceptual entities (such as habitat) which act as boundary objects (Star & Griesemer, 1989), facilitating ongoing collaboration without consensus. The meaning of these boundary objects, however, is contingent not only on the different knowledges brought to bear on their interpretation but rather on what the object affords to the different work practices the object enters into a relation with. These work practices proceed within a media ecology (Fuller, 2005) of affordances – including programming languages, development environments, data availability, organisational arrangements etc. - shaping the way the boundary object is locally specified as a software object referencing the target domain of modelling. It is in this relational and compositional sense of materiality that the material affordances of coding enable and constrain different courses of action during the practical achievement of circulating reference in such a way that novel knowledge claims can be made.

For Latour (1999) scientific representation rests its authoritative claims to speak truthfully about the world on the mobilisation of an entire panoply of meticulously documented and retraceable inscriptions holding meaning stable throughout rapid displacements and transformations. In the Latourian model of circulating reference developed for field science, the work of abstraction proceeds through a nested series of transformations wherein each element is a sign for the preceding element and thing for the succeeding element. In the case of abstraction work for simulation modelling, however, the progression is less obviously from matter to form, but from language to code. In computational science, Humphreys (2009) argues, substantial amounts of authority have to be delegated from scientists to computer programmers because it is hardly possible for the former to examine each computational process leading to a specific model output. However, rather than delegating, the agile process distributes authority within the team as the practical achievement of a collaborative process crafting together relations between narratives, lines of code, and data; a process in which the suspension of consensus plays a key role for facilitating the ongoing collaboration across the sites and worlds of programming and science. The user story initiating the agile abstraction process, although expressed in rather informal speech, refers to preceding work in marine science. Authority, then, would not only rest on the shoulders of the programmer whose coding work remains largely opaque to the domain experts, but also on the domain expert's ability to mobilise allies authorising their truth claims. Whereas code might be a sign system like language, it is articulated with a material apparatus which it instructs to perform operations. These operations produce the diagrammatic model output functioning as the "alignment operator" (Latour, 1999: 67) which organises the passage between a situation and a new narrative about it, making the situation tractable and manipulable under conditions easier to control, and allowing for new knowledge claims to be supported by the diagram.

Boundary objects hold heterogeneous contexts together; their analysis affords an exploration of those contexts through their specific modality of coordination (Star, 2010). I contend that the specific way coordination is achieved between the contexts of marine science and programming not only stems from the need to collaborate across boundaries between worlds characterised by different disciplinary knowledges, but also to align differently equipped material practices of modelling. While the concept of media ecology (Fuller, 2005) alerts us to the agentic potentials arising from the composition of these differently equipped expert practices, something remains to be said about the specific modalities of modelling expertise (Landström & Whatmore, 2014) that collaborate here. What sets simulation models apart from mathematical models is their relation to time. Simulation models not only describe time, but are executed in time; they have a performative dimension (Gramelsberger, 2016). The object-oriented approach to simulation modelling differs from the mathematical modelling of systems as sets of equations because the runtime behaviour of the objects generated from the software code models the system rather than the text of the program itself (Black, 2013). That is to say, in contrast to modelling a system in the form of an equation, modelling with software objects remains incomplete at the time of coding. The inscription in code instead refers to both the preceding circulation of reference from the target domain to the site of coding work and, simultaneously, a future moment when the code will be compiled and executed as a program; when objects start passing messages, interacting to produce the collective behaviour of the systems simulation. Black (2013) opts for a visual and spatial metaphor to describe this changed temporal relation of the software developer to his or her modelling practice: with object orientation, the developer has to "see 'through' the code to the objects that it creates" (Black, 2013: 5). At the moment of writing code, the programming action is oriented towards the anticipated behaviours upon runtime of the program, i.e. the material manipulation of code simultaneously acts upon a "re-presentation" (Latour, 1999c) of the target domain and on the prospective behaviour of the software system. In Latourian terms the strings of code a system modeller types into the integrated development environment are not so much the "fine edge" (Latour, 1986) of a series of material transformations that establish a chain of reference between an inscription device registering material resistance and a formalism such as an equation, but rather operative inscriptions instructing a machine to perform computations which produce further inscriptions as model output. These affordances of object-oriented programming materially mediate expert practice in computational modelling which needs to be coordinated with the knowledge practices of marine science. It is in this double sense that the work of abstraction in modelling is generative (McCormack, 2012): it facilitates passage between world and model, and conjoins different worlds of modelling.

Chapter 6 "This is a manager's tool!" Rationality, agency, and heterodox calculativeness

Where to fish? Developing a spatially explicit agent-based fisheries model, this was a question around which much of the conversation and activity in the consortium's early days pivoted. It is a question about the ways in which fishers might reason about locational choice, and by implication, how to formalise this reasoning in the algorithm determining the artificial agent's behaviour in the computer simulation. Several answers were possible. In the main section of this chapter I will discuss a dispute between modellers over different approaches to formalising locational choice. Detailing how these differences are normatively inflected, and were politically resolved, I will argue that attending to the specific genealogies of the calculative capacities incorporated into more-than-rational economic agents might aid in recovering a normative dimension of economic performativity (Callon, 2007; Mackenzie et al., 2007).

The dispute between modellers concerned the conceptual underpinnings of artificial agents. However, before turning to this conceptual dimension I wish to briefly illustrate how rationality and agency are at stake in the socio-material practices of designing agent algorithms and programming software code. Attending to the various algorithmic solutions for formalising agent reasoning about locational choice, and the programming practices for translating algorithmic solutions into simulation code, discloses how different notions of rationality as well as a certain ambiguity surrounding the location of agency obtain in agent-based modelling. In the section that follows I will discuss two different algorithmic solutions for implementing locational choice in the artificial fisher agents of the agent-based model. These two solutions are called dynamic programming and explore-exploit. Discussing them will by necessity involve the technical language used by the interlocutors of my research which some readers might find difficult. Important, however, are not so much the technical details but rather the differences and continuities between dynamic programming and explore-exploit: while both of these algorithmic solutions enact locational choice as a problem of optimisation, they each place different demands on the rationality of an optimiser. In the main section of this chapter, these terse technicalities shall be enlivened by embedding them in an ethnography of a scientific dispute, returning to optimisation algorithms their historical, normative, and political texture.

6.1 Rationality and agency in locational choice algorithms

In the early days of the project, while the modellers were developing a toy model version of the simulation, two possible algorithmic solutions to the question of locational choice stood out: dynamic programming and explore-exploit. Both of these solutions frame the question of locational choice as an optimisation problem. That is to say, both algorithms attempt to select the optimal choice among a range of decision alternatives, i.e. alternative fishing locations, which will realise maximum profits from fishing for the agent. I shall discuss dynamic programming and explore-exploit in turn.

Dynamic programming is an optimisation method whose basic elements were developed as an auxiliary to military planning during and after WW2. Considerable work had been done in the post-war fields of operations research and systems analysis to adapt and transfer this optimisation technique in attempts to rationalise planning in business and public policy (Erickson et al., 2013; Thomas, 2015). While dynamic programming is well-established and aligned with the mainstream programme of rational choice in economics, the consortium researchers eventually decided against it. An important reason for this decision was their attempt to model large but fine-grained areas with dynamic biomass. In an interview during the early days of the consortium, the software developer working on the model explained to me how dynamic programming could be adapted to locational choice and the reason for ultimately rejecting the method:

> It's basically utility or profit maximisation. Knowing everything, which allocation of effort will make the most money? Imagine there are three spots, A, B and C, and I know the costs associated with going fishing there every day. And I also know for example how much fish is there, and I can either get perfect predictions or I can get expectations that are on average correct. Dynamic programming is getting all this information in and then computing for 300 days where I should go fishing each day, and get the maximum, and that's what I'm gonna do. As long as these spots are few, and knowledge is widespread, that's not a problem. As the number of spots becomes larger, and in fact I've never seen it done for more than 5 by 5 maps, because there are a lot more options, computation-wise solving it becomes slow. The reason is that you have to consider not only ... imagine you have 5 by 5 options every day, for a hundred days that's what, 25000 options? But whenever you go fishing, you change the structure of the biomass, and the biomass moves, then the choice you make on day 1 and the choice you make on day 2 is different, and it's different depending on where you were on day 1. In which case the number of options where to go increases exponentially.

The decision space being too large and too dynamic, the method of dynamic programming would have quickly reached material limits of computation. These material limits had been epistemically productive at earlier points in the history of mathematical optimisation. Faced with the scarce computing capacities available to planners during and immediately after WW2, Herbert Simon developed the notions of bounded rationality and satisficing, i.e. optimisation under constraints, which later morphed into metaphors for the limitations of human cognition and attendant coping strategies (Erickson et al., 2013: 53).

For the consortium scientists, other considerations beyond limited computing capacities played a role too. Whereas the software developer worried chiefly about the feasibility of implementing a solution, he also considered that the perfect knowledge and calculative capacities required to perform optimisation with dynamic programming would not realistically approach the way fishers might reason about locational choice. The assumption that fishers would be omniscient and could compute and rank thousands of decision alternatives even for small areas simply seemed far-fetched. As a result, the solution eventually coded into the toy model used an epsilon-greedy algorithm to implement an explore-exploit strategy for a multi-armed bandit problem. In mathematical optimisation, a bandit problem is a decision problem in which an agent faces a trade-off between allocating effort among alternatives or acquiring knowledge about the probability that an alternative will maximise gain. The former is called exploitation and the latter exploration. An epsilon-greedy algorithm has a threshold parameter at which the agent will exploit rather than keep on exploring. Given that acquiring information is costly, the agent optimises with a satisficing rather than maximising strategy: instead of calculating a global optimum as in dynamic programming, the agent explores and finds satisfying local optima. Implemented in code, the explore-exploit algorithm may look like this:

```
# store the empirical means in an array means<-array[K]
# keep making choices
while(TRUE)
{
     # with probability epsilon, make random choice if
     random < epsilon
     x <- random from 1 to K else
     # otherwise choose option with highest empirical mean x
     <- which.max(means)
     # play and observe reward
     reward<- play(x)
     # update means
     means[x]<- update means[x] with reward
}
```

Fig. 6 Pseudocode of epsilon-greedy algorithm

Although highly abstract in its formalism, this solution maps more closely onto the bounded rationality, as opposed to perfect rationality, which the consortium researchers assumed to obtain in fishers' reasoning and wished to advance as part of their intellectual commitment to questioning the doxa of mainstream economics.[14] Bounded rationality elaborates the rationalisation project rooted in war-time military planning and the productive exchanges between post-war defense systems analysis and academic economics. The theory takes into account the cost of information and limited calculative capacities of rational agents who are held to optimise their decisions with satisficing strategies realised through following rule-based heuristics (Erickson et al., 2013; Mirowski, 2002; Simon, 1983). In the early toy model, then, the confluence of material constraints of computation and a commitment to exploring heterodox theories of economic rationality eventually afforded this specific algorithmic formalisation of the reasoning agents are assumed to engage in when choosing a location to fish.

Questions surround not only the nature of rationality but also the location of agency in agent-based modelling. At the level of programming, the artificial agent making a locational choice is implemented as a network of interacting software objects. Because it has been programmed in an object-oriented language and development paradigm, the algorithm translated into code shown in Fig. 6 is part of an entire series of software objects interacting to produce the effect of locational choice when the simulation is run.[15] During an interview the software developer explained to me the

[14] On the heterodox motivations of the consortium's project see chapter four.
[15] I discuss object-oriented software development in chapter five.

modular design of the code which generates the effect of an autonomous agent choosing where to fish:

> It requires a few objects to work. It requires the algorithm which tells you how to explore-exploit-imitate. There is a sensor which tells you where you currently are. There is an objective function which is the way it chooses, uh, which is a way to define how good I am at the current spot, how good I was on the one before. And then an actuator which tells you, okay, I've chosen the spot now tell the fisher to do it; it's basically a very mechanical thing. The algorithm tells you how, and the adaptation object tells you when. This tells you where are you. The objective function tells you how good is it. (...) So this is an object, this is an object, object, object, object. In object-oriented usually an object is made of different objects. You could split them up a little bit more but in this case that's as good as it gets.

This modular architecture of software code blurs the conceptual boundaries between an agent and its environment. When executing code, the action of choosing a location to fish is an emergent effect of a communication loop within a network of software objects classed as belonging both to the artificial agent and those objects representing the agent's environment including policies, markets, gas prices, and, of course, the fish. Just as the artificial agent is designed as an assemblage of modular software objects, the location of decision is distributed across interacting objects figuring both agent and environment on the same ontological plane. Who or what acts in the decision about fishing locations remains ambiguous at the level of simulation code.[16] However, in the visual output of the simulation the spectator is invited to regard active and autonomous agents moving across a passive marinescape (see Fig. 2). Whereas the technological capacities of object-oriented programming potentially deterritorialise received humanist notions of autonomous agency, the god's eye view offered by the visualisation with its two-dimensional cartographic tropes

[16] On one occasion I pointed out to the software developer that the code architecture of locational choice evokes the notion of distributed agency in actor-network theory. My remark, however, was met with little curiosity. The developer considered agency merely an engineering problem.

reterritorialises an anthropocentric and dualist view of human-environment relations wherein nature figures as belonging to a different ontological plane; passive, separate from, and worked upon by, active and autonomous human agents (cf. Castree, 2004; Haraway, 1987).[17]

The question, where to fish, then, raises further questions about the nature of rationality and the locus of agency. Both of the two algorithmic solutions for locational choice, dynamic programming and explore-exploit, figure the rational dimension of locational choice as a problem of optimisation. However, they evoke different theories of rationality and methods for optimisation which place different demands on the calculative capacities of rational actors. Different theories of rationality are formalised with, and performed through, different algorithms. Implementing these algorithms in code troubles humanist notions of autonomous agency, an unsettling potential which is in turn obscured by the visual output. In the remainder of this chapter, I will discuss how questions of rationality and agency figure into the performativity of heterodox economic modelling. I will do so by bringing a dispute among modellers about agent reasoning into a dialogue with the performativity programme in economic sociology. Substantively, the modellers discussed the conceptual underpinnings of the artificial economic agent at the core of the agent-based model. The dispute among the modellers brings into relief the

[17] That a visual representation of fishing could be just as radically unsettling as its operationalisation in code is evidenced by the anthropological film Leviathan released in 2012. The film-makers of the Harvard Sensory Ethnography Lab, Lucien Castaing-Taylor and Verena Paravel, demonstrate how visual techniques enabled by novel technological capacities might deterritorialise anthropocentric notions of human-marine relations. Affixing miniature digital camera devices to various objects on and off the deck of a fishing vessel and leaving the 87-minute filmic montage without dialogue or verbal narration, the film-makers unsettle anthropocentric audiovisual conventions. The spectator is invited to experience fishing from multiple, more-than-human perspectives as a process distributed across a dynamic assemblage of heterogeneous elements.

differences between disciplinarily inflected approaches to formalising rationality, the normative stakes involved in the framing of locational choice as an optimisation problem, and the politics shaping methodological choice in the development of a decision-support tool for natural resource governance.

The performativity programme in economic sociology, too, problematises the economic agent. Informed by actor-network theory, the rationally calculating actor is de-essentialised as a performative effect of the calculative devices equipping market action (Callon, 1999; Callon & Muniesa, 2005; Mackenzie, 2009). While this programme has proved influential in economic sociology, STS, and geography, it has been criticised for, inter alia, a narrow empirical focus on models and markets presumably functioning according to economic orthodoxy which gives insufficient weight to differences within the economics discipline (Bryan et al., 2012; Lezaun, 2017; Mirowski & Nik-Kah, 2007). Through an empirical focus on a dispute about the purposiveness of agent reasoning among heterodox economic modellers, this chapter will interrogate how the performativity programme divests economic calculation from its normatively inflected telos. I will argue that this elision of the normative dimension of calculativeness might help to explain the special efficacy which the Callon school of economic sociology tends to grant to the performativity of neoclassical economics. I conclude that studies of economic performativity might gain critical purchase by attending to the political stratagems and heterogeneous normative orientations embodied in calculative practices.

6.2 Locating the more-than-rational decision

The basic unit of analysis in contemporary economics is the economic decision, argue both economists and historians of economic thought. Locating the agency of economic actors, then, entails both querying the sources of their decision-making capacities and the sites enfolded into the act of deciding. Retracing the history of the economic agent, Foley (2004) holds that the concept of the agent in the economics discipline developed in conjunction with historically prevalent conceptions of the Self and political preoccupations of the times. Whereas classical political economy figured the agent as representative of a class of workers, capitalists or landowners locked in an existential struggle across class divides, neoclassical economic theory shed the class distinction and conceptualised the agent as an individual choosing and deciding between a range of options on a market. As a "scale model of the whole society" (Foley, 2004: 84), the economic agent as a rational chooser, who became prevalent in neoclassical economics, can be read as indexing a shift towards the sovereign consumer as preocuppying both economic theory and the organisation of Western societies in the latter half of the twentieth century (Amadae, 2003). In order to maximise his or her utility, the homo economicus of neoclassical theory is assumed to choose rationally. Just what that means is contingent on the methodologies and calculative devices the rational choice programme brought to bear on the economic decision. Whereas the theory of rational choice originally defined rationality as preference consistency and transitivity (Ermakoff, 2017), its elaboration, formalisation, and operationalisation for rationalising economic decision-making invest rationality with an objective of optimising input-output relations and maximising the utility of strategic actors (Erickson et al., 2013; Thomas, 2015). As a microfoundation of economic theory, the axiomatic of rational choice and its embodiment in the calculative methods formalising economic behaviour and devices aiding rational decision-making blend descriptive and prescriptive, normative dimensions of rationality (Amadae, 2003).

Whereas the methodological individualism of rational choice figures an autonomous agent as the locus of calculation and rational decision-making, the performativity programme in economic sociology inquires into the conditions under which actors acquire the calculative competencies necessary to make decisions in a market. In a programmatic text on actor-network theory in economic sociology, Callon (1999) accepts a definition of the market as a method of coordination between calculative agents in order to inquire into the conditions under which calculative agents emerge. Decentring and distributing the economic agent, Callon locates calculative agency as a network effect of calculative devices equipping the economic agent which create the "space of calculability" (Callon, 1999: 191) within which decisions can be made rationally. These devices co-perform socio-material operations of framing and disentangling which provide for the information underwriting the calculative capacities of economic actors. In chapter two, I discuss how Callon's definition of calculative agency can be thought of as an attempt to de-essentialise the theory of rational action originating in neoclassical economics. Rather than an axiomatic assumption as in neoclassical economics, rationality in the sense of maximisation is rendered an agentic effect of a de-centred economic actor-network equipped with a variety of calculative devices. However, later elaborations of the performativity programme tend to obscure this specific genealogy of calculativeness. Whereas Callon (1999) still acknowledges the conceptual roots of his notion of calculative agency in neoclassical economics, later programmatic work elaborating on economic performativity elides this specificity of calculation-as-optimisation in favour of universalising calculativeness by reference to the anthropology of everyday mathematics (Callon & Muniesa, 2005). As a consequence, the STS-inspired praxeographies of economic action in the wild of empirical markets, which followed Callon's programmatic injunction, tend to trace the socio-technical networks, or market devices, performing the very ontology of rational action which is presupposed in neoclassical economics (cf. Muniesa, Millo, & Callon, 2007).

The social studies of finance in the wake of the performativity programme pose the question of the rational actor and its contestation by other schools of thought in economics explicitly. Mackenzie (2009) largely follows Callon in conceptualising economic agents, and their capacities to calculate in a rationally optimising manner, as effects of the calculative devices equipping their actions. However, Mackenzie (2009: 23) explicitly acknowledges disputes between orthodox and behavioural schools in economic thought about the rationality of economic agents. Indeed, the computational language of bounded rationality obtaining in some theories of behavioural economics informs Mackenzie's argument for the significance of the performativity approach. Referencing Herbert Simon's work on bounded rationality as well as work on distributed cognition from cognitive science, Mackenzie argues that the limited information processing capacities of embodied human actors by necessity require those actors to enlist various calculative devices. As products of economics, these devices then become performative by co-constituting capacities for action in economies: "the capacity for economics to be performative arises from the cognitive limitations of human beings" (Mackenzie, 2006: 265). The extent to which neoclassical theory closely resembles observed economic action in financial markets, then, becomes a question of the socio-technical "market infrastructures" providing "preconditions for rational economic action" (Mackenzie, 2006: 267). Aligned with behavioural critiques of the standard model of rational action, the contribution of the performativity programme would appear to be an empirical attention to the prosthetics enabling rational calculation. This device-centred perspective constrains its critical purchase to an interrogation of the technicalities of market design (Mackenzie, 2009: 33).

However, several critiques have been levelled at the performativity programme. These critiques variously stress the absence of politics and power in the model of economic performativity formulated by the Callon school and its failure to attend to differentiation within the economics discipline. While accepting the proposition that markets come about as sets of calculative entities, Mirowski and Nik-Kah (2007) take issue with what they perceive as a non-differentiated account of economising actants, highlighting instead the controversies between economists of different stripes and their respective calculative practices. Moreover, they maintain that academic economics may not so much make the world in the image of its model of rational action but rather becomes enlisted by other actors to provide a mathematical veneer for their political strategems in the assembling of markets that may or may not end up functioning according to neoclassical theories. Blok (2011), too, maintains that the performativity programme has paid insufficient attention to political relations, demonstrating how actors such as nongovernmental organisations not only co-perform economies but may contest market framings as such, in effect acting as non-marketising agencies. More recently, Lezaun (2017) has explicitly posed the absence of increasingly influential heterodox economics from the case study-based theorising of the performativity programme as a problem for actor-network theory's continued purchase as an analytical frame for empirical research on economic matters.

Indeed, as economic approaches influenced by behavioural psychology and complexity theory come to challenge the model of rational action in mainstream economics, the economic decision raises questions about the more-than-rational capacities of economic actors. Heterodox theories figure the economic decision as systematically biased and frequently deploying situational heuristics rather than calculative optimisation (Tversky & Kahneman, 1981), constrained by incomplete information and limited calculative capacities (Simon, 1983), and thus contingent upon the informational environment in which it takes place (Thaler, 2000). Pluralism is a contentious issue in the economics discipline and opinions vary about boundary demarcations between orthodoxy and heterodoxy. George (2008: 3) characterises orthodoxy by its narrow range of accepted mathematical models, policed by high-impact economic journals, which tends to exclude considerations of complexity. However, Dow (2008) notes the increasing plurality of schools of thought even in mainstream economics which leads her to question the criteria by which orthodoxy and heterodoxy might be distinguished. From the strict confines of late twentieth century economic thought, behavioural and complexity economics would indeed be considered heterodox to the neoclassical paradigm (Colander, 2000). However, perhaps signalling an adaptation of mainstream economics to challenges from behavioural and complexity approaches, in more recent economic research the "increasing focus on heterogeneous agents reflects a movement away from the idea of the representative agent in an effort to capture a more complex reality" (Dow, 2008: 36). Whether behavioural and complexity approaches will continue to be considered heterodox challenges rather than reform projects within neoclassical economics may rest on the extent to which they question the predominance of mathematical modelling (Boylan & O'Gorman, 2008), methodological individualism (Colander, 2000), and the framework of utility maximisation (Dow, 2008).

Geographers have empirically documented how heterodox theories of economic decision-making are applied in public policy (Berndt & Boeckler, 2016; McCormack & Schwanen, 2011; McMahon, 2015; Whitehead, Jones, & Pykett, 2011). In an interesting twist to the denaturalising move the Callon school performs on the neoclassical ontology of rational action, these geographies demonstrate how translations of economic heterodoxy into public policy turn on the deliberate design of socio-material networks that produce specific agentic effects, the difference being that heterodox stratagems of market design incorporate an explicit awareness of the relationality of economic agents. For instance, in the context of global development policy, Berndt and Boeckler (2016) document how behavioural economics-informed policies aim to exploit regularities in the psychology of decision-making for the engineering of so-called choice architectures which nudge actors towards selecting options deemed beneficial by policy-makers. Enlisting informational devices such as automated reminders and the pre-setting of default options, these policy interventions configure the calculative capacities of decision-making actors by assembling "carefully arranged networks of humans and non-humans" in which "agency is purposefully designed as being distributed between heterogeneous elements" (Berndt & Boeckler, 2016: 23). These geographies of marketisation after markets (Boeckler & Berndt, 2012) or neurocapitalism (Pykett, 2013) raise normative questions about the changing contours of market-oriented governance, but also point at the complex relations between scientific evidence and public policy. They also highlight how the translation of psychological or neuroscientific theories into policy designs proceeds in highly selective and mediated ways insofar as it is subject to political influences stemming both from normative attitudes to state intervention into economic matters and the pragmatic requirements of policy delivery (Whitehead et al., 2011: 2833).

If heterodoxy figures the economic decision as made by an agent whose agency to decide emerges within socio-material networks, which in turn may be purposefully designed elsewhere, which sites suggest themselves for research into economic agency? The case studies of the performativity programme start either in the middle of market transactions, tracing the socio-technical networks generating the calculative capacities of market actors, or follow the formulation of economic theory and its performance as perlocutionary utterance in empirical economies (Pellandini-Simányi, 2016). McCormack and Schwanen (2011: 2801) suggest orienting geographies of decision-making towards multiple sites involved in the decision as a "distributed, relational process" rather than a bounded, discrete event. In particular, they encourage the investigation of privileged sites folded into the process of decision-making. These may be sites where researchers develop theories and techniques of decision-making and articulate them with contexts outside of academia through the dissemination of ideas and devices. Investigating how work at these sites is articulated with other sites of decision-making provides an entry point for understanding how "theories of political and economic life" are linked with "techniques employed to govern this life" (McCormack & Schwanen, 2011: 2802). The following section will attempt such an investigation by tracing a dispute between research scientists about the design of the artificial economic agent sitting at the core of the model-based decision-support tool they are developing for fisheries management.

6.3 The agent dispute: heterodoxy, normativity, politics

During a work meeting in New Orleans, Louisiana, a dispute erupted among the researchers about how to conceptualise the fisher agent in the simulation. These biannual work meetings gathered all British and American consortium members as well as invited consultants and partners for a week of presentations of results and discussions about future directions of the consortium project. At the end of the meeting consortium members would be invited to the French Quarter mansion of the CEO of the marine conservation nonprofit for a reception with drinks, catered gumbo, and watching revellers from a majestic ironwork gallery; a stark contrast to the rather rustic lodgings in Tremé-Lafitte which my graduate student budget afforded me. The dispute in question took place on a hot and rainy April day in a thankfully air-conditioned hotel conference room in downtown New Orleans. Occasioned by a presentation of the explore-exploit algorithm embodied in the toy model, the discussion was meant to elicit proposals for generating agent algorithms from empirical research. Different researchers argued for different ways of theorising agent reasoning. This discussion carried implications for the way the consortium planned to engage in empirical research on fishers' decision-making. The Californian marine science research group was preparing a funding bid for a series of economic experiments with fishers strongly informed by the behaviouralist strand in economic theory. On the British side a new postdoc hire with a background in cognitive science joined the team of a philosopher of mind who runs a laboratory on the psychology of decision making. This philosopher had been named in the original grant proposal, but so far had not been introduced to the entire consortium. The British and American groups found themselves on different sides of the dispute. Substantively at stake was the extent to which the agent should be conceptualised as deviating from a norm of rational, utility-maximising homo economicus or whether to abandon the objective of optimisation altogether when making sense of agent reasoning.

The dispute split the group in roughly two camps. The first camp, led by a postdoctoral scholar from California working on the intersection of ecology and economics, argued for conceptualising the agent as an optimiser whose rationality may be constrained by a number of factors. The other camp, led by the philosopher of mind and cognitive scientist, argued in favour of a more situated model of agent reasoning. This latter model would remain agnostic about the telos of rationality and instead would be empirically derived from field research in, as well as its algorithmic formalisation tailored to, any of the geographical locations where the model would be deployed for management. The dispute touched on a number of entangled epistemological matters such as the objectivity and impartiality of method, ontological matters such as the universality of human behaviour and its biological foundations, and eventually political matters such as the (power) relations between developers and users of a decision-support tool as well as those affected by natural resource management practices. That is to say, in the scientists' deliberation of how to conceptualise the reasoning of natural resource users the question of how they are being governed and by whom played as much a role for settling the debate as questions of methodology. The dispute between the researchers eventually found preliminary closure through the enrolment of an extra-scientific ally into the argument for rationality as calculative optimisation. In the following section, I wish to trace this dispute paying particular attention to the various resources deployed by those arguing on behalf of different ways of conceptualising agent reasoning and the means by which this dispute achieved preliminary closure (Latour, 1987). This tracing will bring into relief the differences obtaining among those reworking rationality in heterodox economics, how those differences are inflected with normative commitments, and the politics involved in translating scientific theories into the devices equipping market governance.

6.3.1 Heterodoxy: opening the black box of agent reasoning

Analysing scientific controversies is a means of opening the "black box" of ready-made science in order to elucidate the richly textured processuality of science-in-the-making (Latour, 1987). The black box metaphor Latour borrows from cybernetics as a way of highlighting the relationality and provisionality of scientific knowledge claims re-emerged in the New Orleans discussion as a way for the philosopher of mind to set his cognitivist theory of agent reasoning apart from behaviourist approaches:

> There are many ways in which we can make sense of agents, and one of them is to treat them as a black box; not treat you as something that has internal representation, but treat you as a bunch of behaviours. And then we can write up a theory that just relates histories of stimuli impinged upon you to histories of how you responded to that. To some extent aspects of economics can be read in that spirit. The difference here is that you are asking, what is the agent representing, and what are they trying to do with that representation when they make a decision. Then this framework would say, first of all, they are asking themselves a question such as, what am I gonna do today, or am I fishing, where on the map am I gonna go. That is a question and then you answer that question.

The erotetic, or question-based, approach to modelling locational choice advanced by the philosopher builds on the mental model theory of reasoning (Johnson-Laird, 2010; Koralus & Mascarenhas, 2013). The theory assumes that agents reason by updating an internal representation – a mental model - of their world through operations of inference. Taking into account empirically observable and experimentally reproducible fallacious inferences, the erotetic approach aims to simultaneously explain the possibility of both fallacious reasoning and sound reasoning within the same framework. The criterion for sound reasoning, here, is held to be the logical validity of conclusions. Note that this theory of reasoning does not assume maximisation or optimisation as a necessary criterion for rationality, but rather the extent to which reasoning satisifies the strictures of logic. Central to the erotetic approach is the role of questions and answers. The approach assumes that, when agents integrate mental models by updating their beliefs and drawing conclusions, they aim to answer questions: "reasoning proceeds by treating successive premises as questions and maximally strong answers to them" (Koralus & Mascarenhas, 2013: 312). Indeed, answering questions is treated as the ultimate aim of reasoning. Optimisation, then, is a special case of reasoning. The philosopher contends that his theory covers decision-making if decision questions are substituted for questions and practical reasons for facts. An erotetic fisher agent may then pose the question of where to fish with a set of possible locations to choose from. Practical reasons (premises) sequentially treated as answers to that question may or may not include locations that are legal, locations that had acceptable profits in the past, avoidance of locations that had unacceptable profit in the past, etc. As both practical reasons and internal representations of locations can differ between fishers and between fisheries, no assumptions as to whether optimisation is the ultimate aim of fisher's reasoning would be built into the agent algorithm which formalises locational choice.

After the philosopher presented his approach, the economist challenged the erotetic model. Invoking allies to support his challenge, namely highly reputable, Nobel-winning research in behavioural psychology as well as evolutionary theory, the economist subjected the philosopher's claims to a trial of strength:

> How concerned are you with trying to connect all the mechanisms that you are looking at to either a proximate cause, a literal cognitive machinery that is well understood, kind of in the spirit of Thinking Fast and Slow, or an ultimate cause, which is kind of an evolutionary incentive to, in a market context or in just a biology context, behave in a certain way?

The cognitive machinery mentioned by the economist refers to one of the metaphors psychologist Daniel Kahneman (2011) deploys in his book Thinking, Fast and Slow which popularised and presented to a general audience his lifetime research on the psychology of intuitive beliefs and choices for which he was awarded the Nobel prize in economics in 2002. Kahneman describes a "machinery of cognition" (2011: 8) consisting of two interacting modes of reasoning, namely intuitive and deliberate. The former mode operates automatically and involuntarily, making rapid choices with little effort. The latter operates in a way that is "slower, serial, effortful, and deliberately controlled" (Kahneman, 2002: 450). Linking the operations of intuition to the psychology of perception, Kahneman proceeded with his collaborator Amos Tversky to devise experiments testing the extent to which intuitive modes of reasoning obtain in choice situations demanding statistical calculation to choose the optimal alternative. From these experiments, the collaborators derived and catalogued a number of systematic errors of reasoning which they defined as solutions to decision problems which deviate from the optimal choice to be expected from statistical calculation. These errors were explained with the simultaneous operation of intuitive and deliberate modes of cognition with the latter more or less successfully correcting the former depending on variables such as the accessibility of thoughts. Despite the machine metaphor of cognition, the "maps of bounded rationality" (Kahneman, 2002) drawn by Kahneman and his collaborator are only tenously connected to the notion of bounded rationality advanced by the computationally informed economics of Herbert Simon (Mirowski, 2002). Kahneman eschews computational analogies in favour of the body, and its evolutionary history, as an explanation for the limits of cognition. Vagaries of attention, effort, perception, and affect obtaining in embodied beings limit the extent to which decision problems are approached in a mode of rational optimisation. Whereas Kahneman puts fairly limited emphasis on the evolutionary foundations of behavioural patterns observed in decision situations, he does suggest that systematic biases such as loss aversion and those induced by embodied perceptual capacities, which contradict the axiomatic assumptions of rational choice, might be linked to traits favourable to the survival of the organism in the early history of human evolution (Kahneman, 2011: 35, 282). However, the philosopher dismisses the connection between human behaviour and evolutionary theory in his response to the economist. Noting the diversity of human behaviours and beliefs, the philosopher claims that trying to tie specific behaviours and beliefs to evolutionary foundations sits on empirically shaky grounds and has questionable explanatory value, judging such attempts "a completely hopeless area." He presents his approach as more circumspect in that he is "not trying to have an explanatory theory of why the fishermen are the way they are, it is more about having a descriptive model of them and see whether it makes sense." The economist does not concede the point. Drawing an analogy to the study of religion, he invokes the biological sciences again as an ally, arguing that evolutionary theory can explain "human universals that you can see across human societies." He argues on behalf of a connection between the mechanisms of behaviour experimentally elicited by behavioural psychology and universal, biological foundations of human behaviour. The philosopher again dismisses the economist's attempt at enrolling biology by doubting the strength of the connection between empirical evidence and evolutionary theories of behaviour, eventually claiming "that is not a mechanism. That is a just-so story why people might have that as a possibility in the species." He expresses doubt that experimentally determining behavioural parameters such as loss aversion in order to modify the theoretical calculus of utility maximisation would have much predictive value. Too different are the geographical locations the consortium wishes to take the model. Consequently, the philosopher reframes the question of agent reasoning as an empirical one:

> We actually have to go to Indonesia and to California ... what I would just caution against is saying that we need some grand philosophical scheme that tells us in advance what the types of things are that people might take into account or not. I think we should just run an experiment on them, and ask them.

Opening the black box of agent reasoning, two contrary positions are in conflict. The philosopher of mind argues for a mental model-based approach to agent reasoning as the more or less fallacious drawing of logical inferences from culturally contingent beliefs. Agnostic about the purpose of agent reasoning, the philosopher is also skeptical about claims as to the biological foundations of human behaviour. Rather than making claims to the universal validity of a model of agent reasoning, he argues instead for an approach of situated modelling based on field and experimental research into agent reasoning in each of the geographical locations which the model represents. On the other side of the dispute, the ecologist-economist argues on behalf of behavioural economics as having experimentally disclosed a universally obtaining model of agent reasoning securely fastened to evolutionary foundations. The next section will elaborate how the dispute invests different concepts of rationality with normative commitments to good science and the proper purpose of reasoning. Following that, the preliminary closure of the dispute will be discussed.

6.3.2 Normativity: contesting the telos of rationality

At this point of the exchange, other participants in the meeting enter the debate. Having remained a fairly silent observer for the most part of the work meeting, the CEO of the conservation organisation participating in, and partly funding, the research consortium, whose background is in finance, asks the two parties in the dispute to clarify in lay person's terms what is at stake in their debate. The economist reacts to the opportunity to restate his point. He challenges the philosopher's attempt at settling the dispute on empirical grounds:

> We might ask fishers what they care about and they give us this really long list. At some point we are going to have to prune that down to behaviours we put in the model and weights that we put on them. My question is, how are we making that decision? Are we making that decision just sort of randomly, based on our own ethnographic intuition, or are we going to try and have some rationality or evolutionary or neuroscientific foundation that we draw from when we can to make those decisions impartially.

The economist challenges the claim that the problem of agent reasoning can be solved empirically by pointing out that methodological choices are informed by theoretical precepts. However, the particular way in which this challenge is formulated deserves some closer scrutiny. In the question of choosing the right method for researching more-than-rational decision-making, the rationality behind making that choice is itself at stake. Note the slippage in the economist's statement between the terminology deployed to describe methodological choices and the terminology describing substantive matters in the empirical domain: ethnographic methods of knowledge-making are equated with intuition and unfavourably contrasted with the rationality of the natural sciences. Intuition and rationality, of course, precisely correspond to the two cognitive systems theorised by behavioural economists to be simultaneously operative in decision-making with the latter ideally keeping the former in check. The argument of the economist transposes the theoretical distinction made by behavioural economists between the fast-and-lose reasoning of intuition and the slow and deliberate reasoning of rationality onto the terrain of research methodology. This mapping of the "architecture of cognition" (Kahneman, 2003) hypothesised to be present in the empirical domain onto the design of the methods appropriate for researching said domain charges the methodological choice at stake with behavioural economics' implicit normative preference for the rationality of statistical reasoning over the systematic biases induced by embodied perception and affect. Keeping with the scientific norm of objectivity (Haraway, 1988), the impartiality desired by the economist when making methodological choices is threatened if left to the embodied "intuition" of an ethnographer and must instead be guaranteed by reference to the natural sciences in which the protocols of disembodied objectivity presumably obtain. At stake in this deliberation, then, is more than a question of research design where commitments to different theories of agent reasoning shape methodological choices for empirical work on fishers' decision process. At stake is simultaneously the negotiation of a shared norm of scientific rationality among the consortium scientists that would orient their own epistemic quest.

Normative orientations are involved not only in debates about methodology but also in the way the researchers debate the telos of agent reasoning. Another participant enters the fray. A pioneer in the field of computational social science, who co-authored an influential monograph on agent-based modelling for social research, this senior researcher had remained silent for the most part of the discussion. He reports the outcome of an "important experiment" in economics conducted at UC Santa Barbara where the objective of participant's decisions about a simulated firm shifted from maximising profits for themselves to keeping the firm in business contingent on the firm's economic fortunes. Participants in the experiment "change their objective function from being profit maximising to staying in business" based on endogenous factors, a result which the senior researcher means to support the sensibility informing the philosopher's approach:

> In this sense now it seems to me that is why you want to have what (the philosopher's) approach here says, let's look at the span of all the things which people might be optimising over. And in order to figure out which ones will be binding in which particular case we will have to do all this, this longer list of what people care about in order to actually figure out what they might be optimising under certain circumstances.

The economist agrees in principle, but emphasises that "we can't completely get rid of the concept of optimisation if we want this model to be generalisable." The following exchange ensues:

> *Computational social scientist:* But that's 1950s Operations Research! Optimisation is a very loaded word. Purposiveness. Agents are purposive.
>
> *Philosopher:* That completely doesn't follow. I mean we can't settle this in this setting...
>
> *Computational social scientist:* Optimisation is not what we are thinking about.
>
> *Economist:* In an abstract sense!
>
> *Computational social scientist:* Purposiveness! Improving. Having an objective, trying to improve your util-... trying to improve your lot in life. But that is different from optimisation which is... that usually means the best.
>
> (crosstalk)
>
> *Economist:* That would be philosophical.

Reverberating in this exchange, and the dispute it is folded into, is a debate within the economics discipline about the nature of rationality, the cultural specificity of the purposeful behaviour of economic agents, the universality of economic laws, and, by implication, the status of the economics discipline itself as a scientific endeavour. It was during the 1940s and the following decades of the Cold War, S.M. Amadae (2003) argues, that this debate came to a head and, in the West, was eventually resolved through the development of rational choice theory. Rational choice theory redefined the very meaning of economic rationality, throwing into relief normative questions about the telos of economic behaviour and the organisation of the economy. Following economist Kenneth Arrow's elaboration in the 1950s, rational choice theory defines rationality in set-theoretic terms as preference consistency and transitivity. In this definition, "to be rational, individuals must know either what they prefer among choices or be indifferent to them in a consistent fashion" (Amadae, 2003: 108).[18] This axiomatic definition of rationality does not per se assume the maximisation of anything – preferences are entirely idiosyncratic and may be both selfish or altruistic - although it does allow for maximisation as a special case. In defining rationality as preference consistency, Arrow responded to a debate within the economics discipline characterised by the confrontation between capitalist and communist economies. In the 1940s the question whether the economic knowledge developed under conditions of capitalist production would equally apply under a different mode of production, and by implication whether economics would yield universal laws, was hotly contested with the nature and purpose of rationality providing a focal point for debates between economists of different political sympathies. Economists arguing on behalf of state planning of the economy claimed that rationality takes on a specificity within capitalist societies, namely the maximisation of profit, allowing that in pre- or non-capitalist societies rationality

[18] Rationality is thus defined as following from two set-theoretic axioms: first, for all x and y, either x R y or y R x; second, for all x, y, and z, x R y and y R z imply x R z. Transitivity would then imply that x will be preferred over z.

"may embody different principles" (Amadae, 2003: 97). At the same time as this postulated plurality of rationalities provided intellectual legitimacy for an economic science specific to planned economies, it posed a problem for those who wanted for the economics discipline to have the status of an objective science and worried about the scope of its theories and models. Given the mathematical tools bestowed on those contemporary economists by the marginalist revolution, in order to formalise and predict the behaviour of economic actors an assumption of utility maximisation had to be made. However, if this assumption only held true in capitalist societies, then the methods of economics could not yield universally valid scientific laws. Working as a defense intellectual at the American think tank RAND Corporation, Kenneth Arrow's set-theoretic redefinition of economic rationality attempted to address all of these problems at once. Redefining rationality as preference consistency simultaneously allowed for utility maximisation as a special case, anchored it to the logical relations of mathematical set theory held to be universally valid, and thereby de-legitimised the notion that economic reason, and by extension economic science, might be culturally relative (Amadae, 2003: 122).

The computational social scientist's remarks on the purposiveness of agents trying to improve their "lot in life," yet his hesitancy to figure this purpose as optimisation, betray the ambiguity following from rational choice theory's settling of the dispute about the cultural relativity of economic reason and economic laws. Whereas marginalist economics defined rational as efficient in the sense of a maximisation of output for a given input, rational choice theory defined rationality as preference consistency and transitivity. The mathematics formalising both approaches to agent reasoning also differ, with the former deploying calculus-based maximisation equations and the latter set-theoretic formalisms. Marginalism's focus on maximisation incorporated a Benthamite utilitarian legacy in its assumption that agents have an "innate propensity to maximise their pleasure" (Amadae, 2003: 237) tethered to the marginalist redefinition of value from production input to subjective utility. With rational choice theory shedding this assumption, rationality ceased to refer to the discipline of economics, which the marginalists wished to free from contingent political relations and elevate to a universal science by formalising their subjective theory of value with a mathematics partly derived from physics, and "instead came to characterise the norms of decision-making for human agents" (Amadae, 2003: 229). However, the intellectual programme launched by rational choice theory and elaborated across American defense think tanks and academic social science retained in its development of tools supporting the rationalisation of planning and decision-making a sense of the telos of rationality as optimisation. Operations Research, which the computational social scientist readily identifies with this telos of optimisation, was one expression of a broad attempt to rationalise decision-making across strategic military, public policy, and business contexts (Erickson et al., 2013; Thomas, 2015). Developing calculative devices for deciding between different options for allocating resources, Operations Research, later called systems analysis, attempted to rationalise planning in the sense of maximisation. Game theory, a cognate approach developed in the same environment of defense intellectuals and academic economics, supported planning through its imaginary of strategic actors competing to maximise their utility in the sense of realising what they most prefer. Behavioural economics responded to this programme by testing the validity of rational choice axioms in actual decision situations, inquiring into the conditions under which preference consistency obtains without giving up on the prescriptive and normative dimension of rationality as maximisation of gain. Throughout these disciplinary developments rationality came to be conceptually redefined in response to competing normative visions of the purpose of economic action and the status of economics.

In the consortium dispute, these issues come to the fore again. Whereas the philosopher argues on behalf of a model of agent reasoning that assumes the universal validity of logical inferences drawn from contingent beliefs, his approach allows for the cultural specificity of both beliefs and the objective of reasoning about those beliefs. The economist, however, insists on the universal validity of economic rationality as maximisation even if conceding that the process by which agents maximise might be hampered by systematic biases. Tethering this assumption of maximisation to both an ontological claim about the evolutionary foundations of human behaviour and a methodological commitment to the generalisibility of economic modelling, the economist reasserts the universal validity of the knowledge of economics grounded in an axiomatic of economic rationality modulated only by biologically determined psychological biases. Whereas the computational social scientist is cognizant of the problematic Cold War heritage of formalising agents as optimisers, his ontological claim about the purpose of agent behaviour betrays a utilitarian legacy with its normative commitment to the maximisation of pleasure.

6.3.3 Politics: settling the dispute

Eventually the dispute was settled not on theoretical or methodological grounds but rather by reference to the political relations obtaining in the world on which the consortium's work product is meant to have some purchase. After a few more clarifying comments from the discussants, the CEO voices concerns about choosing the erotetic approach. Prefacing his intervention with his understanding that the point of the project is to model fishers as economic agents whose empirical behaviour deviates from the norm of utility maximisation, he asks the philosopher

> So is it basically that you are trying to find 15 or 20 indicators that, wherever we take the model, we can quickly get to through interviews and show us to what degree the fishermen actually deviate from homo economicus which you could very easily...?

However, the philosopher disagrees, responding that "it is not so much about building in deviance from the get go" but rather about "getting a view of what the internal mechanisms are that take people from their perception of the world to the relevant decisions." To which the CEO responds:

> That scares me though. Because we are able to ask 20 questions. And we are going to ask them an artisanal Indonesian fishermen and we are going to ask them to a guy who is running a 5 million dollar tuna boat with a helicopter landing place. Those 20 questions have got to get me to somewhere. But what you are saying is, we are going to build some kind of model that basically shows me how a person... why a person does the things that they do. That is much more complicated than 20 questions.

In this intervention, the CEO formulates an important assumption: the fundamental process with which fishers make decisions is the same no matter their differences of capitalisation and culture. What makes them different is the extent to which they deviate in their decisions from the norm of economic rationality, which can be ascertained through a finite series of standardised queries translatable into numerical indicators. The question as to the universality of human behaviour with regards to the means and telos of rationality, a hotly contested matter just minutes before, is thus reduced to a matter concerning the practical requirements of management tool development and deployment. Seizing the moment, the economist seconds, enlisting the concerns voiced by the CEO in order to strengthen his argument for conceptualising the economic agent as an optimiser:

> I think that we all agree that we are not going to build a homo economicus who is all about profits all of the time. But I think there is a critical choice to make. Are we talking about agents that fundamentally have an objective, and what we are trying to understand in this machinery is, what is their objective and what are the constraints under which they are optimising their objective. Or are we saying, we are not going to assume they have an objective and we are just going to try to get specific processes. And my concern for that is that if we do that, I do not see how we could do that without doing really in-depth ethnographic research everywhere we want to use that model.

The CEO agrees:

> We should remember what we want this project to do. This is a manager's tool! The managers are not going to do ethnographic research everywhere they go. They will be happy to ask the 20 questions that say, you know, how are folks under such pressure that generally the objective function is not a fully realised net profit, but probably an operating profit. Or how are folks so culturally into fishing that they will, even for long periods, without making any money. Right? But those are deviations from the pure homo economicus. I am not trying to build a deterministic, ethnographic model about why people do what they do. I am trying to keep it to 20 questions.

Exhorting the researchers to shift their focus towards the project's impact objectives, the CEO redefines the issue at stake in the dispute. Redefining the problem to which a fact or artefact is presented as a solution is a powerful closure mechanism in technoscientific controversies (Pinch & Bijker, 1984: 427). As the dispute cannot be settled by theoretical or methodological fiat, the CEO's intervention deploys a powerful ally by invoking the political relations assumed to obtain in the local contexts of resource governance in which the consortium's work product is supposed to be of use to fisheries managers. Implicit in the CEO's statement is the assertion that the tool the consortium develops is primarily meant to be useful to resource managers (rather than the resource users being managed).[19] Resource managers are assumed to be in a position powerful enough to ignore the consortium's work product if it does not fit into the manager's established work practices. Moreover,

[19] This orientation towards powerful actors as imagined users of the decision-support tool recurred throughout the project. I discuss the productivity of this imagination for the design of the model in chapter four.

resource users are assumed to be in a position relative to resource managers wherein the latter can safely ignore those local differences in resource user's decision-making which an ethnographic approach might be capable of recovering. Assisting resource managers, rather than creating a model which faithfully captures the reasoning processes of fishers, is now the problem to which the agent-based model is framed as a solution.

Although he is not a researcher, the CEO's argument carries weight. Not only does his organisation contribute a substantial amount of project funding, but the relationships his organisation maintains with resource managers in California, Indonesia, and the Philippines are vital for fulfilling the research impact objectives of the consortium. However, the question whether or not the purpose of reasoning is to improve one's lot in life or a particular theory of reasoning is warranted by evolutionary foundations shifts to the background. Easy portability of the decision-support tool across geographical contexts through standardisation is now presented as an important requirement to fulfil the objectives of the consortium which in turn constrains the range of methodologies and attendant theoretical precepts the scientists are able to consider.

Attempting to settle the dispute by reference to the contexts of use of the eventual work product of the consortium, the CEO's intervention inverts the debate about appropriate research design: the political relations assumed to obtain in the contexts in which the outcome of research is to be used now constrain the range of practicable methodologies which in turn determines the theoretical assumptions about the economic rationality of agent decision-making which set off the dispute in the first place. Constraining the variety of modes of reasoning incorporated in the agent-based model, it is the very rigidity of the model that is meant to support its applicability across heterogeneous contexts. If the consortium eschews the situated approach in favour of constrained optimisation, then the finite resources the consortium is able to marshal through its partnerships with fisheries managers are put towards optimal use in the sense of the widest possible dissemination of the decision-support tool. In a moment of perhaps unintended recursivity, the CEO's intervention enacts optimisation while paying lip service to its critique in much the same way behavioural economics empirically qualifies, but remains normatively wedded to, neoclassical rationality.

6.4 Conclusion

As practitioners of heterodox economics, the consortium researchers are engaged in the production of economic knowledge that, while articulated with the legacy of mainstream economics, aims to eschew doxa about economic rationality which they deem unrealistic. While agreeing that the rational actor of mainstream economics cannot be the conceptual underpinning of the locational choice algorithms of the fisher agent, they disagree on different models of reasoning and decision-making. These models are realised with different calculative methods and invested with different normative commitments: the dispute brings into relief that agents reason for a reason, and what the telos of reasoning might be remains a matter of debate playing out in the tension between universality and particularity as well as different disciplinary commitments and histories. Although modified with behavioural parameters, the optimisation methods advanced by the economist, implicitly if ambiguously endorsed by the computational social scientist, and explicitly embraced by the CEO, embody the normative legacy of rational choice. On the other side, the question-based algorithm of reasoning does not incorporate any claims to the universality of rationality as maximisation and would allow for the heterogeneity and situatedness of the substantive beliefs underlying, as well as the telos orienting, agent reasoning across heterogeneous geographical contexts. Occuring at a privileged site where theories of decision-making are disputed and folded into calculative devices equipping decision processes elsewhere, the New Orleans dispute between modellers should allow for drawing two conclusions about the way theories of economic life are linked to ways of governing economic decisions (McCormack & Schwanen, 2011). The first conclusion regards the role of political stratagems in adjudicating between rival economic theories and their eventual performative efficacy. The second concerns the normative dimension of calculation and its role for investigations of economic performativity. I shall discuss them in turn.

The performativity programme has been criticised for its implicit assumption of economic knowledge and its performance through models and other material mediators as the prime mover of the social processes unfolding as empirical economies (Bryan et al., 2012). Critics have pointed at the absence of politics other than the politics of expertise in the heroic role afforded to economic knowledge in the performativity programme, highlighting how economic knowledges are enlisted by actors outside of the economics discipline towards the realisation of their specific ends. Bryan et al. (2012) and Mirowski & Nik-Kah (2007) both argue that expert economic calculation has been strategically deployed to realise economic relations favourable to actors not invested in knowledge production, but instead in the accumulation of wealth and political power.[20] This would suggest that political stratagems and their articulation with economic knowledges would have to assume a more prominent role for the analysis of the performance of market economies rather than those economies being the result of "the more or less chaotic, regular and general upsurge of calculative agencies formatted and equipped to act on the basis of a logic of accumulation and maximization" as Callon (2005: 5) claims. Whereas Callon leaves it open just how the basis of this formatting is formed, one source of such a logic can be located in the play of political relations diverse economic knowledges are embroiled in. In the case of the consortium, the injunction to pursue a framework of agent reasoning turning on a universalised, normative rationality of maximisation was uttered by the CEO of a conservation NGO. That is to say, an extra-scientific actor enlisted a faction in a scientific dispute for other than epistemic ends, namely the reform of fisheries management practices in the locations where the NGO wishes to operate. The specific economic knowledge claim about rationality as optimisation was advantageous to an important and influential actor by affording ease of portability through standardisation of the model. That this specific model of economic rationality as maximisation prevailed in the dispute, then, is not so much due to its meeting felicitous conditions which, in any case, could only be meaningfully specified a posteriori, but rather because it was politically opportune. This finding suggests the entwinement of political context of model use and the practices of model development (Svetlova & Dirksen, 2014) as a source of the specific formatting of calculative agencies.

[20] In her discussion of the policy devices emerging from the post-WW2 research programme into rational action, Amadae (2003: 11) maintains that these planning and decision-support tools and the concept of rationality they embodied achieved stature not because they could be proven to produce better decisions, but rather through their routinisation through successful embedding in the worlds of policy professionals whose ends and practices they legitimised as objective and scientific.

A further conclusion concerns the manner in which the normative dimension of calculation has been written out of the economic sociologies of the performativity programme. As discussed in the review section of this chapter as well as in chapter two, early versions of the performativity programme still acknowledged the indebtedness of its notion of calculativeness to neoclassical theories of rational action. Later elaborations elided this specific genealogy, instead rendering calculation an execution of a series of equipped practices. This later operationalisation of calculativeness divests calculation from its telos, an interrogation of which would bring into relief the normative dimension of rationality. For the proponents of rational choice, maximisation in the sense of realising preferences is the very point of calculating states of the world. Moreover, this objective of maximisation was held to be not only descriptive but claimed to be consistent with rationality as an anthropological universal embroiled in a struggle between political-economic orders in which the claim to the universal validity of economics as a scientific discpline was invested (Amadae, 2003). Whereas Callon and Muniesa's (2005) definition of calculation, consistent with rational choice, is meant to render descriptive accounts of the socio-technical networks generating economic agency, rational choice theory blends the descriptive and prescriptive dimensions of rationality by not only giving an account of how calculation proceeds but also intimating that reasonable actors should calculate in the optimising way the theory and its attendant tools and methods would suggest (Amadae, 2003; Ermakoff, 2017). Evacuating the calculative means for realising economic rationality of their normative dimension, this blending of descriptive and prescriptive dimensions is obscured in the praxeographies of calculative agency suggested by the performativity programme.

However, calculative processes might well incorporate heterogeneous and contested normative orientations. Eliding these heterogeneities would obscure different possible economic performativities and constrain the critical purchase of the performativity perspective to reforming the market designs following from neoclassical economics without questioning its normative telos of economic action. The dispute among the consortium researchers brings into relief that normative questions about just what economic action is for, and according to which principles economic agents should act, are not external to the phenomenon of calculation. Tracing the work of calculative devices, studies of the performativity programme tend to be situated in medias res of the socio-technical infrastructures supporting empirical economies. This is consistent with an important methodological principle of actor-network theory, namely aversion to reduction (Latour, 2005b). ANT is committed to explaining the efficacy of a social phenomenon by rendering a rich description of the phenomenon rather than referring to an explanans external to the phenomenon itself. However, when the descriptive tracing of calculativeness neglects the normative dimension embodied in the devices equipping calculative actors, it would seem that ANT's elaboration for a sociology of economic agency has little purchase on the way in which the kinds of normative questions economic actors, including academic economists, themselves grapple with are involved in the production of specific economic worlds. These questions cannot be recovered when praxeographies of calculative agency are not cognizant of the cultural specificity of calculative practices and the specific genealogy of their articulation with economic rationality. Indeed, it would seem that universalising calculation in such a way produces the curious effect by which market economies following from the felicitous performance of neoclassical theories can appear as the only possibility in the economic sociologies following from Callon's programme. This special efficacy granted to the performativity of neoclassical economics has been noted by Callon (2005: 11) himself and in turn criticised by others (Bryan et al., 2012; Lezaun, 2017; Mirowski & Nik-Kah, 2007). Understanding accounts of economic performativity as co-performative of that which they describe, I submit that this special efficacy might be explained as an effect of the methodological untethering of economic calculation from its various historical articulations with rationality and its culturally specific telos. Recovering these linkages would perhaps contribute to returning to the economic performativity programme a critical purchase beyond tinkering with the technicalities of market design.

Chapter 7 Just add noise: the anti-politics of computational policy optimisation

"That's no problem, we just add noise", said the principal investigator. I was dumbstruck. His was a response to an account he had asked me to give about my ethnographic research into the workings of the Pacific Fisheries Management Council (henceforth PFMC). The exchange took place in New Orleans at a week-long team meeting of the international research consortium. Seated around a conference table on an April afternoon, the team discussed how to model the "policy agent" in their simulation of West Coast fisheries. The policy agent was meant to represent an environmental management organisation like the PFMC processing information about the state of the fishery and then setting a management policy. How to design that information-processing, policy-setting mechanism was the question at hand. None of the modellers present had firsthand experience with the way the organisation they sought to model makes decisions. The principal investigator knew, however, that I had spent some time researching that organisation and turned to me for an explanation of how the PFMC works. Caught somewhat flat-footed by his request, I improvised a rather rambling account of the intricate politics shaping how information was taken into account in the Council's proceedings, finishing my contribution by expressing doubt about whether the vagaries and vicissitudes I witnessed could be meaningfully formalised. The comeback was swift and dismissive: "we just add noise". A consultant at the table, who is a marine biologist by training, seconded: of course there would be "ad-hocery" the likes of which I had just described, but the PFMC could nevertheless be expected to make decisions in largely regular and rule-following ways the formalisation of which should certainly be conceivable. The team then turned to discussing the question of how to obtain quantitative data from which to derive these regularities. My contribution dismissed, I remained silent for the rest of the meeting.

Such tales of ethnographic failure tend to remain marginal in scholarship, serving at best to enliven accounts of fieldwork before moving on to the more successful encounters with interlocutors from which theoretical insights might be gained (Jemielniak & Kostera, 2010). Instead I wish to dwell on this incident for a moment and treat it as diagnostic. As a social scientist with some empirical insight into the PFMC, I had been interpellated as an expert on the organisation in which the modellers took a specific interest. What little expertise I had to offer, however, turned out not to be relevant to and, at worst, to confound, their interest in designing an algorithm which would formalise the decision-making processes of that organisation. The modellers could readily dismiss my account without having to fear any consequence: I was by far the most junior academic in the room and had more to lose from endangering my research relationship with the consortium by insisting on my standpoint than they had from sidelining my contribution. Rendering those aspects of the PFMC at work which had centred my own analytical attention as merely "noise" was made possible by this very power relation between myself and my interlocutors. My failure to enrol into the community of modellers, scientists, conservationists and consultants gathered around that conference table in New Orleans leads into questions about the politics of their project of policy optimisation. In this chapter I wish to interrogate the consortium's dismissal of "noise" as disclosing a perspective on environmental governance that forecloses the material politics of policy-making. First, I will discuss computational policy optimisation as an expert problematisation of environmental governance that turns on the translation of policies into parameters and of political articulation into calculation. The chapter then discusses and develops some theoretical resources that might aid an analysis of the material politics of policy-making in practice. Deploying this analytical framework, the remainder of the chapter will document an ethnographic episode of policy-making at the Pacific Fishery Management Council in order to describe and analyse the very processes dismissed as "noise" which remain absent from the project of policy optimisation. Finally I will conclude with some thoughts about the way in which an appreciation of the materiality of governance might elucidate an anti-political dimension of reform projects such as that pursued by the consortium.

7.1 Rendering governance computational

Optimising policy-making is a project rooted in the development of the field of policy analysis.[21] Comprising a set of calculative practices, policy analysis casts governance as the challenge of matching expert knowledge with managerial action: empirically identified problems are translated into technical issues with optimal solutions and alternative means to attain these solutions are then evaluated as to their effectiveness and efficiency before selecting a policy alternative (Fischer, 2003). Reversing that process, the consortium chose an approach to policy optimisation that combines computer simulation with machine learning to generate policies that most closely match desired outcomes. Rather than setting policies ex ante and then ranking their performance in simulated scenarios, desired system states (such as optimal harvest or biological conservation) are defined at the outset with an optimisation algorithm discovering those combinations of policies most closely approximating the desired

[21] The history and normative dimension of various calculative techniques for optimisation are discussed in greater detail in the preceding chapter.

outcomes. This approach turns on the translation of fisheries management policies into numerically defined parameter sets. Policies such as the length of a fishing season or the geographical placement of a marine protected area are translated into parameters (start- and end-time or coordinates respectively) that in a simulation run could take any given value. Taken together these parameter sets comprise a multidimensional parameter space which is then searched by the optimisation algorithm iteratively running simulated scenarios to find the optimal point or region on that space in relation to the desired system state. The optimisation algorithm acts as a "policy agent" gaining information about the system from each model run. A model run simulates a specific policy scenario in order for the policy agent to then iteratively predict with stochastic confidence where next to search the parameter space of all possible policy combinations through further model runs. As one of my interlocutors explains, noise, in this approach, figures as the possible distortion of the relation between information about the system state gleaned from model data and the prediction where to search the parameter space next by simulating a further policy scenario. This noise could stem from measurement errors, random fluctuations or implementation failures; it intervenes into the relation between knowledge about the system and the action altering system states.

This proposal for improving the governance of fisheries is thoroughly computational. In her study of international development programmes, anthropologist Tania Murray Li (2007) identifies two key practices through which experts translate a "will to improve" into a programme. First, an expert problematisation identifies deficiencies to be remedied through the design and implementation of a programme. Second, the domain to be improved is rendered technical through calculation, i.e. delimiting a boundary within which a finite set of discrete entities and relations are made visible and manipulable in order to achieve a desired result.[22] Crucially, she argues that the "identification of a problem is intimately linked with the availability of a solution" so that the practices of problematisation and rendering technical "co-emerge within a governmental assemblage in which certain sorts of diagnoses, prescriptions, and techniques are available to the expert who is properly trained" (Li, 2007: 7). In the case of the consortium both their problematisation of fisheries policy-making and the way in which they render it technical are shaped by computer science expertise and the computational techniques available to them. The consortium advances an approach to policy-optimisation which parallels a recent shift in computer science from deterministic programming of algorithms towards the design of machine learning systems (Domingos, 2015: 7). In the deterministic approach, a policy would be translated into an algorithm processing data input and generating an output result which can then be ranked against a desired performance of said policy. In the machine learning approach, this relation is inverted: a desired outcome in the form of a score function and data generated through simulation runs figure as inputs to a machine learning system which generates the algorithm, i.e. combination of policies, that most closely approximates the desired outcome. Improving the rules that govern fisheries is thus translated into a problem of computational optimisation to be solved through machine learning. Morever, this expert problematisation of policy-making and the proposed computational remedy aim for a process of automation that reorganises the relation between human deliberation and machinic calculation. Human effort is to be expended in defining the goals of policy and then an automated

[22] Drawing on the work of Michel Callon, Tania Murray Li's notion of calculation inherits the problem of its non-specificity and the elision of its normative roots in neoclassical economics which I discuss in the preceding chapter.

process tasked with discovering policies most likely to attain those goals. The principal investigator envisions this process combining human decision and machinic calculation as a redesign of the very practice of policy-making:

> This is what I am very excited about at the moment because this is a different way to do policy. You spend all of your effort deciding what state you want the system to be in and finding a metric to decide that, and then the optimiser finds the policy for you. Say, we define success as catching the most species A and conserving most of species B. Here is all the parameters you can change, there you go, optimiser, you run the model, find out what's the best policy that gives us an optimum point. So it's nice, it's policy ... it's kind of a goal-orientated policy creation.

The way in which this problematisation of fisheries management envisions the policy-making process is made plausible with the rhetorical use of computational complexity. Assuming that policies could indeed be figured as parameter sets, as soon as they exceed a certain number of possible combinations, finding the optimal combination presents as what in computer science parlance is called a hard problem: it cannot be solved in a reasonable amount of time or, as the principal investigator put it, "once you get over ten parameters with five different values each, it's like the age of the universe to do that." Hence the task of finding those combinations of policies is handed over to the optimisation algorithm as a stochastic technique that searches for optima in such a vast parameter space. If applied in management practice, the space of possible solutions searched by the optimisation algorithm, or "policy universe," is supposed to be constrained to practically feasible policies through stakeholder consultations. Deliberation is meant to take place at the beginning of an otherwise automated process: people decide which management goals to pursue and ensure that the computational system does not suggest policies which may be mathematically optimal but practically unfeasible. The deficiency identified by this programme of improvement is contingent upon the technical solution at hand: policy-making is rendered computational in order to optimise it with the help of automated combinatorial search techniques.

How, then, shall we understand the curious place of "noise" in this rendering computational of governance? Expert practices of problematising and rendering technical are necessarily shaped by constitutive absences as "programmers must screen out refractory processes to circumscribe an arena of intervention in which calculations can be applied" (Li, 2007: 2). Remaining silenced at the time of programme development, that which exceeds attempts at framing the domain to be governed as calculable is bound to return when plans for improvement are politically contested (Li, 2007: 12)[23]. In the following section, I intend to develop a sense of/for noise as registering that which remains absent, and might potentially trouble, the project of computational policy optimisation. Following that, the remainder of the chapter attempts to think an ethnographic episode of governance in action at the Pacific Fishery Management Council with this sense of/for noise in order to tune into the clamour of practical mediations and political articulations reverberating throughout the assemblage of rule-making.

7.2 Noise and the material politics of policy-making

Noise has been discussed as a force whose inventive capacities exceed distortion. Based on his reading of information theory, Michel Serres (1982) inverts the relation between noise and order, arguing for the inventive and foundational role of noise for any process of communication and, by extension, for any practice of ordering. Rather

[23] Engaging with economic externalities as framing effects, Callon (2010) makes a similar argument about the return of those entities which exceed the calculative frame. See also Barry (2002) on the anti-political effects of metrological regimes.

than figuring as a distortion to be reduced, noise, in this reading, registers the productive presence of mediation. In Shannon and Weaver's (1964) mathematical theory of information, the absence of any interference would mean the immediacy of communication or identity of sender and receiver. Without noise, communication would neither be possible nor necessary: the informational value of a signal is at its highest in the middle range between absolute and zero noise. Discussing various forms of passage, for instance the mediation between forms of knowing in art and science, Serres extends this operational principle of noise beyond the mathematical theory of communication which had been originally formulated during wartime as a foundation of military signals engineering. Following Serres, noise can be read as indexing the lively and productive materiality of mediation: establishing a relation of passage between fields or entities involves material means which do not remain silent and passive but rather affect that relation and its relata. The work necessary to facilitate passage between different fields not only leaves traces in the form of noise, but also potentially transforms that being transported and thus acts "as a possible source of invention" (Brown, 2002: 2).

This relation between mediation and invention informs the concept of translation developed in actor-network theory. As Callon (1986) argues in his classic text on the sociology of translation, enlisting actants into a network entails their continuous displacement and transformation through wich an ensemble of relationships is established that generates novel agentic capacities. However, the process establishing passage between actors, and the alignment of their interests, remains provisional and contested precisely because translation incorporates an element of modification which adds a measure of instability and unpredictability to the ensemble of relations.

The negotiation and modification of actant interests and goals necessary for enlisting them into a network plays out in trials of strength: every translation of an actants' interests and goals involves a betrayal in the sense that interests and goals do not remain unmodified and this modification might become a source of contestation.

This relational theory of translation has informed some of the ways in which objects have been brought into focus in theories of politics. In geography, Rutland and Aylett (2008) suggest an object-oriented praxeography of environmental policy-making through a detailed investigation of the ways in which "subjects and objects of politics come together in processes of consultation and contestation" (Rutland & Aylett, 2008: 643). Translation, here, refers to the gradual alignment of an array of interests of actors with different goals who are involved in the process of policy-making and serves to explain how policy objectives and priorities emerge by facilitating passage between heterogeneous actors at the collective level. In addition, the work of translation simultaneously shapes the object to be governed through a policy by embedding it into a specific set of relations within the wider network of policy-making (Rutland & Aylett, 2008: 636). In policy-making, then, policies, political actors, and objects of politics emerge simultaneously through the work of assembling a network that translates the interests of different actors.

In chapter two I discuss how work in geography and STS has centered the objects of politics as contested entities. Properties of material objects are relational, dynamic, and contingent on different knowledge practices which might result in knowledge controversies (cf. Whatmore, 2009) pitting different articulations of materials against each other in such a way that decisions have to be reached without a shared factual basis in which to ground political consensus (Barry, 2013; see also Hinchcliffe, 2001). As objects of controversies, materials provoke antagonism and dissensus in political processes in which their relational properties are at stake. Drawing on a radical democratic theory of the political (Mouffe, 2005), Barry goes on to argue that dispute about material properties can occasion the moment of the political in the sense of an articulation of irreducible dissensus between different actors (Barry, 2013: 12). However, the means by which such dispute is organised might well have anti-political effects by acting to constrain the articulation of dissensus (Barry, 2002). In STS work on issue formation, a similar sensibility for the "association between material and social constituents" (Marres, 2007: 762) obtains. Public controversies articulate material entities as issues in which different actors are "jointly but antagonistically" (Marres, 2007: 773) implicated through their divergent attachments to objects. Implication, here, denotes ties between human actors and material entities that are not only discursive, in the sense of different interpretive frames rendering objects meaningful in different ways, but material in the sense of physical, technical, and practical ties which might well be irreconcilable between different groups of actors. That is to say, competing issue articulations highlight not only different ways of knowing an issue but rather different ways of being, bringing into relief antagonistic material attachments of human actors to nonhuman entities. In this sense, political controversies around issues are interventions into the very organisation of heterogeneous socio-material collectivities.

If attending to noise means attending to the productive, inventive and mediating work necessary for assembling, and facilitating passage between, heterogeneous actors and entities, then attending to the noise of policy-making might disclose how political orderings, too, proceed through inventive and contested socio-material associations in which actors and objects of politics are simultaneously at stake. The following section will attempt to read an ethnographic episode of environmental policy-making in action through this analytical lens.

7.3 Governance in action at the Pacific Fishery Management Council

Fig. 7 The Council hears testimony from a federal scientist

On the dry and dusty outskirts of Sacramento, bordered by the busy Capital City Freeway and the sprawling grounds of the California Exposition and State Fair, the DoubleTree Hilton hotel provided a venue for the 233rd session of the Pacific Fishery Management Council (PFMC) that could hardly be further removed from the meeting's maritime subject matter (Fig. 7). In March 2016 I spent a week in

Sacramento to participate in the 233rd session of the PFMC as well as its various advisory bodies and to speak with a number of participating scientists, regulators, fishing industry representatives, and Council staff. The PFMC had been brought to my attention in conversations with the British consortium scientists who considered its Scientific and Statistical Committee as a key actor to whom they wished to make their work product relevant.

The Pacific Fishery Management Council is one of eight regional fishery management councils in the United States established by the Magnuson-Stevens Act of 1976. Meeting five times per calendar year, the Council develops fishery management measures for each of the species or species groups within its remit. Fisheries policies developed by the Council are laid down in detailed, publicly available, and periodically revised management plans. These plans are then submitted for approval to the Secretary of Commerce through the National Marine Fisheries Service (NMFS), a division of the National Oceanic and Atmospheric Agency (NOAA). The maritime area governed by the PFMC is coextensive with the Exclusive Economic Zone spanning between 3 and 200 nautical miles off the Pacific shore of the states of California, Washington and Oregon whereas the area extending three miles from shore falls under the jurisdiction of the individual states.[24]

[24] Indeed an argument could be made that in establishing the jurisdiction of regional fishery management councils the Magnuson-Stevens Act produced the Exclusive Economic Zone in the first place by effectively excluding foreign fishing off the United States coast (cf. Finley, 2011). However, the transboundary movement of animals confounds such territorialisations of maritime space. Current governance practice recognises that "because fish move between state and federal waters without regard to political boundaries, the Council’s plans generally cover the entire area out to 200 miles" (PFMC, 2007: 6).

The PFMC consists of council members, staff members, and members of its Scientific and Statistical Committee as well as various advisory subpanels. The organisational acrhitecture of the PFMC reflects a modern constitution which separates the domains of nature and society (Latour, 2004): scientific advisory bodies are tasked with speaking on behalf of nature, furnishing through their review process facts about the nature of the systems the Council is tasked to govern. Other advisory bodies represent the interests of various social constituencies affected by the management process including the fishing industry, conservationists, technical managers, and law enforcement. However, as we shall later see, such purifications of social and natural domains are troubled by the hybrid and sprawling nature of the political matters the advisory bodies consider and take work to maintain in the practice of issue articulation. The Council itself has 14 voting members including the directors of state fish and wildlife departments from California, Oregon, Washington and Idaho, the regional director of the National Marine Fisheries Service, a tribal representative, and eight governor-appointed citizens "who are familiar with the fishing industry, marine conservation, or both" (PFMC, 2007: 11). Further five non-voting members of the Council represent the Pacific States Marine Fisheries Commission, the federal Fish and Wildlife Service, the state of Alaska, the Department of State, and the Coast Guard.[25] About a dozen staff members based in Portland, Oregon, assist the Council in preparing meetings and management plans with individual staff officers dedicated to specific species or species groups. Whereas the Council sets the agenda for meetings, staff members compile extensive "briefing books" detailing the issues to be discussed and decided at Council meetings, the supporting information received from scientific

[25] The landlocked state of Idaho is represented because it contains part of the Columbia River Basin which is an important habitat for anadromous species such as salmon. The state of Alaska is represented in the PFMC for similar reasons of transboundary migration although it also maintains its own regional fishery management council.

and other advisory committees, statements from state and federal agencies, and public comments. These briefing books, running into hundreds of pages, are then submitted to Council and advisory members as decision-supporting information before each meeting and made publicly available on the PFMC website. Council proceedings are open for the interested public to observe and testimony can be submitted in written or oral form when the PFMC convenes for one of its week-long scheduled sessions.

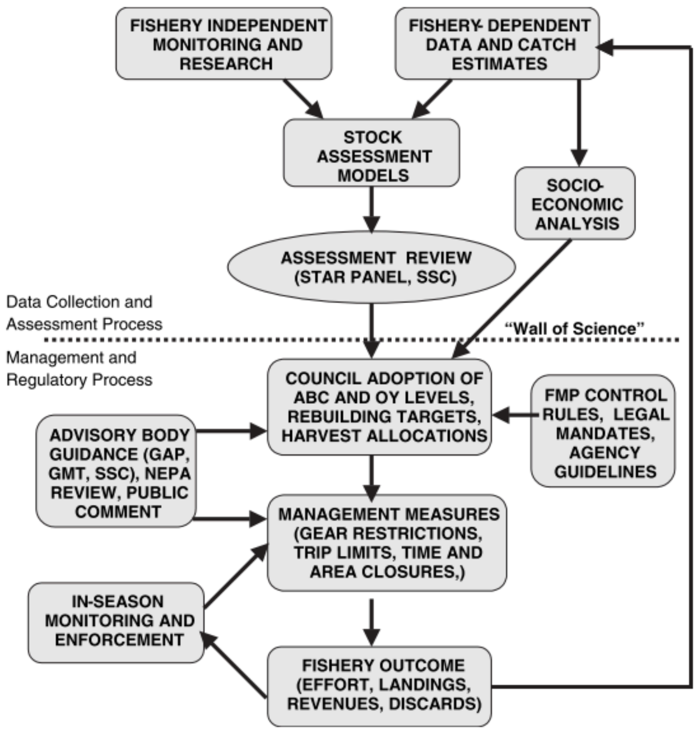

Fig. 8 Schematic overview of the PFMC process for using scientific advice in resource management (in: Field, Punt, Methot, & Thomson, 2006)[26]

Scientific advice has a legally defined role in the governance process. The Magnuson-Stevens Fishery Conservation and Management Act of 2007 stipulates that each regional fishery management council shall establish a Scientific and Statistical

[26] Note the "Wall of Science" clearly demarcating the boundary meant to separate science from policy.

Committee (SSC) which furnishes what the Magnuson-Stevens Act calls "best available science" as the evidence basis on which the Council decides harvest quotas and other policy actions. The document specifying the operating procedures of the Council prescribes that, while scientific advice shall "inform policy decisions by the Council," it shall at the same time "focus on the scientific merit of a proposed action and remain separate and independent from Council policy decisions" (PFMC, 2015: 28). A paper co-authored by a PFMC science advisor asserts this delineation of the respective purviews of scientists and policy-makers as constituting a "wall of science" (Field et al., 2006; see Fig. 8). While routinely prescribed in institutional procedures regulating the conduct of scientific advice, such strict separation between scientific advice and policy decisions is difficult to uphold in practice and takes ongoing work by scientists and policy-makers for delineating and negotiating the boundaries between science and policy (Gieryn, 1995; Jasanoff, 1987). As will be shown later, such boundary work is at stake in the way the Scientific and Statistical Committee articulates its advice simultaneously to its relationships to other bodies within the PFMC. The thirteen members of the SSC are appointed by the Council selecting experts from state fishery management agencies, the National Marine Fisheries Service, tribal agencies, and several at-large positions occupied by experts drawn from academia. The SSC itself does not produce original research. Instead, committee advice is based on reviewing and evaluating research produced elsewhere, e.g. in the regional science centres of the National Marine Fisheries Service, and SSC members have to excuse themselves from deliberations if they have been directly involved in the development of research under review. The disciplinary composition of the SSC privileges the natural and mathematical sciences with the Council operating procedures calling for the inclusion of three committee members from the social sciences to be drawn primarily from the economics discipline.

The PFMC manages fish according to species or species group. As a consequence, advisory subpanels are formed of members from the fishing industry concerned with the harvesting of specific species or species groups. In my fieldwork I focussed on the Groundfish Advisory Subpanel (GAP) because the modellers whose work I took as a starting point for my ethnography were also modelling groundfish fisheries. Delineating its remit within the socio-natural division inscribed into the organisational architecture of the PFMC, the GAP is explicitly tasked with advising the Council on the "socioeconomic implications" of its management activity as well as providing a conduit along which "current trends and developments in fishery matters" (PFMC, 2015: 13) can be relayed to the Council. The 21 members of the GAP are appointed by the Council from representatives of the fishing industry classified by gear type, geography, commercial or recreational fisheries, processors, and tribal fishers as well as one representative of a conservation group. The panel advises the Council on the development of management plans with regard to questions of the fishing capacity of the fleet harvesting groundfish, the effects of policy on local economies and social structures, and conflicts between resource users as well as problems of enforcement.

7.3.1 Follow the issue: articulating agenda item G.8

Before travelling to Sacramento, I prepared my visit by calling a Council staff member who, while at first surprised that someone would take an interest in researching the Council as an organisation, quickly offered to help me find my way through its dense web of procedures, committees, and documents. After I explained my interest in understanding how the PFMC arrives at decisions utilising evidence, the staff member recommended picking a specific agenda item and following its trajectory through various advisory committees before being brought on the Council floor and decided upon. This recommendation resonated with my methodological sensibility for following practices-in-the-making. As a consequence, I selected agenda item G.8 in which changes to gear regulations in the trawl catch share programme for groundfish were at stake. Following the agenda item G.8 meant following its scheduled progression through the different conference rooms of the hotel in which different advisory bodies met and its articulation, materialisation, and provisional stabilisation as an issue in the reports these advisory bodies produced. The journey of agenda item G.8 reveals policy-making as a verb indeed: as situated practice-in-the-making in which heterogeneous actors attempt to simultaneously articulate issues and enrol each other in acts of noisy translations. Aware that the boundaries I draw around the policy process stem partly from the spatio-temporal boundedness of my own ethnographic presence, in what follows I will nevertheless render a diachronic account of policy in action.

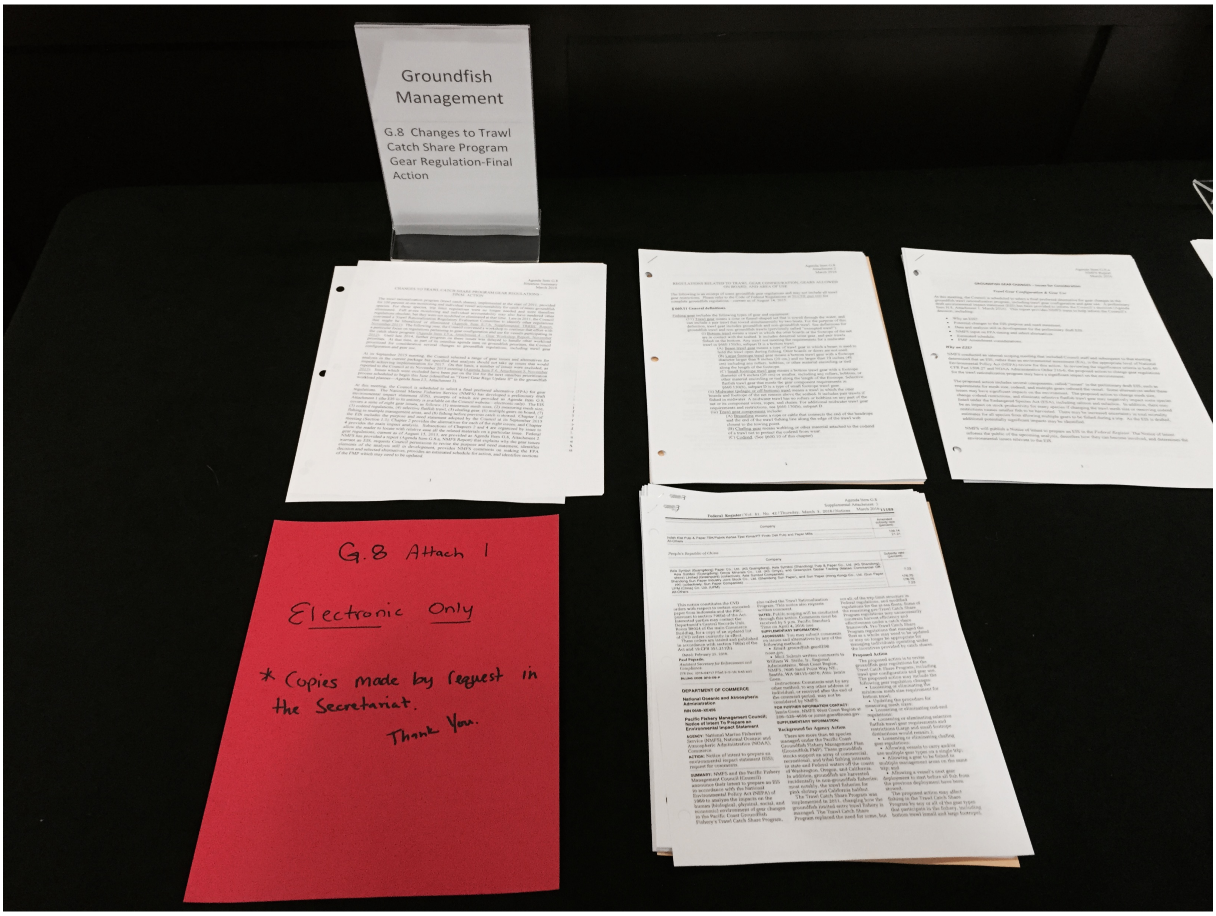

Fig. 9 The stack of briefing documents for agenda item G.8

Proceeding through the hotel lobby to the conference space on the first day of the PFMC session, the visitor immediately happens upon a long table covered with a heavy black cloth. On this table, stacks of paper are laid out and marked with signs referring to individual agenda items (Fig. 9). Upon approaching the table and taking a closer look, each stack referring to an agenda item contains a number of documents: situation summaries prepared by Council staff, excerpts of pertinent regulation, entries in the Federal Register announcing the preparation of environmental impact statements, comments submitted by conservation organisations and industry associations, and decision templates enumerating the alternatives brought before the Council. As the session progresses these document stacks grow: added to each pile are the reports of the advisory bodies summarising their deliberations of each agenda item and their recommendations to the Council. Producing these piles is the task of the Council secretariat. Temporarily installed in a room adjacent to the lobby, the secretariat is busy collecting, collating, and formatting the steady stream of reports flowing from the advisory bodies which are in constant session, moving through the agenda.

The documents in the stack brief the Council, its advisory bodies, and the participating public on the substance of the agenda item under consideration. One of the documents in the stack for agenda item G.8 is the situation summary. Prepared by Council staff before the session, the double-paged document is titled "Changes to trawl catch share program gear regulations – final action." The document traces the history of the agenda item relating to previous Council meetings and actions, details what action the Council is scheduled to take on the item at the current meeting, and refers to supporting materials contained in the stack. In the situation summary, the agenda item is discussed as relating to changes in regulations governing the configuration and use of fishing gear in the groundfish trawl fleet. Detailed regulations prescribing what kind of fishing gear can be used in which way in the West Coast groundfish fishery are codified as part of American administrative law in the Code of Federal Regulations.

The procedural purpose of the deliberations under agenda item G.8 is to decide which changes to these regulations the Council should recommend to the Secretary of Commerce. Eight changes to gear regulations are under deliberation in item G.8. These include five regulations governing gear configurations such as minimum mesh size and its measurement as well as the design of specific parts of the gear. Further under consideration are three regulations governing the use of multiple kinds of gears on the same fishing vessel, whether fishing activity should be allowed across the boundaries of multiple management areas, and whether catch can be hauled onboard a fishing vessel before previous catch has been stowed away. Potentially relaxing strict classificatory, technical, and geographical separations, these last three changes to regulations are bound to provoke controversy during the following advisory body meetings.

A further document in the stack titled "FPA decision template for changes to trawl catch share program gear regulations – final action" tabulates all of the eight gear regulations and enumerates the various decision alternatives under consideration for each of the regulations (Fig. 10). As the situation summary details, in this session the Council is scheduled to select final preferred alternatives from the decision template, i.e. to make a decision which alterations or amendments to the regulations should be recommended to the Secretary of Commerce for enactment as administrative law. The order in which the decision alternatives are tabulated follows from a draft environmental impact statement prepared by the National Marine Fisheries Service of which a summary is also contained in the stack.[27]

[27] Under the National Environmental Policy Act the NMFS is required to prepare an environmental assessment or (more comprehensive) environmental impact statement for a policy change dependent on the expected severity of its impact.

Agenda Item G.8
Supplemental Attachment 4
March 2016

FPA DECISION TEMPLATE FOR
CHANGES TO TRAWL CATCH SHARE PROGRAM GEAR REGULATIONS –
FINAL ACTION

The following is a list of the trawl gear issues and alternatives for Council action at this meeting. See the referenced Chapter 2 sections for a full description of each of the alternatives and the related Chapter 4 sections for a discussion of the impacts of the alternatives.

Minimum mesh size (Issue A, DEIS Sections 2.1 and 4.1)		**Council FPA**
Alternative A1 (No-action)	4.5 inches for bottom trawl and 3 inches for midwater trawl.	
Alternative A2	4 inches for bottom trawl.	
Alternative A3	No minimum mesh size for bottom or midwater trawl.	
Measuring mesh size (Issue B, DEIS Sections 2.2 and 4.2)		
Alternative B1 (No-action)	Trawl mesh size measurements taken between knots.	
Alternative B2	Trawl mesh size measurements taken between knots or, in knotless mesh, between corners.	
Codend (Issue C, DEIS Sections 2.3 and 4.3)		
Alternative C1 (No-action)	Only single-walled codends could be used in any trawl. Double-walled codends prohibited. Chafing gear could not be used to create a double-walled codend.	
Alternative C2	No codend restrictions.	
Selective Flatfish Trawl (Issue D, DEIS Sections 2.4 and 4.4)		
Alternative D1 (No-action)	SFFT would be a two-seamed net as further defined at §660.130(b)(3)(ii)(A). SFFT required shoreward of the RCA north of 40°10' N. latitude, and permitted, but not required, shoreward of the RCA south of 40°10' N. latitude. SFFT permitted seaward of the RCA coastwide.	
Alternative D2	The SFFT definition would be modified to allow a two-seam or a four-seam net.	
Alternative D3	The SFFT definition would be modified to allow two-seam or four-seam net AND would eliminate the SFFT requirement shoreward of the RCA north of 40°10' N. latitude and would replace it with small footrope (like south of 40°10').	
Chafing Gear (Issue E, DEIS Sections 2.5 and 4.5)		
Alternative E1 (No-action)	Bottom trawl chafing gear last 50 meshes, less than 50 percent circumference, etc. (see §660.130(b)(3)(iii)) Midwater trawl chafing gear may not cover top of codend, etc. (see §660.130(b)(4)(i))	
AlternativeE2	Bottom trawl chafing gear revised to match midwater trawl chafing gear requirements.	
Alternative E3	Eliminate chafing gear restrictions for bottom trawl and midwater trawl. (assumes retain prohibition on double-walled codend, but related Alternative C2 would remove prohibition)	

Fig. 10 Facsimile of the decision template for agenda item G.8 listing the decision alternatives under consideration

The agenda item G.8 has a history preceding the 233rd meeting of the PFMC. In the year 2011 a rationalisation programme introducing catch shares for the groundfish fishery had been implemented. Under this new regime, individual vessels are allocated shares of fish species, or Individual Fishing Quotas (IFQ), as a proportion of the overall harvest allocation of the fishery. Catch shares substituted for previous environmental regulations which had limited the number of trips a vessel could undertake and thereby, in principle, the catch share programme left it to the discretion of vessel operators to decide how often and with which means to fish for their share. The vessel operator's accountability is enforced through a surveillance system placing observers or electronic monitoring systems on each vessel operating in the fishery. However, some regulations from the pre-rationalisation era remained in place, including the gear regulations under consideration under the agenda item G.8. During an interview in the hotel lobby, a Council staff member involved in the regulatory process for groundfish fisheries explained to me the rationale behind the proposed changes to gear regulations:

> When we implemented the programme there was a real push to get the programme up and running. But there was a mutual understanding between all the parties involved that there were specific issues that had to be tabled for later discussion once we had an idea how the programme was going to function (...) One of the issues that was brought up in the development of the trawl rationalisation programme was, you know, when you have individual accountability and it is in a vessel's own best interest to make the most of their fishing opportunities, they will have built-in incentives to reduce bycatch, reduce catch of unmarketable fish, reduce catch of protected species, and reduce gear interactions with the seafloor if you are not bottom-trawling but using a more midwater gear type. All of this was discussed in the development of trawl rationalisation and it was sort of like, well, we can't tackle all of that now. Because we really don't know how the programme will work! How well it will work. But the programme is working pretty much the way that we designed it to work. And so now, coupled with a consultation that is happening on all of the groundfish fisheries and their impact on protected species, we are looking at making some big liberalisations in the restrictions that are imposed on the folks participating in the trawl rationalisation programme. So the idea is to allow them some additional flexibility.

Whereas the proposed liberalisations follow from the rationale of economic incentives for marine conservation informing the catch share programme, a draft environmental impact statement (EIS) prepared by the National Marine Fisheries Service (NMFS) flags several issues. Contending that some of the decision alternatives may have "significant impact on the environment," the EIS details some of the impacts expected from gear regulation changes. Changes to gear use restrictions may increase "uncertainty in total mortality estimates for all species" because catch could no longer be unambiguously attributed to gear types and management areas which in turn could lower the quality of the data used for fish stock assessments. Further issues pertain to difficulties in the on-deck enforcement of sorting requirements as electronic surveillance substitutes for human observers on fishing vessels. Flagged as problematic is also the effect liberalised trawl gear regulations might have on the ability of fishing vessels to access protected rockfish habitat.[28] Noting that many of these potential effects of gear regulation liberalisations remain uncertain, the NMFS document calls for delaying the decision until further research on impacts and consultations have been conducted.

The various briefing documents contained in the stack for agenda item G.8 enact fishing gear as an informationally enriched material (Barry, 2013). They list properties of fishing gear and define its relations to various practices and concerns. The issue of fishing gear regulation is articulated through its attachments to different actors gathered at the PFMC meeting, namely fishers, scientists, and policy-makers. Their relations to fishing gear, however, diverge contingent on the manner in which fishing gear matters to their practices. Fishers relate to fishing gear as their working tools, scientists relate to gear through sampling practices, and policy-makers through attempts to design a consistent regulatory regime. At the PFMC, gear emerges as a contested object embedded in, and articulated through the insistence on, divergent material and discursive relations with different actors competing for their preferred policy alternatives. It might be tempting to take neat distinctions between different actors and their attendant concerns and material practices for granted. However, following the gear issue through the different advisory bodies brings into relief the work involved in articulating gear as a tangle of relations simultaneously with the

[28] The consortium's attempt to simulate the effects of these regulatory restrictions occasioned the abstraction of rockfish habitat discussed in chapter five.

boundaries and interests of the actors affected by the gear issue. That the gear issue overflows the boundaries of advisory bodies and their procedurally prescribed purview is reflected in the language a Council staffer employs to describe the agenda item:

> For this issue there is a lot of overlap between the committees. There is a lot of interplay and topics that are cross-committee.

This choice of over-, inter-, and cross- as qualifiers betrays the hybridity of the gear issue as its attachments proliferate without regard for the formal procedures laying down the organisational architecture of the PFMC. Following agenda item G.8 through the scientific and fishing industry advisory bodies of the Council traces the articulation of fishing gear as an issue in which heterogeneous actors are "jointly but antagonistically implicated" (Marres, 2007: 773). The next sections will attempt such a tracing, emphasising the relational co-construction of actors and issues while remaining attentive to the political dimension of issue articulations. Whereas the joint implication of these actors in the issue will condition the partial translation of fishers' interest in high harvest allocations into the scientist's interest in data integrity, the antagonistic dimension of divergent attachments to fishing gear will occasion a political moment too. In this moment, a space of dissensus opens in which the irreducibility of fishing as a situated practice to the prescriptive procedures of science-based environmental governance is openly articulated. The following section will show how noisy translations provisionally arraying different practices and knowledges as well as humans and nonhumans are inevitably involved in the work of policy-making as it proceeds along attempts at resolving such imbroglios during advisory body meetings.

7.3.2 At the Scientific and Statistical Committee

Fig. 11 The Scientific and Statistical Committee (SSC) prepares for session

Arriving a few minutes early in the hotel conference room where the SSC meeting is about to begin, I am greeted by an informal atmosphere of casual banter among the mostly male members of the scientific advisory body. The dozen science advisors mingle around a rectangular table with some chairs and standing tables at the edges of the room provided for members of the public (Fig. 11). I take a seat on one of those chairs and introduce myself to my neighbour. Working for a Californian conservation organisation, she gives me an irony-tinged rundown of how "fun" the meetings of the various advisory committees are that she routinely attends as an observer. To her mind, the advisory bodies are where the action is in the PFMC since the Council members themselves, although vested with the power of decision-making, have little scientific training or practical experience with fisheries and thus routinely rely on the advice produced at the SSC and other bodies to inform their decisions. Eventually, the chair of the committee calls the meeting to order. A brief round of introductions follows. Most of the scientists serving on the SSC have a tenure of over five years with a senior member, a mathematician whose assertive voice commands the room, having served for fifteen years. After the executive director of the PFMC briefly greets and thanks the committee members for their service, committee business proceeds with a discussion of agenda item G.8.

A federal scientist from the Northwest Fisheries Science Center of the National Marine Fisheries Service (NMFS) gives a presentation outlining the issues with the proposed liberalisation that had been detailed in the draft environmental impact statement: the potential impact on fish populations of altering mesh size to allow for the targeting of certain species, the impact of liberalising chafing gear restrictions on allowing trawl vessels "access to areas that haven't been accessible over the last fifteen years and what impacts that might have on habitat," as well as the impact of allowing multiple gears to be fished on one trip and allowing fishing across multiple management areas on the integrity of the data used for stock assessments. Prefacing his elaboration of this list of issues with the comment that "a lot of these measures were implemented back about fifteen years ago when we were initiating the rebuilding process" in order to "keep trawlers out of habitat," the presenter notes that with the new catch share programme predicated on "observation and accountability" there now exist "other disincentives for going in there." After elaborating briefly on each of the issues mentioned in the draft environmental impact statement and referring to the document itself for more detail, the federal scientist eventually concludes that he "got into this mainly because of these two issues: some of the options there would allow either multiple gears or multiple areas on a single trip without sorting" which he fears could have a detrimental impact on the "integrity" of the "data supply chain" for stock assessments.

The SSC is presented with two problems: first, how to relate to the issue. Which attachments of the gear issue in front of them, formulated in the language of impacts, matter for the advisory body tasked with ensuring the "scientific merit" of Council policy actions? That is to say, which of the many relations of the gear issue detailed in the impact statement fall within the purview of the SSC and how? Second, how to relate to the Council. At the current Council session, the agenda item G.8 is scheduled for the selection of a final preferred alternative, meaning that the Council is supposed to render a policy decision on the matter before them. This scheduling adds a certain urgency to the proceedings. Yet the federal scientist giving the presentation cautions that "there are some who feel that more analysis or more specificity in the analysis would benefit the final decision-making", preferring to spend more time studying the issue. Should the SSC, then, comment on the decision alternatives or rather recommend delaying the decision altogether?

In the discussion that follows both of these problems are addressed simultaneously. The articulation of the fishing gear issue (how to relate to gear regulation changes) is co-produced with the boundaries of the SSC (how to relate to the other bodies of the PFMC). As the presenter takes questions from members of the advisory body, a dialogue ensues during which the members of the advisory body, gradually and laboriously, determine just how the SSC is interested in the gear issue at the same time as they delineate the SSC's purview in relation to other advisory bodies and the Council. As the first remark following the presentation, a member of the SSC expresses his surprise about the extent of the criticism of gear liberalisations, presumably covering each area of the proposed changes. The presenter responds:

> I think the issues were not necessarily with each area of change but with some of the sub-options. For instance, with multiple gears the primary concern would be for not moving forward with the option that allows catch to be commingled. Even beyond that though, with the option that requires sorting by gear to be maintained there is the question of how do we ensure integrity of that? So I think the point of that letter was to say that some options would appear to compromise the integrity of the data. Other options may be feasible, but probably need more consideration as to how the integrity of the data can be maintained. What procedures would have to go into that, not only on the boat, for making sure the sorting is done and it is clearly understood, you know, what fish from what gear in what area. But when those fish come off the boat, that it is clearly understood by the sampler, by the plant, what gear those fish have been caught with. How are we gonna have data that is as useful for stock assessment as it is now? You know, we need to ensure the integrity along that path and I don't think there has been analysis at this point of what steps would be required in order to do that.

This response of the federal scientist emphasises a specific attachment to the gear liberalisation issue which the SSC should consider, namely data integrity. The integrity of data on which stock assessments are based would potentially be threatened by some of the decision alternatives under consideration. By way of the federal scientist's response, the ability to distinguish between the provenance and the type of gear with which haul sampled for stock assessments has been fished is now made salient as the primary attachment of the advisory body to the gear issue. As the meeting proceeds, other possible impacts relating to altering mesh size and allowing rockfish habitat access are sidelined.

The way the SSC articulates its interest in the gear issue as one being related to data integrity is contingent on the material practices of sampling through which data for stock assessments are produced. Periodically, the SSC reviews assessments of fish stocks produced by regional fisheries science centers through data collection and modelling. These assessments are based on sample data collected at-sea through observers on fishing vessels or by dockside monitors. Sample data serve as input for population abundance forecast models. After SSC review, these forecasts then form the basis on which the Council decides seasonal harvest allocations for the entire fishery. These periodic stock assessments are a central task of the "technical management" for which the SSC is obliged to furnish through its review "best available science" which accounts for the salience of data integrity in the discussion.[29]

The data practices involved in stock assessment are discussed simultaneously with a self-understanding of the purpose and role of the SSC in the regulatory process. A committe member submits that there is a "spectrum" on one end of which the SSC could state "let's just make really strict requirements and that will deal with the problem". However, he proceeds to argue that the SSC should not micro-manage the operations of fishing vessels and observers, but rather let fishers and observers on the boats work out how to maintain separation of catch in such a way that the gear- and area-specific attribution of sampling data is not negatively affected by liberalising gear restrictions. The presenter responds and a dialogue ensues:

> *NMFS scientist:* A minority of the sampling that we use in assessments now comes from observers. The vast majority of it comes from shoreside samples. That's another part in the supply chain of these data. There is no way of monitoring, no way of assessing whether there has been compliance.
>
> *SSC member:* Isn't this more an issue for the enforcement consultants? I think we can identify what the data needs are. We can say there needs to be a trace.
>
> *NMFS scientist:* There needs to be a plan for doing this and there currently is no plan. That's expressed.

[29] The distinction between technical management and strategic management is discussed in chapter four: the former denotes a focus on seasonal harvest allocations and the latter a longer term focus on the development of the regulatory regime.

> *SSC member:* Right. The SSC's purview could be to say that somehow the plan has to ensure that we get the right data. But exactly how that is accomplished seems to be more of an enforcement issue.
>
> *NMFS scientist:* But that speaks to the adoption of a final preferred alternative at this meeting if the analysis isn't there how these things would be accomplished. That should exist before the Council selects one of the alternatives. And they also need to consider that if they move ahead with electronic monitoring instead of requiring a hundred percent observer coverage, how does that sort of thing interact with this? It's not that you guys need to comment on how all of that would work. I think more important is just to potentially bring their attention to the fact that there may be interactions between this and some of the other actions that the Council has under consideration right now.

In this dialogue, the maintenance of data integrity and the purview of the SSC are simultaneously at stake. The salience of data integrity as the way in which the SSC should be interested in gear liberalisation is contingent on the articulation of a specific material attachment of fisheries science to fishing gear. This attachment involves the materiality of scientific representation: abstracting data from field observation entails organising stable pathways along which reference can circulate from the field to a centre of calculation. These pathways are laborious to maintain (Latour, 1999a). The exchange between the committee member and the presenter considers the various material practices, actors, and sites enlisted into the "data supply chain" of stock assessment: how would sampling data be affected by allowing the use of multiple gear, in multiple areas, and allowing to haul catch on board without stowing catch from a previous haul? And how is the integrity of this data practice to be enforced when electronic monitoring by video camera substitutes for human observers on deck? A stable "data supply chain" between at-sea and shoreside sampling and population forecast modelling in the NMFS science centers has to be maintained in such a way that the classificatory boundaries sorting sampling data by gear type, management area, and haul remain undisturbed. Maintaining a "trace" entails that fishing practices have to be ordered in such a way that data can circulate along a chain of reference (Latour, 1999a) from vessel to model.

At the same time, the practicalities of maintaining data integrity provoke consideration of the purview of the SSC. While the interaction of fishing and data practices constitutes a chief concern for the scientists, the specific way these practices should be re-ordered in such a way that the "trace" can be maintained also presents a problem for the self-understanding of the advisory body. As the SSC member notes, commenting on questions of compliance with regulations is principally an issue for another advisory body, namely the enforcement consultants comprising Coast Guard and other law enforcement agencies. The SSC member does not wish to micro-manage at the danger of potentially overreaching beyond what he perceives to be the purview of the SSC. The presenter offers a way out of this problem by suggesting that the SSC should not prescribe specific practices but rather comment on the absence of knowledge about "how all of that would work." Highlighting non-knowledge about the implications of changing material practices of fishing for the material practices of sampling becomes a way of simultaneously articulating the attachments that matter in the gear issue and the boundaries of the SSC in relation to other advisory bodies in the PFMC.

Moreover, highlighting non-knowledge also becomes a way of doing boundary work in relation to the policy-makers on the Council (Gieryn, 1995; Jasanoff, 1987). After a round of additional clarifying questions, the rapporteur sums up what he perceives as an emerging consensus of the advisory body on the issue. The impacts relating to gear construction changes and mesh size are not an issue for the SSC, however some of the decision alternatives under consideration potentially destabilising the integrity of the data supply chain are considered "non-starters." The science advisors now turn towards each other to discuss what to state in their report to the Council. An SSC member asks:

> *SSC member 1:* Are we explicitly asked to weigh in on whether or not we are supporting selecting a final preferred alternative or are we asked to weigh in on NMFS's request to wait?
>
> *SSC member 2:* The Council requires standardisation for the sake of the stock assessments and data streams. I am not sure whether they are asking us to do some evaluation of how real those concerns are about the data quality. They didn't specifically ask us to recommend delay or not delay.
>
> *SSC member 1:* Well, we sort of are indirectly by pointing out some limitations and problems with the cumulative effects and things like that.
>
> *SSC member 2:* If we decide we do not want to say yes or no on whether to delay we can make a conscious choice not to say it whether we suggest a delay. We could say that we will not make a recommendation on whether or not to delay.
>
> *SSC member 3:* The question is, does the Council have enough in front of it to make a full decision? We shouldn't make a recommendation on whether to go forward or not, but we should certainly say whether the analysis provides the appropriate information to make a decision which ... you can read between the lines what you are saying, but you are not saying quite the same thing. If we think that there is not enough information for the Council to make a full decision, that is probably what we should say.
>
> *SSC member 1:* That sounds reasonable.

Bound by Council operating procedures to comment only on the scientific merit of policy actions and not express policy preferences, the SSC has to negotiate that boundary whilst at the same time taking into account that some of the policies potentially enacted by the Council might have a detrimental impact on the SSC's ability to provide what it considers accurate scientific information. The solution a senior SSC member eventually presents, to invite the Council to "read between the lines," and to which the rest of the committee agrees, is one that emphasises non-knowledge as a way of hinting at a policy preference without explicitly expressing a preference. In his study of organisational agnotology, Rayner (Rayner, 2012: 108) observes that organisations tend to develop strategies for excluding "uncomfortable" forms of knowledge and understanding which might potentially "undermine key organisational arrangements or the ability of institutions to pursue their goals". Whereas Rayner focusses on the socially stabilising function of suppressing and displacing knowledge, in this specific instance it is the practice of explicitly emphasising the unknown which functions to maintain a key organisational arrangement, namely the science-policy boundary defined in the Council operating procedures which restrict the SSC from expressing policy preferences. As the committee's detailed discussion of the minutiae of catch sampling and stock assessment makes evident, SSC members indeed know how some policy alternatives would be "non-starters" from their perspective. However, they refrain from communicating this knowledge in their report. Inviting the Council to read between the lines, the science advisors emphasise to the Council the risk of a possible increase of uncertainty inhering in some of the decision alternatives as a way of enacting the boundary between scientific advice and the formulation of policy.

In the document which the SSC eventually adds to the stack on the lobby table, the ambiguities and hesitation obtaining in the deliberations preceding the report are effaced. In terse language and authoritative voice the report notes the "greater uncertainty" generated by some of the decision alternatives, highlighting how the sub-options allowing for fishing with multiple gear and fishing across multiple management areas "could affect the quality of the data available for analyses that inform management." Barely longer than a single page, the document thus articulates the issue of gear liberalisations as one related to "analytical issues." The report mentions that these issues could potentially be alleviated by requiring specific on-deck material practices such as sorting and monitoring, but at the same time does not express an explicit preference for any of these requirements, instead noting that their consequences for fishers and enforcement agencies "have not been well-analyzed to date and may require additional consultation." The report document does more than merely record the deliberations of SSC members. The document processes the deliberations of the scientific advisory body into authority and administration by transmitting and storing its proceedings as well as erasing the history of its own production. Both law and science attain authority through the effacement of the history of their making (cf. Vismann, 2008: 26). Through the act of silencing the laborious deliberations going into its very production, the report as a document participates in establishing the authority of its contents as scientific advice for a policy-making body. Processed by the secretariat and inserted into the record of the PFMC as scientific advice, the report stabilisises the SSC's articulation of the gear issue as one defined through its attachments to the data practices underpinning management (cf. Asdal, 2015).

Emphasising the risks to data integrity, the SSC articulates the issue of gear liberalisations as one defined through the material practices of sampling while simultaneously delineating its boundaries as a scientific advisory committee. The next section will elaborate how the SSC's specific articulation of the gear issue is contested by the representatives of the fishing industry assembled on the Groundfish Advisory Subpanel. However, the specific manner in which this contestation proceeds discloses a partial translation of the interests of fishers into the interests of scientists;

a translation mediated by the nexus between the materiality of sampling practices, data uncertainty, and policy decisions.

7.3.3 At the Groundfish Advisory Subpanel

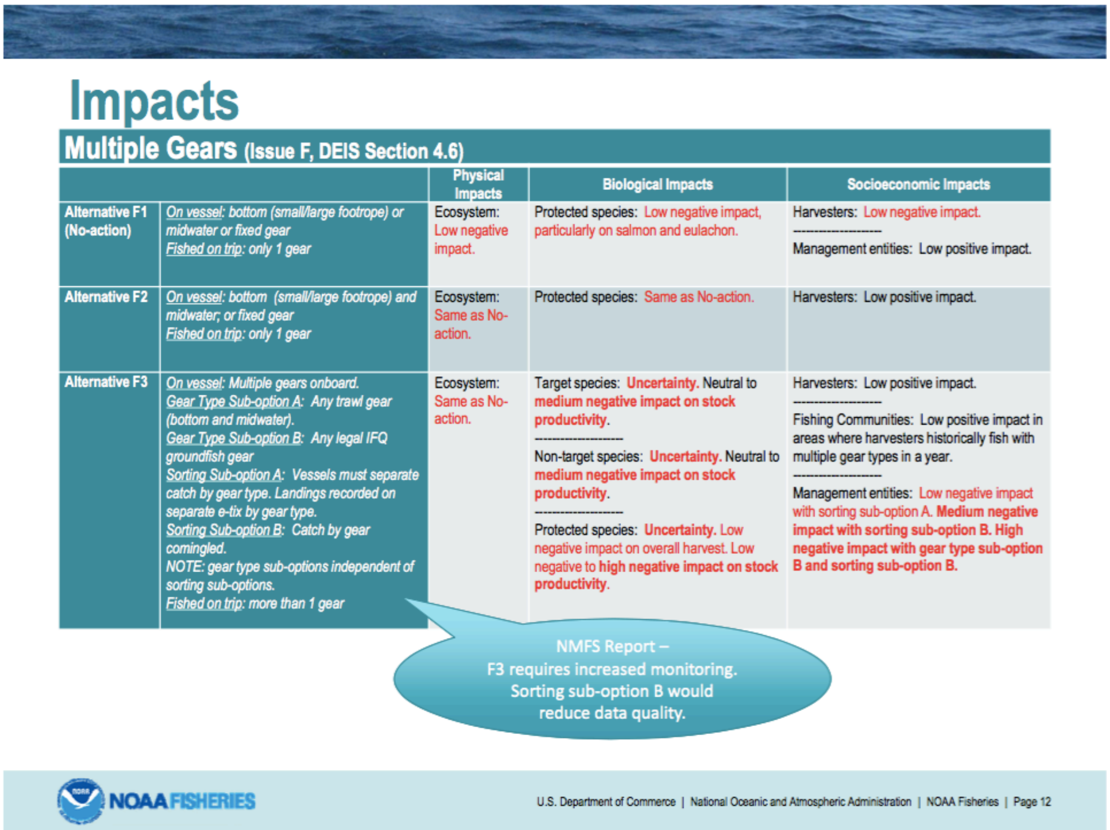

Fig. 12 Facsimile of NMFS presentation listing impacts of proposed gear liberalisations

In a different conference room, scheduled after the SSC meeting has concluded, the Groundfish Advisory Subpanel meets to discuss agenda item G.8. The panel consists of mostly middle-aged men representing fishing vessel operators, on-shore processors, seafood industry associations, and recreational fishing associations. The atmosphere is informal: during the meeting there will be lively exchange and crosstalk between committee members and the fishermen seated in the public area with the latter frequently speaking up outside of the formal period set aside for public comments. The chair of the panel welcomes a federal scientist from the NMFS (different from the one who presented to the SSC) who proceeds to give a PowerPoint-supported presentation about agenda item G.8. Her presentation is structured along the various issues listed and impacts identified in the draft environmental impact statement (Fig. 12). The scientist invites comment from the GAP members, emphasising that procedurally the current PFMC session acts as a "public scoping meeting for this EIS." Most of the issues she presents one after another, however, remain uncontroversial with the representatives of the fishing industry who will occasionally stress impacts of liberalisations they perceive as beneficial but not sufficiently emphasised as such in the draft EIS. However, the proceedings become more lively when the issues of fishing with multiple gears on the same vessel as well as commingling catch and their respective impacts on data quality come up for debate. The federal scientist notes that the decision alternatives allowing for using multiple gears and commingling catch would likely reduce data quality and that NMFS would be "discouraging that sub-option". Responding to the presentation, a GAP member asks to clarify the extent to which data quality would be affected and whether this data would be related to catch accounting or stock assessment or both. Another fisher seconds, doubting that given the small amount of vessels likely to fish with multiple gears there would be much of a discernible impact on data quality. The scientist responds that, to her mind, stock assessment would be the bigger issue here, referring to the SSC:

> The SSC report is available. They say that the multiple gear issue could affect the quality of the data available for analysis that informs management. And they also mention the greater uncertainty in the data used for stock assessment if you allow for commingling. It doesn't speak to quite... does that mean we can't do it? Or would we just be using lower data quality?

The confusion of the presenter here as to the SSC's recommendations stems from the deliberate ambiguity in the way the report was formulated: the SSC had to carefully hint at a policy preference whilst demarcating a boundary between science and policy through emphasising non-knowledge. While this strategy allowed the SSC to delineate the boundaries of its purview, it presents a problem for the GAP: would lower data quality be acceptable and, if yes, to what extent? This problem occasioned a discussion among the members of the GAP of stock assessment and sampling practices the technical proficiency of which surprised the ethnographer. One of the fishing industry representatives launched into an exegesis of what the scientific advisors could have meant with their stated impacts on data quality and speculated how to possibly alleviate their concerns:

> The data quality... I wasn't in their meeting so I am reading between the lines. The selectivity of gear is an important component in any of the stock assessments. All of the stock assessments have wrestled with that in the past. I mentioned that the gear changes we had 15-20 years ago... whether you go from 3 inch to 4,5 inch changes the selectivity of the trawl gear. And what the stock assessment people do is they time block the selectivity. And they use this selectivity curve for this period and a different selectivity curve for a more recent period. Same thing could be done here. Alternatively you just create a new gear type. On paper. Somebody used two gears. And you start a new data series of new selectivity and it adds just one more parameter to the stock assessment. There are ways around it short of, uh, sorting everything down, keeping everything separately. Cameras in the fish hold and all the types of things that have been proposed. From the data standpoint I think it can be resolved. From a catch accounting standpoint, I don't think it matters what gear you used. You caught the fish, your account will be credited for the fish.

A different fisher suggests that logbook data should be sufficient to account for the type of gear used. However, another member of the panel responds that logbook data does not inform stock assessment:

> The selectivity comes in through the port samplers when they do the measurements. It is a length frequency issue. They take a sample of the fish and that is the selectivity of that gear in terms of the size and the maturity. Having it recorded in the logbook that you used that gear doesn't in itself provide that because it is tied to the port sampler.

Another GAP member seconds:

> I think the issue isn't that the information isn't available. The crux of the issue is that the uncertainty is increased. It is not that it can't be done. But that it increases the uncertainty in the information being used. The issue is the uncertainty in the data, not the lack of data.

That settles it for the moment. There seems to be no way around accepting the SSC's articulation of the gear issue as one that is defined by its attachments to the material practices of sampling for stock assessment. And yet the ethnographer is left to wonder about both the detailed knowledge of the fishers assembled on the panel concerning the sampling practices of fisheries science and their ready aquiescence to the scientist's interest in low uncertainty in stock assessment data. Unfortunately I did not get a chance to put this question to a GAP member. However, I later expressed my surprise that fishers care so much about uncertainty in scientific data to a Council staffer. She went on to explain:

> They want to consider that because our Council has a reputation for, if there is increased uncertainty, they take a more precautionary approach. Which means less fish. They've made those connections very distinctly in their minds. When we say this will make the data that we are using for our stock assessments more uncertain, they go, oh, well, for assessments that we have now that are more uncertain the Council takes a more precautionary approach when they are setting the harvest levels, then they make reductions to that to buffer against that uncertainty. So if we are dramatically going to be increasing the uncertainty across all the assessments, that is going to affect all of us, every fishery, negatively. They've gotten through enough stock assessments to know what the implications of higher uncertainty are.

This relation between uncertainty and precaution translates the interest of fishers in high harvest allocations into the interest of scientists in data integrity. The calculative regime of resource management compels fishers to understand their own fishing practices through the metrics produced by stock assessment science and align their practices accordingly (cf. Miller & Rose, 1990; Rutland & Aylett, 2008). Uncertainty has a key role in the calculative practices underwriting harvest allocations; a role which is detailed in a PFMC fact sheet on management thresholds and the risk of overfishing (Fig. 13).

Overfishing limit: The most fish caught in a year without overfishing

The overfishing limit (OFL) is the best estimate of the maximum amount of a stock that can be caught in a year without resulting in overfishing. This is a scientific (as opposed to policy) determination made by the Scientific and Statistical Committee. OFLs are set for every actively managed stock or stock complex.

Acceptable biological catch: Measures scientific uncertainty

The acceptable biological catch (ABC) is an annual catch level recommended by the Scientific and Statistical Committee based on the OFL. The ABC considers the uncertainty in estimating the OFL and, under the Pacific Coast Groundfish FMP, is always less than the OFL. An annual catch limit cannot exceed the ABC. In general, the more scientific uncertainty there is in estimating the OFL, the bigger the difference between the ABC and OFL.

An ABC control rule is a specified approach to calculate the ABC for a stock. It is established by the Council with advice from its Scientific and Statistical Committee. The SSC's recommendation for ABC should be based on the control rule, although exceptions are allowed if they are well-justified. The P* ABC control rule is the most commonly utilized ABC rule used by the Pacific Council (see details below).

P* (P-star)/σ (sigma): The risk of overfishing

P* (the probability of overfishing) is a multiplier that equates to the risk of exceeding the OFL. A high P* of 0.5 means there is a 50% risk of overfishing and, when applied to set the ABC, determines an ABC equal to the OFL (which is not allowed in the Pacific Coast Groundfish FMP). A low P* of 0.1 means a 10% risk of overfishing. The ABC buffer is calculated by applying the P* to a biomass variance (σ); high sigmas coupled with low P*s determine larger ABC buffers. The SSC determines the sigma, which varies by the category of stock (stocks are categorized by the level of uncertainty in determining the OFL; higher sigmas are specified for stocks with greater uncertainty). The P* value is a policy determination made by the Council reflecting their preferred level of risk tolerance in setting an overall harvest level for the stock or stock complex. The highest P* allowed in the Pacific Coast Groundfish FMP is 0.45.

Annual catch limit: The total catch limit for an actively managed stock or stock complex

The annual catch limit (ACL) is the amount of total catch (i.e., landings + discard mortalities) specified for an actively managed stock or stock complex. The ACL can be set equal to or less than the ABC. The ACL accounts for all sources of fishing-related mortality including catches in research activities. The Council sets the ACL based on conservation concerns (e.g., rebuilding objectives), socioeconomic considerations, ecological considerations, and/or the preferred level of risk in harvesting the stock or stock complex. Inseason management of the fishery is done to prevent exceeding an ACL, including early closure of the fishery, if inseason catch monitoring projects early attainment of an ACL.

PACIFIC FISHERY MANAGEMENT COUNCIL

Fig. 13 Facsimile of PFMC fact sheet detailing the calculation of management thresholds

Whereas the scientists on the SSC determine the uncertainty in a fish stock, the policy-makers on the Council determine which risk of overfishing they find acceptable. These metrics are then combined to calculate the acceptable biological catch which sets an upper limit for the annual harvest allocations. The way this calculation incorporates metrics distributed between science and policy accounts for the importance of low uncertainty in stock assessments reviewed by SSC scientists for achieving high harvest allocations decided by Council policy-makers. While federal law requires setting scientifically supported annual catch limits, the specific way of calculating this limit for groundfish is particular to the PFMC. According to the Council staffer, the fishers' past experience of the consequences of uncertainty in stock assessments for their own economic prospects compelled them to align their practices with the scientific practices of sampling and stock assessment. Dependent for their ability to harvest fish on the integrity of the material mediations circulating reference between vessel at sea, dockside monitor, and population abundance model in the fisheries science centre, the fishers had to make the scientist's priorities their own.

However, at the same time as they are enlisted into the scientist's network of data practices by accepting the importance of data integrity, the fishers contest this translation when it displaces their interest in profit-making to a degree they find unacceptable. Displacing interests of actors, translation incorporates a degree of betrayal of those interests which might occasion moments of contesting the network into which actors are enlisted (Callon, 1986; Rutland & Aylett, 2008).
This contestation surfaced when the discussion moved on to the question of whether catch caught with different gear could be hauled on deck before previous catch had been stowed, that is, the issue of commingling. The NMFS presenter details the different decision alternatives prohibiting or allowing to bring catch from two different hauls caught with different gear on deck at the same time. Casually, she mentions that the status quo does not allow "mixing of hauls before the observer had a chance to sample the catch". A member of the GAP reacts with surprise:

> *GAP member 1:* Is this required now? I didn't even know this was a regulation now. You can't bring two tows on board at the same time?
>
> *NMFS scientist:* No.
>
> *GAP member 1:* Why?
>
> *GAP member 2:* (sarcastically) Because that's the law. (laughter)
>
> *GAP member 3:* I am assuming it is for sampling?
>
> *NMFS scientist:* Yes, it is to allow the observer to sample.

In the meantime a stock assessment scientist has joined the audience and rises to speak. She explains that this provision is necessary for sampling at tow level which allows to aggregate data by categories such as area, age, species and so forth. Responding to this intervention, the fisher who raised the issue contends that the policy is not being observed at the moment which, to his mind, throws into doubt whether it is even necessary. What so far had been calm and collected proceedings become suddenly agitated as the fisher raises his voice towards the scientists:

> You want perfection! You are asking far more than is required to get accurate information! ... We are breaking the law here and we don't even know. You think the world is working according to this rule. I don't think it is. Nobody knows about this rule!

Another fisher from the audience seconds, arguing that this question "is really academic" because while the rule may be on the books, it is however not being enforced at the moment. Observing the rule would mean in some instances five to six hours of idling out at sea while the observer, paid by the vessel operator, samples the haul with the vessel remaining unproductive during this time. The other fishers agree that "in the real world it won't work" with one fisher nodding in the direction of the NMFS representative and sardonically saying:

> Few people in that office worry about the practicalities. No offense. You need to go fishing to realise what you are trying to practice!

In this moment, issue articulation occasions the explicit voicing of a dissensus grounded in antagonistic attachments to fishing gear. Scientists articulate the gear issue as one defined through its attachments to data practices. Fishers articulate the gear issue as one that is defined through its attachments to their fishing practices. While the fishers have to accept that their own practices at sea have to be aligned with scientific data practices to ensure high harvest allocations, they contest what they perceive to be unworkable demands placed on their fishing practices by the prescriptive regulations ensuring the integrity of data practices. Geographers and STS scholars have emphasised the indeterminacy of practices-in-the-making vis à vis prescriptive procedures in science (Pickering, 1992), technology (Suchman, 2007), and environmental policy (Hinchcliffe, 2001). Dealing with contingencies in situated ways, fishing practices at sea are irreducible to the formal procedures which regulate those practices for the purpose of ensuring data integrity for stock assessments. This irreducibility brings into relief the manner in which the alignment between different articulations of fishing gear, respectively defined through its attachments to fishing or data practices, remains provisional and potentially contested. This alignment might turn into conflict if, in the process of competing issue articulations, divergent material attachments impinge upon one another in such a way that an actors' interests are displaced too far. In other words, the articulation of the gear issue occasions a political moment (cf. Barry, 2002; see also Mouffe, 2005) in the sense of an explicit voicing of dissensus grounded in an irreducible antagonism between the prescriptive procedures stabilising the scientific data supply chain and the contingent practices of fishing; an antagonism which had only provisionally been contained in the incumbent regulatory settlement.

This articulation of the issue, in which fishers' interest in high harvest allocations is only translated into scientists' interest in data integrity to the extent that the efficient workability of fishing practices remains ensured, is stabilised in the eventual report the GAP files with the Council secretariat. The preface of the report stresses the need to allow for "greater economic viability and efficiency" of the fishing fleet, arguing that "several of the alternatives are operationally impractical." On nine pages, the report then proceeds to make a detailed case for preferences for each of the decision alternatives in the decision template. While responding to the concerns voiced by the SSC as to greater uncertainty in data needed for stock assessments, the report argues that impacts on data would likely be minimal and that alternative data sources would ensure that "sufficient data should be able to be parsed or collated to sufficiently inform stock assessments." Detailed recommendations on the design of data processing so as to mitigate perceived impacts of gear liberalisations follow, bookended by once more emphasising the need to "create efficiencies and better economic vitality for the fleet." The relations enacted in the GAP report thus take into account the articulation of the gear issue advanced by the SSC, but attempt to modify the issue from a primary concern with data integrity to one in which data practices are aligned with fishing practices in such a way that fishing efficiency is not compromised.

7.4 Conclusion

Rationalist models of deliberative democracy tend to assume actors reaching some compromise or consensus through negotiating their established interests in relation to external matters of fact (Mouffe, 2005). Through empirical study these models have been problematised as insufficiently accounting for the co-production of actors, interests, and facts in policy-making (Hinchcliffe, 2001). Rather than a firm factual ground in which to anchor deliberations, political matters are multi-valent, ambiguous, and occasion controversy about their properties in relation to different actor's interests and practices (cf. Barry, 2013; Braun & Whatmore, 2010; Latour, 2005). Following agenda item G.8 discloses fishing gear as such a political matter. During the advisory body meetings of the PFMC, the fishing gear issue is relationally co-constituted with actors and their interests. The issue of liberalising fishing gear restrictions came to be articulated as a tangle of divergent material and practical ties between different actors and fishing gear. Both scientific and industry advisory bodies were able to settle on an agreement that a significant sub-set of the proposed liberalisations were uncontroversial precisely because their material properties, i.e. mesh size, codend design etc., proved unproblematic in the sense that they did not constitute any interference with the material practices of neither scientists nor fishers.

However, the proposed liberalisations concerning multiple gear use and commingling occasioned articulations of divergent and irreconcilable practical and material attachments to the gear issue that placed into conflict the alignment of interests of scientists in data integrity and the interests of fishers in efficient work practices. These interests did not pre-exist the deliberations themselves. Although expressed in talk and written reports about gear, these interests issue from the specific socio-material networks enacting fishing and marine science: in order to achieve high harvest allocations, the socio-material network of fishing has to be aligned with the socio-material network of stock sampling and population forecasting. This alignment translated fishers' interest in high harvest allocations into scientists' interest in data integrity. However, this settlement became contested when the prescriptive procedures of policy where confronted with the practices-in-the-making of fishing.

When controversy erupted, it did not turn exclusively on different ways of knowing gear. As much as fishers and science advisors are jointly implicated in the gear issue, the difference between their attachments to gear is not reducible to competing forms of expertise, but rather has an irreducibly practical and material character too (Marres, 2007). This socio-material dimension of the political contestation comes to the fore when the fishers claim that their interests are displaced too far, threatening their fishing practices through prescriptive procedures meant to secure data integrity which place unworkable demands on their practices at sea. This contestation is political in the sense of articulating an irreducible antagonism between the entanglement of fishing gear with the socio-material networks of fishing and marine science respectively. That is to say, fishing gear is a political matter provoking controversy in which not only different ways of informationally enriching materials are at stake but the very material relations of fishing gear to actor's practices. The different materialities of the practices in which gear is implicated – harvesting and data gathering – contributes to the articulation of gear as a contested entity, that is, as a matter of concern (Latour, 2005a). From the outset, "gear" was by no means a stable matter of fact, much less the impact liberalising restrictions of gear might have on fishers, fish, data and so forth. Sprawling across a number of actors – the NMFS, fisheries science centers, SSC, GAP, etc – "gear" had to be articulated and stabilised as an issue defined by attachments to actors and their practices simultaneously with those actors boundaries and their specific interest in the gear issue.

Metrological regimes have been analysed as to their capacity to contain political conflict (Barry, 2002). The network of data practices comprising sampling, stock assessment, uncertainty estimates and population forecasting in principle displaces political conflict about overfishing into a metrological regime that would allow the conduct of economic affairs to remain undisturbed from political disagreement. However, rather than displacing conflict, metrology in this case occasions the articulation of antagonistic material attachments in the formation of an issue (cf. Marres, 2007). While the fishing industry's interest in harvest allocations had been translated into scientists' interest in data integrity, this translation remained provisional and became contested when metrological practices format and constrain fishing practices to a degree fishers deem threatening to their profits. It speaks to the powerful role of the uncertainty determination of the SSC, enshrined in PFMC procedures, that in their report the GAP did not contest the SSC concern with data integrity as such, but rather the notion that data quality would be negatively impacted by liberalisations and that their integrity could not be maintained by different means. In the advisory body proceedings, metrology, then, becomes a political site at which actors and interests are formed simultaneously to the articulation of issues as antagonistic material attachments. In other words, metrology itself is rendered political.

Noise indexes the political and inventive work of translation as it relationally configures actors, interests, and issues. This work has a political dimension in the sense of occasioning the articulation of irreducible antagonisms. Moreover this work is inventive in the sense of generating the actors, interests, and issues at stake in policy. In the project of policy optimisation, however, the material politics inherent in the work of translation are screened out of the frame making policy calculabe. Actors are meant to negotiate the ends of policy in the form of an objective function embodying the trade-offs between different system states corresponding to actor's pre-established interests. In order to computationally discover optimal policies, policy has to be kept separate from politics in such a way that policy becomes a technical means amenable to mathematical optimisation for the realisation of political ends negotiable among actors with pre-formed interests. The means of environmental politics are assumed to be independent from actors and their interests in order to be unproblematically translatable into policy parameters. However, these means themselves occasioned the formation of political collectivities which are contingent not on pre-formed interests but rather shared material practices linking actors to issues in antagonistic ways. The means are meaningful in the sense of mattering differently to different actors; they are lively things with consequences of their own which are disclosed in the noisy mediations between actors, interests, and issues. Relegating noise to a distortion to be reduced, computational policy optimisation dismisses the inventive work of translation; limiting the articulation of disagreement, it forecloses the political.

Chapter 8 Summary and conclusion

In what follows I wish to summarise key findings of this study with respect to questions concerning, first, how more-than-rational modelling takes hold in environmental management practices, second, how the materiality of computational modelling affects the work of science and policy, and third, what difference more-than-rational modelling might make for the production of socio-natures. Threading these empirical findings through debates in geography, science studies, and economic sociology, I will draw out their theoretical implications. The chapter concludes with some thoughts on potentials for further research that could expand on this study.

8.1 More-than-rational modelling at work

The agent-based model this thesis investigates had to be envisioned first, then the plausibility and timeliness of its novel methodology argued with funding bodies in order to marshal resources, and finally the model had to be designed in such a way that actors concerned with environmental management would accept it as a useful device supporting their practices. In chapter four I discuss an attempt by an international research consortium to render human dimensions of marine ecosystems knowable and governable for fisheries management. The professional and scientific discourse of fisheries management problematises human dimensions as a key source of uncertainty obstructing the prediction of responses to management strategies. Responding to this problematisation, the consortium whose work I observed advances an understanding of human dimensions which turns on simulating emergent collective behaviour in a complex system with the help of agent-based modelling.

In chapter two I discuss how the literature on modelling in STS and geography emphasises the entwinement of science and policy in model development, drawing attention to the practices with which scientific aspects of models may be derived from the political and management contexts in which models are put to work (Lane et al., 2011; Svetlova & Dirksen, 2014). In this study I have examined how this process of entwinement proceeds in a situation of competing calculative methods where more-than-rational modelling is meant to substitute for mainstream bioeconomic models in fisheries management: chapter four argues for analytical attention to the work metaphors do for imagining marine management as the steering of a complex system and the material affordances of models shaping the embedding of this imaginary into the knowledge infrastructures of marine management. Analysing a series of white papers and grant proposals which lay out a transformative research programme for innovating fisheries management in the face of resource overuse and environmental change, I discuss how metaphorical trafficking between ecology and macroprudential regulation theory renders plausible the imagination of both fisheries and finance as structurally homologous systems which can be known and governed by similar computational means for the modelling of complex systems. As this imaginary of a future nature of technologically-enabled sustainable resource management travelled outside of the confines of the internal project literature of the consortium, however, it encountered a number of challenges which altered its innovating promise: in order to marshal resources, the consortium had to translate a funding bodies' concern with global commons into their own concern with human behaviour, and as a result shift their initial objective from replacing the Maximum Sustainable Yield paradigm towards a more complementary approach, supporting policy actors in the operationalisation of Ecosystem-Based Fisheries Management.

Attending to the work of enlisting policy actors, such as high-level scientists at NOAA Fisheries, into the consortium's project disclosed how successfully embedding an agent-based model into the knowledge infrastructures of fisheries management entailed simultaneously constructing social and technical relations: in applied fisheries management, material affordances of models such as the intellectual tractability for non-scientists of the processes with which models generate results shape the extent to which modelling as a scientific knowledge practice can enter into an infrastructural relation to management decision-making. Locally negotiated norms governing what counts as credible scientific knowledge constrain the suite of models which are permitted to inform the policy process by supporting knowledge claims which stand up to public scrutiny. Chapter four identifies this materially embodied relation between the predictive practices of science and the regulatory practices justifying policy decisions as shaping the choices of consortium scientists when they designed the technical capacities of their agent-based model with respect to model coupling and interoperability. The success of heterodox economic models to substitute for incumbent mainstream economic models in environmental management, I suggest, might be contingent on a further dimension in addition to the work of convincing policy or scientific actors of the improved realism or predictive power of models incorporating the more-than-rational dimensions of human behaviour. A model's potential to take hold in management might be contingent on the extent to which the affordances of heterodox models support the locally established norms and protocols structuring working relations between science and policy that result from earlier settlements between different actors participating in management. In the following section I wish to indicate some theoretical implications of this empirical finding.

Envisioning and enacting a different future nature is a halting process: imaginaries of future oceans do not seamlessly and smoothly translate into infrastructures for fisheries management. This empirical observation informs a theoretical contribution by drawing together literatures from science and technology studies on socio-technical imaginaries and geographical literatures on environmental knowledge infrastructures and the performance of plural natures. The literature on socio-technical imaginaries is concerned with the narratives animating innovation and change and rendering scientific and technological systems meaningful (Fujimura, 2003; Jasanoff, 2015b; Suchman, 2012). In contrast, the literature on environmental knowledge infrastructures (Blok et al., 2016) investigates how embedding different technoscientific knowledge practices into environmental governance processes conjures up plural natures (cf. Bingham & Hinchcliffe, 2008). The former literature focusses on the meanings mobilised to marshal resources for the making of technoscientific futures yet, while gesturing at material infrastructures as the conduit along which envisioned futures gain purchase on the world, pays relatively little analytical attention to the material practices with which infrastructures are made and maintained. The latter literature, in contrast, focusses on the modalities and performative effects of infrastructuring practices, paying little attention to the imaginative anteriority of infrastructures and the manner in which their making and remaking is motivated by envisionings of futures both technoscientific and natural.

Drawing imaginaries and infrastructures together, I argue that the enactment of an envisioned future nature with the help of new technology necessitates the laborious and simultaneous construction of social and material relations: in the case presented, the modellers are aware of the simultaneity of this task, consciously and strategically engaging in what they call "socialising the model." I contend that their practice of "socialising the model" is best understood as infrastructuring work which aims to embed more-than-rational modelling into a routinised relation of support between scientific modelling and regulatory practices. When engaging in this infrastructuring work, modellers make choices that privilege some actors, in this case, high-level scientists and policy-makers, and render others absent, namely resource users, with possible consequences for the ways future socio-natures are enacted. These choices are justified with reference to funding needs and the assumption that reforming an environmental knowledge infrastructure will have to accommodate established hierarchical power relations in fisheries management. However, despite the strategic enlisting of actors presumed to be at elevated hierarchical positions, the inertia of infrastructural relations between science and policy, resulting from situated and contingent settlements of struggles between diverse actors in applied management, limits the extent to which ambitious envisionings of future natures can travel and eventually be realised.

This empirical finding suggests the potential of complementing the process model of socio-technical change advanced in the theory of socio-technical imaginaries (Jasanoff, 2015b) with a relational theory of infrastructure (Slota & Bowker, 2017; Star & Ruhleder, 1996): the extent to which material artefacts animated by socio-technical imaginaries can support novel forms of practice, and thus enact different socio-natures, is contingent on materially embodied power relations in which some material practices are routinised and the work of some actors rendered invisible. Whereas socio-technical imaginaries vociferously promote future possibilities, I suggest that the more muted and mundane work of infrastructuring serves as the analytical focal point for explaining how imaginaries might succeed or fail to enact their promises.

8.2 More-than-rational modelling and the materiality of computation

A further research objective concerned the manner in which the materiality of computation might affect modelling practices. Chapter five elaborates a relational and materialist account of computational modelling by way of a thick description of the practice of abstraction. The chapter identifies a process in computational modelling, which I call agile abstraction, with which modellers achieve coordination between an interdisciplinary and geographically dispersed team simultaneously with the representational work of rendering elements of the target domain of the model in software code. The empirical contribution of the chapter concerns a way for interdisciplinary modelling teams to coordinate not just different expert knowledges, but indeed different material practices of modelling. These material practices differ with respect to disciplinary knowledges, modelling equipment, and specific interest in modelling: fisheries ecology versus software engineering, equation-based modelling versus object-oriented programming, validation versus code delivery, respectively, describe the configuration of different expert knowledge practices and interests that had to be coordinated. These different practices enact different model ontologies: relative to the practices in which it became involved, the agent-based model appeared as an epistemic thing, supporting the creation of new scientific knowledge, or as a technical artefact, raising problems of engineering a software architecture (Merz, 1999a).

Through a detailed praxeography of an episode of modelling fish habitat, I identify and describe agile abstraction as a process which iteratively and sequentially generates boundary objects mediating between different expert knowledge practices in the team. Simultaneous to its coordinating function, the agile abstraction process circulates reference (Latour, 1999a) from verbal descriptions of the target domain furnished by fisheries scientists to software objects inscribed in code by a software developer. The circulation of reference proceeds through the collaborative work of gradually transforming boundary objects (Star & Griesemer, 1989) such as fish habitat from verbal scenario descriptions to formalisms inscribable into software code. This collaborative work of representation, which modellers call abstraction, is formatted by the commercial software development methodology agile programming. Agile programming suggests protocols for the close and continuous collaboration between software developers and domain experts. As an adaptation of agile programming to scientific model development, agile abstraction simultaneously enables the work of scientific representation and interdisciplinary collaboration in a computational simulation setting. While agile abstraction structures the work of scientific representation in iterative cycles of collaborative work mediated by boundary objects, the achievement of code inscription proceeds in the local context of software development as a contingent crafting together of layered material affordances of the various devices and materials equipping programming practice. In this local context of crafting software objects, classificatory decisions about model entities are being made by the software developer which remain opaque to the participating marine scientists on the team. However, as a result of their close involvement in the agile abstraction process the marine scientists can nevertheless interpret model outputs as valid representations of the target domain. In what follows I wish to draw some theoretical conclusions from these empirical findings.

Despite the wide-spread use of software-based computational models in science, so far social studies of science have paid little attention to the production of software. While software studies have emphasised the socio-materiality of software work, bringing this concern into a dialogue with pragmatic theories of scientific representation (Latour, 1987, 1999c) would be an original contribution of this study. Shifting from questions of epistemology to the performance of ontologies, praxeographies of science and technology attribute the success of technoscientific orderings to the pragmatic constructions through which science intervenes into the world rather than a scientific rationality affording privileged access to an external reality (Latour, 1990). Developed through ethnographies of laboratory and field science, pragmatic theories of scientific representation attempt to close the chasm between world and word by filling it with "inscription devices" (Latour, 1987), transforming material substances into formalisms, and practices of "circulating reference" (Latour, 1999c), organising a chain of material transformations between field and other sites of scientific work along which claims of equivalence can travel. Investigating scientific representation, here, becomes refocussed on a detailed documentation of the myriad material practices with which scientists enact their knowledge claims.

However, computational modelling is a scientific practice different from field and laboratory. The technicity of computer models complicates pragmatic accounts of scientific representation developed in relation to experimental and field practices

(Knuuttila, 2005). In the case examined, inscription does not register the resistance of a material substrate in an experimental setting and reference does not circulate between field site and university office. Rather than that, I argue that the agile abstraction process circulates reference between verbal descriptions of the problem domain and software inscriptions in the model domain, i.e. between language and code. However, this is not to mean that materiality does not matter. Abstraction is a materially mediated practice: in painstaking collaborative work, the team has to gradually transform verbal descriptions of model scenarios into formalisms translatable into object-oriented software code. I contend that this transformation is irreducible to explicit rule-following or logical cognition, crucially involving the practical skill of programming software code. Programming is an equipped practice enlisting a number of different devices the skilled practical combination of which in the act of programming shapes the kinds of ontological cuts enacted in abstraction: crafting together a dynamic assemblage of heterogeneous elements, the work of coding releases an agentic potential that adds a measure of contingency and indeterminacy to the performance of ontological cuts in computational modelling. With its emphasis on the lively materiality of media objects, the concept media ecology (Fuller, 2005) suggests this more-than-rational dimension of the work of computer simulation which is irreducible to logical cognition: when a logical problem relating to the classification of "habitat" arises, it is the media ecology of layered affordances within which programming work plays out that shapes the eventual transformation of "habitat" into a software object. When the software developer crafts together different materials and devices comprising a collaboratively worked upon boundary object, his software development environment, data sources etc. in the act of writing software, this assemblage enacts an ontological cut (Barad, 2003) isolating "habitat" as a model abstraction with specific attributes. As a result, my study offers an empirically grounded contribution to the pragmatist literature on scientific representation, demonstrating how this literature can be complemented with a media studies literature on the materiality of software in order to account for the specificity of the scientific practice of computer simulation.

A further finding concerns the challenge which the opacity of code poses to the epistemic authority of scientific knowledge claims based on computational evidence. Philosophy of computational science problematises that considerable epistemic authority falls on computer programmers whose work, in much of its technical detail, remains opaque to other scientists (Humphreys, 2009). While the software code resulting from their collaborative work indeed remains opaque for most of the scientists on the team, the agile abstraction process enrols them into the software development process in such a way that the authority to claim the validity of model outputs does not exclusively fall on one or the other, but is distributed between scientist and programmer. This distribution is achieved by iteratively generating boundary objects as entities whose collaborative material reworkings as descriptions, scenarios, and formalisms offer interpretive flexibility in relation to different knowledges as well as specific affordances to differently equipped expert practices. Reworking the boundary object analytic proposed by Star and Griesemer (Star & Griesemer, 1989) beyond the mind/matter dualism it inherits from its roots in symbolic interactionism, I propose to understand boundary objects as hybrid material and conceptual entities with a more lively role in processes of interdisciplinary modelling: in the case presented, the boundary object's capacity to coordinate work between different actors had been contingent not only on divergent expert knowledges brought to bear on the object's interpretation, but also on the affordances the object offered to differently equipped material practices. Thus the study contributes an empirically grounded reworking of the well-established boundary object analytic in science and technology studies that helps to explain how scientists and programmers collaborate for the construction of valid model-based knowledge claims in computational social science.

8.3 Rationalising environmental governance as anti-politics

A further research objective concerned the difference computational modelling makes to the constitution of socio-natures. I addressed this question by examining how rendering policy-making computational affects the political potential issuing from the lively materialities of more-than-human worlds. Chapter seven turns attention towards the relation between a site of scientific work and a site of political work. The chapter proceeds by interrogating two senses of noise obtaining at these sites: first, noise as error introduced in the computational practices of policy optimisation and, second, noise as registering the inventive work of mediation in the making of policy. I analyse computational policy optimisation as an expert problematisation (Li, 2007) of environmental governance which turns on the translation of policy into parameters and of issue articulation into calculation. A technoscientific reform project for improving the governance of fisheries frames the problem of making rules governing natural resource economies in such a way that available solutions from computer science, namely machine learning methods, can appear as means for improvement. By rendering policies as numerical parameters, the scientists identify a deficiency in fisheries governance, namely the difficulty of finding optimal combinations of policy parameters in a large parameter space. This deficiency is contingent on the solutions the scientists bring to bear on the problem, namely searching a large parameter space efficiently with mathematical optimisation methods.

Whereas in this rendering computational of governance noise appears as disturbing the relation between information about a system and management action, I argue for the analytical value of a sense for noise as inventive mediation (Serres, 1982) in order to understand how actors and their objectives co-emerge through the articulation of issues as materially mediated concerns. With this analytical sensibility for the productivity of noisy mediations, I contrast the computational reform project of the consortium scientists with an ethnographic account of the practice of policy-making at the Pacific Fishery Management Council, documenting the simultaneous formation of actors, interests, and issues in environmental governance.

Following discussions about the liberalisation of regulations for fishing gear through the Pacific Fishery Management Council's various subcommittees, I examine how the gear issue is contingent on different material attachments to different actors and comes to be co-constituted with their boundaries and interests. Fishing gear regulations materially interact both with the productivity of fishers and the data quality of scientists in such a way that these different actors are, through their respective materially mediated practices, "jointly and antagonistically" (Marres, 2007: 773) implicated in the issue of gear regulation. These divergent ways of being implicated in gear regulation are articulated in advisory committees of fishers and scientists simultaneously with the boundaries of these committees' respective purview and the formulation of the committees' interests in how the gear issue should be addressed by the decision-making body. In the course of these articulations, the fisher's interest in maintaining high harvest quota allocations is partially translated into the scientist's interest in high quality data for stock assessments. A metrological regime tethering decisions about harvest quota allocation to the quality of stock assessment data formats this translation, but it also occasions a moment of the political in the sense of the voicing of antagonistic and dissenting issue articulations (cf. Barry, 2013). I contend that it is in these noisy, contested translations of actors' interests that socio-material collectivities are re-made in the making of policy. By way of contrasting this contested and generative process of policy-making, to which a sense of noise as inventive mediation alerts us, with the promise of computational policy optimisation, I argue that the latter incorporates an anti-political potential which forecloses the moment of the political sparked by the antagonistic articulation of the very issues at stake in policy-making.

This finding suggests that certain use scenarios for agent-based models in environmental policy-making should be scrutinised for their assumptions as to the rationality of the policy-making process. In chapter one I note how environmental scientists promote the potentials of agent-based modelling for optimising the array of policies governing coupled socio-environmental systems (Verburg et al., 2016). However, such attempts to increase with the soundness of evidence the expediency of policy might founder on the irreducibility of environmental policy-making to the rational deliberation of optimal policies. Computational policy optimisation belongs to a lineage of policy analysis which aims to increase the rationality of public policy, deploying methods of technical analysis in order to sidestep the messiness of politics in the making of policy (Fischer, 1989, 2003). Interpretive policy scholars have noted the analogy between positivist models of scientific reasoning and rational policy analysis, criticising how substituting rational analysis for a struggle between conflicting interpretations "bleeds the political life out of the policy-making process" (Fischer, 1989: 944). In chapter two, I discuss how materialist theories of political life emphasise the conflicts and antagonisms sparked by relations between lively materials and political collectivities (Barry, 2013; Braun & Whatmore, 2010).

My ethnography of policy-making suggests certain limits to the promise of computational policy optimisation. These limits issue from a conceptual division inherent in computational policy optimisation between policy as a technical means to achieve policy objectives as politically contested ends. To be clear, none of my interlocutors wished to completely substitute technical analysis for political choice. Instead they hoped to develop computational means for increasing the soundness and expediency of policies realising policy objectives with these objectives remaining subject to political choice. Nevertheless, I submit that policy is not a neutral means for realising pre-given political ends by clearly defined political actors. I suggest instead that a policy such as fishing gear liberalisation is the site of issue articulations in which objectives, interests, and actors are simultaneously made and re-made in a noisy process of translation. The practice of environmental policy-making as a re-making of socio-material collectives throws doubt on the promise of computational optimisation to increase the rationality of environmental policy-making: assuming a division between policies and objectives, rationalising policy-making neglects the irreducibly political moment inhering in the articulation of issues as antagonistic ways of being implicated in the very materialities policy aims to regulate. These material antagonisms disclose the indivisibility and relationality of objectives, policies, and actors; they are recovered and articulated in the painstaking deliberation of the very policies which computational optimisation methods are meant to automatically generate.

8.4 Effacing difference: heterodoxy, heterogeneity, and economic performativity

Further to the research objective concerning the difference more-than-rational modelling makes to the production of socio-natures, I wish to address two interrelated issues. The first issue concerns the performativity of heterodox economic modelling. The second concerns the kinds of human-environment relations in marine space in whose enactment more-than-rational modelling is implicated. I shall discuss these issues in turn.

In a specific sense of economic performativity as the enactment of economic theory, my methodological choices constrained the extent to which I could observe the performative agency of heterodox economic modelling. My fieldwork being temporally limited to the observation of the early stages of model development and diffusion, I was not able to observe the model being applied in decision making, let alone repeatedly over time, which would be a precondition for drawing inferences as to the enactment of the theory incorporated in the model in an empirical economy (cf. Mackenzie, 2006). This presents a clear limitation of my study.

However, this methodological constraint afforded me a fortuitous, if serendipitous, observation of a dispute between heterodox modellers which, I contend, carries implications for the analytical framework of economic performativity in economic sociology and its employment in the geographical literature on the marketisation of socio-natures. The argument I wish to make comprises two parts: first, I will argue that the economic performativity literature following Michel Callon tends to divest calculation from its normative telos and therefore remains unable to account for economic difference, producing the effect of a uniform process of economisation which plays out according to a logic of maximisation. Second, I wish to argue on behalf of the implications of this finding for geographical scholarship on the marketisation of socio-natures, parts of which draw on the economic performativity framework in order to account for empirical processes of neoliberalisation. This literature has been criticised for its inability to account for the articulation of the locally differentiated economic phenomena its case studies examine with the translocal process of neoliberalisation of which their cases are held to be a part. I suggest that my study contributes an empirically grounded insight into how the achievement of translocality is articulated with the enactment of a uniform economic rationality incorporated into the calculative devices at work in formatting human-environment relations.

In chapter six, I analyse a dispute between heterodox modellers about the formalisation of agent reasoning. The figure of the agent rests at the centre of the eponymous computational method, agent-based modelling, into which the rhetorics of innovation and heterodoxy invest their claims of doing environmental management differently. The dispute among the modellers about how to select methodologies for researching and formalising the locational choice of more-than-rational fisher agents discloses how different algorithmic solutions are invested with divergent notions of rationality and agency. Examining how the controversial discussion of agent reasoning in the team surfaced entangled epistemological, ontological, and normative investments in different calculative methods formalising agent reasoning, I argue that the dispute was settled not on epistemic grounds but rather through the re-definition of the problem of agent reasoning by a non-scientific collaborator: this conservationist invoked the salience of the modelling effort to decision-makers and the ease of geographical portability of the model in order to take side in the dispute for a universalist notion of rationality as maximisation. That is to say, the calculative capacities of the more-than-rational fisher agent in the model had been constructed simultaneously with a political stratagem defining which actors matter in fisheries management and to whom the model should be made relevant.

I contend that this empirical finding is relevant to the performativity programme in economic sociology and its reverberations in geography. The performativity programme has been challenged for excluding controversies within the economics discipline as well as heterodox economics from its case studies, neglecting the political and normative dimension of economic performances, and having little critical purchase on the spread of marketising processes other than offering sociological redescriptions of marketising agencies (Blok, 2011; Bryan et al., 2012; Lezaun, 2017; Mirowski & Nik-Kah, 2007). Moreover, Callon's attribution of the spread of capitalist market economies to a "more or less chaotic, regular and general upsurge of calculative agencies formatted and equipped to act on the basis of a logic of accumulation and maximisation" (Callon, 2005: 3) remains unsatisfying. Just where this uniform logic of accumulation and maximization comes from is left unexplained. This lacuna can be addressed by examining the elision of calculation and maximisation in the analytical framework of economic performativity. In chapter two, I examine how Callon's early work on economic performativity started from a notion of calculation as maximisation drawn from neoclassical economics. I discuss how this specificity of calculation had later been elided by universalising calculation as maximisation. In addition, chapter seven examines how a dispute between heterodox economists about the calculative capacities of more-than-rational fisher agents re-opens the question of the cultural contingency of the maximising telos of calculation, throwing its normative dimension into relief. The chapter contrasts the normative teloi of different kinds of calculation surfacing in the dispute among heterodox modellers with the way in which the performativity literature gradually divested its operationalisation of the central concept of calculation from its theoretical roots in neoclassical economics and its attendant normative inflection of calculation as utilitarian maximisation.

I suggest that this universalisation of neoclassical calculation blinds the case studies of the economic performativity programme to economic difference and limits its critical purchase to reforming the prosthetics of market calculation. Universalising a specific form of calculation in the economic performativity framework constrains its scope to discovering market performances at work in the world which conform to the neoclassical notion of calculation as rational maximisation. In contrast, geographical scholarship has demonstrated the possibility of "reading for difference" in research on economic performativity (Gibson-Graham, 2008). Moreover, the effacing of difference stands in contradiction to the critical kernel of the theory of performativity: as elaborated by Butler (2010), performativity is meant to de-stabilise notions of the ontological substance of social phenomena like "gender" or "economy" and instead explain them as effects of repeated discursive practices which always hold the possibility of difference, e.g. by reflecting on the normative dimension of the socially binding effects of certain performances and thus doing "gender" or "economy" differently. To the extent that analyses of calculative assemblages are not cognizant of the specificity of calculation as maximisation, they risk complicity with co-performing the effect of the very ontological substance which the theory of performativity is meant to destabilise, namely a monolithic capitalist economy operating according to a singular logic of maximisation. Economic difference, then, is rendered invisible.

This leads into the second part of the argument: I suggest that attending to the practices with which calculative devices are formatted such that they incorporate a specific logic of calculation as maximisation might contribute to geographical analyses of the tension between local economic difference and translocal economic process. The geographical literature on neoliberalisation documents the persistent heterogeneity of local socio-natures in the face of translocal processes of marketisation (for a comprehensive review see Bakker, 2010). These case studies emphasise the variegated ways in which neoliberal policies proceed, stemming from the local modulation of marketising strategies by unruly materialities and geographically differentiated cultural practices. This heterogeneity forms a point of contention for those postulating a neoliberalisation of nature through the spread of market-oriented forms of environmental governance, casting doubt on whether a unified process of neoliberalisation can be meaningfully identified given the high variability which numerous case studies on marketising processes document (Castree, 2005).

Geographical case studies on marketisation in fisheries illustrate this tension between translocal process and local modulation. Fisheries management had been gradually economised in the second half of the twentieth century when economists and political actors circulated bioeconomic models embodying neoclassical assumptions through fora of global governance such as the Food and Agriculture Organisation (Finley, 2011; Hubbard, 2014; Mansfield, 2004). Informing rationalisation strategies in fisheries management, these neoclassical models have become performative at different sites: a series of studies on the remaking of North Atlantic fisheries demonstrates the performativity of neoclassical economics through the construction of a socio-technical assemblage comprising market devices such as catch shares and at-sea electronic equipment which configure fishers as rational agents exploiting and trading a privatised fisheries resource (Holm & Nielsen, 2007; Johnsen et al., 2009). In Britain, the introduction of fishing rights markets gradually replaced traditional cooperative vessel-ownership arrangements with forms of ownership aligned with the theory of the firm (Cardwell, 2015). In contrast, limits to the uniform rationalisation of fisheries management have been demonstrated by Hebert (2014) for the case of an Alaskan salmon fishery. In the Alaskan case, market devices such as catch shares and quality standards fail to performatively reorder fishing practices, with the enactment of market designs encountering constraints in the historically specific and locally contingent cultural practices of fishing in Bristol Bay. Taken together, these studies contribute to an understanding of the variegated forms which processes of neoliberalising natures take, with local heterogeneities modulating the enactment of a uniform political economy of the ocean.

However, Castree (2005) points at the difficulty such case studies encounter when they posit that highly heterogeneous economic phenomena share substantive commonalities that would justify understanding them as part of a broader process of neoliberalisation. In her response, Bakker (2010: 721) agrees in principle with Castree's critique, urging geographical scholarship on neoliberalisation to better account for the way in which local cases might be articulated with translocal processes of neoliberalisation. To be clear, I do not claim to solve the problem to which Castree's critique and Bakker's response alerts geographical scholarship. But I wish to suggest that my study indicates some promising avenues for research in a performative idiom which might account for the production of *effects* of uniformity and their diffusion obtaining in the economic processes in which scholarship on neoliberalisation takes an interest. In what follows I will sketch how the production of a uniform economic rationality had been keyed to efforts at global diffusion of the agent-based model.

Throughout my study, more-than-rational modelling emerges as a site at which claims about the universality of economic rationality and the particularity of geographically differentiated fishing practices clash in a dispute between heterodox economic modellers about algorithmically formalising fishing behaviour, thus revealing a tension between heterodoxy and heterogeneity. This tension is amplified through the global ambition of the modelling project. Responding to a problematisation of the oceans as a global common-pool resource, the consortium promises to address the management of this global commons by modelling resource use with heterodox economic methods (chapter four). Departing from the behavioural micro-assumptions of neoclassical economics, the consortium translates the concern of a funding body with the sustainable management of the ocean as a global commons into their own concern with the modelling of more-than-rational fishing behaviour. Presenting heterodox economic modelling as a solution to that problem, the consortium problematises overfishing in the planet's oceans in such a way that it becomes amenable to technical management, namely through the development and diffusion of an agent-based fisheries model.

As a case of expert problematisation (Li, 2007), this technical rendering positions expert calculation as both diagnostic and prescriptive to the problem of governing the global ocean commons. However, as Kennedy (2016: 96) observes, not every problem gets to be global: in order to become a matter of global governance, problems have to be imagined as affecting the entire planet through telling stories simultaneously with making those problems amenable to managerial solutions which respond to the technical competencies of those professional elites who are in the business of global governance. Technoscientific knowledge practices are central for the development of stories and techniques which render environmental problems global, raising questions about the politics of expertise involved in elevating specific situated knowledges to the status of universal knowledge that can legitimise governance at the global scale (Martello & Jasanoff, 2004). But not all knowledge travels equally well: I suggest that the way in which the consortium constructs the fishing agent at the expense of local differences in fishing behaviour had been keyed to the effort at making the model globally mobile.

The literature on transdisciplinarity helps to explain how the effacement of difference proceeded simultaneously with the rendering mobile of the model. The consortium constructed the more-than-rational fisher as an actor who is absent from the sites at which their constructions proceed but nevertheless implicated as the object of their work (cf. Clarke & Reiner, 2014). Keeping fishers absent was made possible through the specific transdisciplinary design of the modelling project. Building a decision-support tool for applied fisheries management based on the integration of knowledges from a variety of disciplines and in collaboration with a major ocean conservation nonprofit, the consortium's project can be characterised as an attempt to do transdisciplinary environmental research. Transdisciplinary projects collaborate with non-scientists in the formulation of research objectives and the integration of non-scientific knowledges in such a way that research outcomes are made relevant for decision-making (Landström, 2017). The selection of collaborators and the integration of different knowledges are fraught with a politics of knowledge because the openness of problem definitions, the choice of actors and disciplines, and the timing of bringing collaborators into the project leave considerable room for powerful actors to strategise around their preferred outcomes (Schaper-Rinkel, 2010). Keeping fishers absent from the modelling project excluded those whose collective behaviour became eventually framed as the problem to be addressed through modelling. The translation of the funding agency's problematisation of global ocean commons into a problem of modelling fishing behaviour had been negotiated between the funding body, the consortium scientists, and the collaborating conservation organisation. When prompted by the funding body's reviewers to include consideration of the politics of fisheries management into the revised project proposal, the impact strategy formulated in response listed high-level actors in policy and science advice as relevant stakeholders for the consortium project (see chapter four).

The transdisciplinary imperative to integrate different actors and knowledges also comes fraught with a practical politics of coordinating different ontologies as they pertain to problem definitions and the inclusion and exclusion of knowledges about the relevance of which for solving the problem there might be considerable disagreement within research teams (Klenk & Meehan, 2015). In chapter six, I discuss how a methodology with the potential to presence the heterogeneity of rationales and practices of fishing had been dismissed in the service of the wager that a more standardised model will travel with greater ease to the various sites around the globe at which fisheries management is being practiced. Within the consortium, problem definitions were subject to negotiation and re-negotiation when the stated intent to more realistically model locational choice became embroiled in a dispute over particularity and universality of fishing rationalities with the non-scientific collaborator taking side in the dispute by reference to the assumed needs of fisheries managers. The problem, then, was no longer to achieve more realistic models by tailoring algorithms to heterogeneous locations but to provide greater ease of use of the tool to fisheries managers through standardisation. As that dispute about different ontologies of more-than-rational calculation shows, the ontological politics (Mol, 2002) within the team played out simultanously with the pursuit of political stratagems defining who matters in the world of fishing and consequently towards whom the consortium should orient its activities. In this instance, the transdisciplinary intent as to the salience of research outcomes to decision-makers became a resource deployed to achieve closure in an interdisciplinary dispute about different ontologies and problematisations. The resulting "manager's tool" is a tool that effaces the heterogeneity of local fishing practices in favour of a uniform economic rationality grounded in the objective of optimisation.

The intrusion of the heterogeneity of fishing rationales and practices was systematically kept at bay in the pursuit of rendering the model mobile. Reducing the heterogeneity of fishing rationales and practices to degrees of deviance from the universal rationality of profit maximisation, the model is mobilised and made to travel in such a way that the consortium's project can achieve the global scale it had promised to address when responding to the funding call. Achieving a global knowledge of fishing behaviour, then, comes at the price of homogenisation: the heterogeneity of local fishing rationales and practices had to be flattened for the global ocean commons to be amenable to the expert practices of resource management professionals. Heterodoxy against heterogeneity: in order to make the model travel, altering the doxa of resource economics entailed effacing different kinds of fishing.

This empirical finding would suggest that research into the marketisation of socio-natures might potentially benefit from attending more closely to the practical effacement of difference in economic calculation. While studies on the marketisation of environmental governance indeed attend to the effacement of difference in making nonhuman kinds calculable and exchangeable (e.g. MacKenzie, 2009), sometimes documenting the ironies such projects of making things the same entail, my intention here is to draw attention to the normative telos which calculative devices incorporate, i.e. not only what is being calculated, but also to what end such calculation proceeds. This dimension might perhaps be less evident in the calculative devices framing nonhuman kinds, but assumes particular urgency in the case of social simulation for environmental governance: here, the normatively inflected calculative capacities of economic agents are explicitly at stake and become formatted in the regulatory practices of economic governance such models underwrite. Empirically examining the specific practices with which such models are put to work, i.e. how the specific formatting of calculative devices and the political practices of their circulation and deployment are entwined, might help elucidating the production of uniformity effects in the marketisation of local socio-natures. The diffusion and efficacy of economising assemblages which enact a neoclassical rationality of maximisation might then be explained without either invoking a logic of neoliberal capitalism external to these assemblages or resorting to an obfuscating language of chaotic "upsurge". Instead the co-production of economic expertise with the political relations through which this expertise is made to travel and gain purchase on the world comes into focus.

8.5 Looping: agile abstraction, accelerated adaptation, and artificial life

During my fieldwork with the consortium I began to notice a striking similarity between the social practices and the technical artefacts I observed. This similarity raised questions about a certain techno-cultural zeitgeist to which more-than-rational modelling responds. By way of concluding this thesis, I wish to outline some tentative thoughts on the potential of more-than-rational modelling as an object for future research into the socio-materiality of cognition in computer simulation.

The ways in which the consortium scientists organised their work processes, and structured their relations with important actors in the worlds of policy and science, were homologous to the design of the artefact that is their work product, i.e. the agent-based model, and mirrored the themes with which they imagine and narrate its significance for the governance of complex systems. I began to call this recurring isomorphism *the loop*. In computing, a loop is part of the control flow architecture of a programme: looping allows for specifying a sequence of instructions once and then executing this sequence several times until some condition is met that terminates the iteration. In cybernetics, the loop regulates the behaviour of a dynamic system through cycles of feedback between variables adapting to, and acting upon, one another (Rosenblueth, Wiener, & Bigelow, 1943).

The loop takes the form of an iterative cycle which, as an organising principle, recurred throughout my encounters with the scientists. Instances of the loop occured across scales from the algorithmic logic driving the behaviour of an individual artifical agent to the process organising interdisciplinary collaboration in the modelling team. In chapter six, I discuss how for choosing fishing locations the optimisation algorithm animating the artificial agent in the simulation iteratively searches a grid for optimal resource exploitation, settling into cycles of exploitation or exploration dependent on a given threshold parameter. (On the level of code the agent itself is made up of a series of software objects linked through loops of information flow.) Collectively, the agents respond to each others' success, learning through iterative cycles of exploration, exploitation, and imitation to settle into an emergent pattern of group behaviour contingent on feedbacks between policies, agent behaviour, and environment (chapter five). These collective behaviours, in turn, figure as the simulation output which serves as input for the policy optimiser, iteratively running simulations under different parameter configurations in order to search for the optimal combination of policy parameters within the parameter space (chapter seven). Constructing this software system, the interdisciplinary team of modellers organise their collaborative work in "agile" cycles of iterative abstracting, coding, and demonstrating which, bit by bit, build up the software system rather than planning all of its features in advance (chapter five). Circulating model prototypes to important actors in the worlds of policy and science, the team elicits feedback which they turn into features built into their work product, thereby iteratively "socialising" the model to ensure its embedding as a decision-support tool into the knowledge infrastructure of fisheries management (chapter four). The loop echoed across disputes about agent reasoning and the design of algorithms, musings on collective emergent behaviour and the method of policy optimisation, and modes of inter- and transdisciplinary research.

Research participants mobilised metaphors drawn from biology when they talked about the loop, for instance when reflecting on agile software development as a way of "growing" code or likening the simulated emergence of collective behavioural patterns to evolutionary processes. This presence of a vocabulary of life within a computational practice comes as less of a surprise when considering the genealogy of agent-based modelling. The very claim to uniqueness of agent-based modelling as a simulation methodology, of course, embodies the loop: contrary to equation-based modelling, agent-based models do not describe the aggregate properties of the system in advance but rather generate them as collective emergent behaviour of agents iteratively interacting in simulation steps. As the title of a seminal work on social simulation suggests, agent-based modelling means "growing" the system "from the bottom up" (Epstein & Axtell, 1996).

As a computational technique, agent-based modelling arose from the cultural discourse and technoscientific practice of artificial life which itself emerged at the close of the twentieth century as a response to the failed promises of Cold War artificial intelligence research (Kember, 2003). The advance planning approach of Cold War artificial intelligence, which aimed to simulate intelligent action through complete internal representations of an environment on the basis of which optimal courses of action could be rationally planned in advance, proved incapable of coping with the infinitely detailed, ambiguous and changing environments in which computer systems were to act intelligently. Substituting bottom-up self-organisation for a military-rooted logic of top-down command and control, artificial life embodied in the design of robotics and artifical agent systems a more-than-rational mode of iterative adaptation to changing environments through feedback loops. Eliding the difference between in vitro and in silico through informational and cybernetic metaphors, artificial life researchers claimed to recreate with the help of computational simulation the self-organised emergence of living systems (Helmreich, 1998). At the same time as artificial life researchers eschewed the rational planning optimism of artificial intelligence in favour of bottom-up self-organisation to cope with complex environments, commercial software developers tasked with designing complex software systems started questioning the wisdom of received project management methodologies in the face of repeated project failures. Responding to these failures with the development of agile methodologies, software development came to privilege self-organising teams continuously adapting to changing conditions over executing a plan with explicitly formulated requirements (cf. Beck et al., 2001).

How, then, to make sense of the loop? Technoscientific work is situated within and responds to the cultural preoccupations of its time (Forman, 1971). Iterative adaptation appears as a way of coping with, and making sense of, situations of uncertainty and change that threaten to overwhelm attempts at rational planning. The principles of adaptation and iteration informing both agent-based modelling and agile software development might then be understood as reflective of a shift towards the possibility of disorder, the loss of control, and the limits of deterministic planning that came to preoccupy technoscientific cultures from the 1970s onwards under the banner of complexity and nonlinear dynamics (Hayles, 1990). Responding to this shift, the loop as a logic of coping with complexity is prefigured in the „agile" work practices of the consortium scientists as they construct their complex systems simulation. Moreover, the loop also accelerates adaptive management as a logic of governing complex systems in the face of uncertainty: rooted in systems theory, adaptive management governs socio-ecological systems through an iterative cycle of assessment, intervention, monitoring, and adaptation within which adaptive feedback loops between observation and decision have a central role (Holling, 1978; Holling & Meffet, 1996). Promising faster, better and cheaper fisheries management in its white papers, the consortium wishes to speed this adaptive management cycle up in such a way that reactions to policies can be predicted in advance of management intervention rather than having to go through slower cycles of empirical observation of the outcomes of interventions and eventual adaptation.

In addition, that the loop would simultaneously characterise the narration of the significance of the technical artefact the consortium constructs, the functional logic of the technical artefact itself, and the social orderings through which the scientists organise their collaborative work also tempts to think about this isomorphism in relation to the socio-materiality of cognition. Work in STS and anthropology argues for understanding (scientific) reasoning as a social practice extending beyond the individual, with shared styles of thought both reflecting and stabilising the social orderings in which categories are formed (Douglas, 1986). Organising their work practices in a way that is isomorphic both to the categories they bring to bear on the world and the material practices with which they simulate this world, the scientists would appear to simultaneously reinforce the social coherence and epistemic plausibility of their collective enterprise. For this reinforcement, the materiality of modelling as a collective effort of cognitive work seems to play an important role: invocations of material limits to computation shape the privileging of calculative techniques embodying the loop over more linear techniques (chapter six and seven) and the layered affordances generated by the crafting together of object orientation and agility invite iterative cycles of interdisciplinary work on the fundamental categories abstracted in the model (chapter five). Beyond the epistemic effects of model materialities described in the literature (Knuuttila, 2005; Landström et al., 2013), an isomorphism like the loop would then raise the question how model materialities are related to the sociality of cognition in scientific work. That is to say, the loop would suggest investigating models not only as "things forcing thought" (Braun & Whatmore, 2010), but also as things stabilising social orderings in which particular thoughts can gain force.

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