Idealized Representations, Inferential Devices and Cross-Disciplinary Tools: Theoretical Models in Social Sciences

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1. Introduction

The term “model” is nowadays in wide use across the sciences, and increasingly so also in the social sciences. This proliferation of the things called models in sciences reflects the increasing mathematization of diverse disciplines as well as the increasing importance of computational techniques. Although modelling may be regarded as a specific theoretical strategy bearing “a historical signature” (Godfrey-Smith 2006), it is equally clear that such things that we would now conceptualize as models have existed throughout the history of science and technology. However, the importance of models grew in the nineteenth century largely as a result of the need to postulate and reason about unobserved theoretical entities in a tractable but rigorous manner (Hesse 2000). The word model usually referred to concrete objects, like mechanical models, composed of, for example, movable bars, cords, wheels and rollers or to moulds made of wax as well as physiological (anatomical) models made of plastic. Indeed, in his famous encyclopedia entry on models, Ludwig Bolzmann precludes maps, charts, musical notes or figures from being models, since models “always involve a concrete spatial analogy in three dimensions” (1911). Boltzmann did not require, however, that models should physically exist for they could also be mentally conceived. In Boltzmann’s essay scientific models still retain a close relationship to many other things denoted by the word “model”, such as exemplars, moulds, or even people functioning as models for the artist or the medical student. Yet at the same time models are couched in more modern terms as representations, standing to objects in the same kind of relationship as “thoughts stand to things” (ibid.).

If the word model was polysemous in Boltzmann’s days, this certainly applies to our present understanding of models. The kinds of things called models in science include for instance physical three-dimensional things, diagrams, mathematical equations, computer programs, organisms and even laboratory populations. To this heterogeneous ensemble the social sciences add their own characteristic understanding of models: In social sciences often an analytically useful conceptualisation of phenomena represented in a 2-2 field or a hypothesis represented by a boxes and arrows diagram can be called a model. In the face of this plurality we limit our focus to what we call theoretical models, sometimes called formal models (Hesse 2000, Morton 1999). By theoretical models we mean devices that are used to infer non-trivial consequences from prior, usually theoretical, assumptions. By non-triviality we mean that the inference is not transparent to the unaided theorist, but instead essentially involves some kind of manipulation of the model, usually syntactic manipulation of symbols according to well-defined rules. Thus such models are often indeed "formal" in the sense that they express "the form or structure of physical entities or processes without any semantic referring to specific objects or properties" (Hesse 2000). Obvious candidates for theoretical models in the sense intended here are mathematical models, but also chemical formulas (such as H2O for water), simulations, iconic presentations like diagrams, and purely physical devices, such as the hydraulic economy of A. W. Phillips, qualify (see Morgan and Boumans 2004). The focus on theoretical models also means that we are not addressing statistical models of either descriptive or causal kind. Although statistical models always involve prior theoretical assumptions, they are still essentially data-driven in the sense that the conclusions of interest are about *estimates* of some parameter or other. Especially causal models involve completely different philosophical issues from those of theoretical modelling and would thus deserve a separate entry.

When it comes to constructing and using theoretical models economists have undoubtedly been pioneers among the social scientists: since the Second World War model-building has become the main theoretical practice of economists (e.g. Solow 1997). Subsequently, the modelling methods adopted and developed by economists have been disseminated to other social sciences. Especially the political scientists have been inspired by the rational choice style of modelling and the associated mathematical techniques used by the economists (see Morton 1999) whereas sociologists have preferred statistical modelling being rather sceptical towards modelling social phenomena in abstract mathematical terms (Edling 2002). However, the situation is changing rapidly as various kinds of modelling methods, studied in the section 5 below, have increasingly crossed the borders of different social sciences.

In the following (section 2) we will first study the nature of models reviewing general philosophical perspectives to models with a special emphasis on their relationship to theories on one hand, and to the world, on the other. Next (in section 4) we consider more specifically some important topics pertaining to modelling: representation, idealization, and the different uses models are put to in science. In the section 5 we study some modelling methods and associated practices that are most widely used across social sciences. The modelling practices covered include rational choice methods, evolutionary game theory, network models and agent-based simulations (for a more thorough treatment of agent-based simulations the reader is referred to the chapter 32 on artificial worlds and agent-based simulation in this book). Our account is grounded on the general philosophy of science and largely inspired by the relatively encompassing philosophical and methodological discussions on economics, which are due to the more pervasive role of modelling in economics than in other social sciences. However, we expect our discussion to apply also to the other social sciences to the extent that they use theoretical models.

2. General philosophical perspectives on models

The discussion of models in the philosophy of science has heterogeneous beginnings, testifying to a variety of theoretical, formal, and practical aspirations that have different and even conflicting goals (see e.g. Bailer-Jones 1999). The current philosophical interest in models may be seen as arising from two historical trends. First, the problems facing the received syntactic view of the structure of scientific knowledge have given rise to general philosophical accounts of theories construed around the concept of model. Second, the focus has shifted from the use of formal logical machinery and the so-called general philosophy of science to cover also the philosophies of the special sciences, which address problems closer to the actual scientific practice. And that praxis is usually highly model-centred. Because of these divergent backgrounds and motivations, philosophical accounts of modelling have tended to concentrate on different questions. What has been common is the interest in representation, although what is at stake differs with respect to what questions are asked. Finally, whereas models have traditionally been conceived through their relationship to the theories on one hand to and to the world, on the other hand, in the recent discussion models have been relegated an independent cognitive or epistemic status. This has served to underline what is specific to modelling as a theoretical strategy of its own.

2.1. Models and theories: The syntactic and the semantic approach

Philosophy of science provides us with two attempts to formalize the general structure of scientific knowledge: the syntactic view of theories, once called the “received view“, and the more recent model-theoretic semantic approach. According to the syntactic view, a model is designed to give an interpretation of an uninterpreted formalism or calculus. For the proponents of the syntactic view, a scientific theory was such an uninterpreted or partially interpreted formalism, a syntactic structure consisting of a set of axioms. Thus, for instance Ernest Nagel, defined a model as an interpretation of “the abstract calculus which supplies some flesh for the skeletal structure in terms of more or less familiar conceptual or visualizable materials“ (1961, 90). To interpret a theory was to specify a model for it, which makes all the axioms of the theory true (or false). Consequently, a model for a theory T could be defined as a set of true propositions with the same formal structure or calculus as T (96).

The semantic conception contested this “linguistic“ view of theories by replacing the syntactic formulation of the theory with the theory’s models, which are non-linguistic entities. In this view, theories are not assemblages of propositions or statements, but “extralinguistic entities, which may be described or characterized by a number of different linguistic formulations“ (Suppe 1977, 221). These extralinguistic entities—models—are taken to be structures that are defined either by the use of set-theoretical predicates (e.g. Suppes 1961, da Costa and Fench 1990) or by the use of any suitable mathematical language (e.g. van Fraassen 1980), such as a set of trajectories in some state-space (Giere 1988). The emergence of the semantic conception dates back to the 1960’s with impulses both from mathematics and computer science (see Suppe 1989, Prologue) as well as from the intrinsic problems of the syntactic approach arising from its linguistic orientation.

Of the semantic approaches to models (and theories) perhaps the best-known are those of Bas van Fraassen (1980) and Ronald Giere (1988). According to both of them a theory can more or less be identified with a family of models, although their approaches differ from each other in the degree of their abstractness and in the ways they utilise aspects of the semantic approach to accommodate their divergent standpoints to the empiricism-realism debate (French and Ladyman 1999, 104). For Van Fraassen, the "new picture of theories" is thoroughly empiricist with only the empirical substructures having a role in theory evaluation (they should be isomorphic to the structure of appearances consisting of experimental and observational reports).

In contrast, Giere, a (constructive) realist, denies that the relation between a model and a real system should be isomorphic. Giere (1988) develops his account of models on the basis of classical mechanics as presented in standard textbooks proposing that the "linear oscillator", for example, is not a single model with different specific versions but a cluster of models of varying degrees of specificity (80). Consequently Giere finds in physics textbooks "a population of models consisting of related families of models" (82). The models as such are not true or false with respect to the world; the role of the theory is rather to claim a "good fit" between the models and some important types of real systems. Consequently, Giere suggests that a theory is comprised of two elements: (1) a population of models, and (2) various hypotheses linking those models with systems in the real world (85). Another important strand of the semantic approach consists of the German structuralists (see e.g. Balzer, Moulines and Sneed 1987), who are mostly concerned with the architectonics of scientific research programmes than with individual models.

Although both syntactic and semantic accounts were originally presented in the context of physics, echoes of these general ways of thinking can be found in the methodological writings of economists and philosophers of economics. The standard microeconomic principles are often presented in an axiomatic form and the intuition that axiomatization in itself has some obvious intrinsic epistemic virtues leads quickly to the idea that the function of the models is to relate the theory to observations. Thus, for instance, Tjalling Koopmans defined in his famous *Three Essays on The State of Economic Science* (1957) economic theory as a set of postulates. Since the implications of these postulates are neither self-evident, nor "readily tested by observation" one has to resort to modelling:

> In this situation, it is desirable that we arrange and record our logical deductions in such a manner that any particular conclusion or observationally refutable

implication can be traced to the postulates on which it rests [...]. Considerations of this order suggest that we look upon economic theory as a sequence of conceptional *models* that seek to express in simplified form different aspects of an always more complicated reality". (Koopmans, 1957, p 142)

Here the idea of the economic theory as a set of axioms from which logical consequences can be deduced is close to the syntactic approach to scientific theories. Indeed, the axiomatic ideal of science has long roots in economics: Already in the nineteenth-century the so-called Marginalist economists attempted to axiomatize demand functions as logical consequences of more fundamental properties of individual behaviours. Their aim was to provide an axiomatic foundation for the model of market equilibrium (see Brown and Deaton 1972). This way of proceeding has been coined as "a neo-Walrasian research program" by Weintraub (1985).

However, Koopmans's idea of economic theory as a sequence of models seems also to anticipate the semantic conception. Somewhat more recently, Daniel Hausman has also argued for a semantic interpretation of economic models along the lines of the German structuralists. Hausman conceives what he calls the core equilibrium *theory* to be a set of law-like sentences which can be used to construct more or less demanding definitions (predicates) of kinds of systems. These definitions are the models that economists work with and their primary usage, being definitions, is conceptual exploration. According to Hausman it does not make sense to ask whether definitions are true or not – the empirical content lies in theoretical hypotheses, which are putative applications of these predicates to real systems in the world (Hausman 1992, ch. 5). Chao (2002) in turn argues that the semantic conception of models provides also a fruitful vantage point from which to approach econometric modelling.

2.2. Practice-oriented approaches

Whereas the syntactic and semantic approaches focus on defining models and situating them vis-à-vis to theories, the more practice-oriented approaches to models have targeted the pragmatic and cognitive role of models in scientific enterprise. This usually involves detailed investigation of specific models and taking into account different aspects of the actual *production* of scientific knowledge. For instance in the turn of 1960's, when the discussion on models was beginning to flourish, various writers including Achinstein (1968), Black (1962), Hesse (1966) and Hutten (1954) likened models to analogies and metaphors in their attempt to understand how models function in scientific reasoning. Moreover, both Max Black and Peter Achinstein created typologies of models in an effort to give a more complete account of the variety of models used in science.

It is of interest that both Black and Achinstein still started their discussion of models by considering scale models, three-dimensional physical objects, which Black thought were the "standard cases" of models in the literal sense of the word. The purpose of making scale models is to reproduce selected features of the "original" in a relatively manipulable or accessible embodiment. "We try to bring the remote and the unknown to our own level of middle-sized existence. There is, however something self-defeating in this aim, since … we are forced to replace a living tissue by some inadequate substitute, and a sheer change of size may upset the balance of factors in the original" (221). Thus, "inferences from a scale model to an original are intrinsically precarious and in need of supplementary validation and correction" (ibid.). Achinstein, too, paid attention to the manipulability or "workability" of physical models (which he called representational models). According to him "representational models, although used in all the sciences, are particularly central in engineering. Instead of investigating an object directly, the engineer may construct a representation of it, which can be studied more readily" (1968, 209).

The idea of models as stand-ins that enable surrogate reasoning was later formulated by Swoyer (1991) and has now been taken up by many other authors writing about models. What characterises theoretical modelling is a certain epistemic dynamic making use of surrogate reasoning: one first builds something or sets something up, then investigates the properties of that constructed thing, and then ponders how the discovered properties of the constructed thing relate to the real world. Weisberg (2007) and Godfrey-Smith (2006) have characterized this specifically model-based reasoning as *indirect representation*. They claim that instead of directly abstracting some salient aspects of data or a target system into a workable and more systematic scientific representation (direct representation), modellers seek to understand the real world through the procedure of constructing and analyzing hypothetical systems - in other other words, models. A modeller begins to attack a problem by coming up with a set of simple theoretical principles that, when combined, might be expected to solve the problem (such as providing an explanation for a puzzling phenomenon). This account of models takes them close to fiction in that instead of directly representing actual systems, modellers examine “tightly constrained” possible systems (for fiction in science see Suárez 2009). Reasoning with models is thus essentially learning about *hypothetical* surrogate systems (since any representation, whether direct or indirect, can, in a sense, be considered a surrogate with respect to the real systems).

Margaret Morrison’s and Mary Morgan’s conception of *models as mediators*, as investigative instruments between theory and data, also stresses the epistemic importance of building models and inferring or learning from models. Additionally, they extend the idea of manipulating a mathematical model to be, to some extent, analogous to experimentation (see also Mäki 1992, 2005). The mediating role of models between theory and data was inspired by Morgan’s earlier work on econometric modelling (Morgan 1990) and also builds on the work of Nancy Cartwright (1983). In arguing that the fundamental laws of physics do not describe the occurrent regularities that exist in nature, Cartwright turned her focus to models. There is a gap between the general theoretical principles of physics and the messiness and complexity of data which phenomenological laws in turn strive to capture. It is the task of models to bridge this gap: “The route from the theory to reality is from theory to model, and then from model to the phenomenological law. The phenomenological laws are indeed true of the objects of reality—or might be; but the fundamental laws are true only of objects in the model” (4). For a model to function as a bridge between theory and data, a model has to include some genuine properties of the objects modelled. But in addition to that, models contain properties of convenience and fiction (15). These features are needed to bring the objects modelled into the confines of the theory. Thus model-building is a pragmatic activity in which “adjustments are made where literal correctness does not matter very much in order to get correct effects where we want to get them; and very often…one distortion is put right by another” (140). In both Cartwright’s account of models as bridges and that of Morrison and Morgan’s as mediators models occupy the middle space between the theory and the world (or data), thus linking them.

In their account on models as mediating instruments Morrison and Morgan stress how “additional ‘outside’ elements” are brought into models (1999, 11). With this they mean that models cannot entirely be derived from either theory or data, which, apart from making them “at least” partly *autonomous*, also enables them to connect the different realms. Marcel Boumans (1999) moves even further away from the simple theory-data-framework by showing how heterogeneous kinds of ingredients seemingly simple mathematical models can be made of. The business cycle models Boumans studied contained analogies, metaphors, theoretical notions, mathematical concepts, mathematical techniques, stylized facts, empirical data and, finally, relevant policy views. The role of the model is not only to mediate, but also to provide a common forum in which all these considerations can be jointly handled.

The idea of models as mediators resonates interestingly with Robert Merton’s appeal for theories of the middle range, theories that would mediate between grand sociological theories and empirical research. Merton famously accused sociological theorizing as being too abstract and general for being any use in understanding specific empirical phenomena. Grand theories á la Talcott Parsons serve only to conceptualize empirical social phenomena and do not actually exclude any possibilities. Thus grand theories do not offer any grounds for making inferences to what might happen or might have happened and are for this reason non-explanatory. On the other hand, banal empiricism, either in the guise of simply running regressions or cataloguing the qualitative interpretations or meanings that the subjects attach to their social context, is purely descriptive and thus also non-explanatory (Merton 1957, 5). Model building can indeed be seen as a promising methodology for providing such mediating theories (e.g., Hedström 2005).

2.3. Models and the world: Representation

The philosophical discussion on models has spawned a discussion on scientific representation. The hope has been that the notion of (adequate) representation might capture the epistemic value of models better than the concept of truth (see however, Mäki forthcoming). Despite the differences in their approaches, philosophers of science have tended to be nearly unanimous in saying that models have to be representative in order to give us knowledge (Bailer-Jones 2003; da Costa and French 1990; French and Ladyman 1999; Frigg 2002; Morrison and Morgan 1999; Giere

2004). Often, representation has been made *the* crucial property of models (see e.g. Hughes 1997, and Suárez 1999, Contessa 2007, Mäki 2009). A characteristic statement of this linkage is given by Paul Teller (2001, 397):

> I take the stand that, in principle, anything can be a model, and that what makes a thing into a model is the fact that it is regarded or used as a representation of something by the model users. Thus in saying what a model is the weight is shifted to the problem of understanding the nature of representation.

However, here the agreement between philosophers tends to end as their preferred accounts of representation differ widely from each other. In the discussion on models and scientific representation three different kinds of approaches can be discerned depending on whether representation is analysed in terms of a two-place or (at least) a three-place relation, or as a combination of the two.

The semantic accounts conceive of representation as a two-place relation between the model and a target system. This representational relationship between models and their target systems is usually analysed in terms of isomorphism or a partial isomorphism: a given structure represents its target system if both are structurally isomorphic or partially isomorphic to each other, i.e., there is relation-preserving mapping between the model and its target (van Fraassen 1980, Suppe 1977; French 2003; French and Ladyman 1999). Another candidate relation offered for the analysis of representation by the proponents of the semantic view is similarity (Giere 1988). However, as similarity seems to be an observer and purpose relative notion, the recent formulations of similarity account of representation tend to be pragmatic (Giere 2004, forthcoming).

Although perhaps intuitively appealing, the accounts of representation that are formulated in terms of a two-place relation of either isomorphism or similarity are ridden with numerous problems. Firstly, as such they do not have the formal and other properties that a satisfactory account of representation is expected to possess (see e.g. Suárez 2003 and Frigg 2006). For instance, both isomorphism and similarity denotes a symmetric relation whereas representation does not: we want a model to represent its target system but not vice versa (this critique goes back to Nelson Goodman 1972). Secondly, isomorphism is a relationship between two structures, whereas scientific representation assumes a relationship between a structure and a real world target system. Roman Frigg (2006) argues that structural isomorphism is not sufficient to pin down a representational relationship between a model and a target since the same structure can be instantiated by different target systems. On the other hand, a given target system does not exemplify a single unique structure since it can be sliced up in multiple different ways, depending on the perspective adopted (Frigg 2006, 56-59). Isomorphism alone is thus not able to fix the extension of representation.

Eventually, the structuralist account on representation turns out not to be an account of how models link to the world, but an account of how models link to each other. Since real world systems are not "structures" in any obvious way, any isomorphic relationship between them and the real world target systems involves that these parts of the empirical world are already modelled (or represented) somehow. This has, of course, been noticed by the proponents of the semantic theory: Patrick Suppes (1962) invoked "models of data" as the empirical benchmark against which theoretical models are compared. Thus the isomorphism required by the structuralist account concerns actually the relationship between a theoretical model and an empirical model. Indeed, in their attempt to rehabilitate the semantic conception via the notion of partial isomorphism, French and Ladyman remark (in a footnote) that they are not claiming that the "gap between a theory or model and reality can be closed simply by a formal relation between model-theoretic structures. The gap is more fundamental than that … What is required is an understanding of the relationship between one category of things, "the world", "reality", whatever, and another category, namely, that which represents the world" (1999, 119).

The pragmatic approaches to representation deny that the representational relationship could be regarded as a two-place relation of correspondence between the representative vehicle and its target (Suárez 2004, Giere 2004, Frigg 2006). This way of conceiving representation, the pragmatists claim, tends to reduce the intentional character of representation to the respective properties of the representative vehicle and its target object (see especially Suárez 2004). Since from the pragmatist perspective representation presumes always an intentional activity from the part of representation users, the representational relation is at least a three-place relation including also the users of representation (Bailer-Jones 2003, Giere forthcoming).

Depending on the analysis in question, also other factors, such as the purposes of the representers and the possible audiences are taken into account (Giere, 2004).

The hybrid accounts of representation in turn try to steer a middle course between the structural and pragmatic conceptions by combining a two-place relation between a model and a target with the pragmatic aspects of representation. Andreas Bartels (2006) suggests that representation can be grounded on a weaker notion of homomorphism which dispenses with a one-to-one bijective mapping required by isomorphism. Homomorphism provides thus an explication for the "representational content" of a model. Yet, for a model to be able to refer to any target an intentional or causal representational mechanism is also needed. Mäki (2009) combines the pragmatic representative aspect of models with the resemblance aspect (understood in largely semantic terms). The idea is that the intended goals and audiences specify the pragmatic constraints in the context of which resemblance aspect highlights the ontological constraints imposed on representation by the world.

One might interpret the hybrid accounts as attempts to overcome the deflationary nature of pragmatic accounts while still admitting the inherently pragmatic nature of representation. Namely, the thoroughly pragmatic approaches to representation (dis)solve some of the problems of the semantic notion of representation mentioned above, either by avoiding them, or by the introduction of the users' intentions which create the directionality needed to establish a representative relationship. But this comes at a price. When representation is grounded primarily on the specific goals and representing activity of humans as opposed to the facts about the representative vehicle and the target object, as a result nothing very substantive can be said about the relationship of representation in general. This seems not to be a problem for the proponents of the pragmatic approach (see Giere 2004, Suárez 2004), of whom Mauricio Suárez has gone farthest in arguing for a minimalist account of representation which resists saying anything substantive about the supposed basis on which the representational power of representative vehicles rests (that is, whether it rests, for instance, on isomorphism, similarity or denotation). Instead, Suárez builds his inferential account of representation directly on the idea of surrogate reasoning: i.e. the model represents something in virtue of its capacity to lead a "competent and informed user to a consideration of the target", and the right kind of constitution for to allow agents to correctly draw inferences from it (Suárez 2004). While the aforementioned representational capacity of a model is created and maintained by the inferential activity of representation-users, the stipulation concerning the right kind of constitution saves the intuition that the properties of the model-objects should have something to do with their intrinsic qualities – which accounts for the objectivity that is expected from scientific representation. Suárez's account on scientific representation is thus in line with Robert Brandom's view of representation in general: it is the inferential properties of objects that constitute their representational properties and appealing to any primitive representational concepts to explain inferential properties would therefore put the cart before the horse (Brandom 1994).

If the semantic properties of a model do not determine its pragmatic dimensions but rather vice versa, then the epistemic value of models need not be tied to their putative success in representing their target systems *accurately*. As Donato and Zamora (2009) point out, this opens up a fresh perspective on the acceptability of models: what makes a model "enlightening" apart from its predictive success is the amount and successfulness of the inferential links it forges to our existing corpus of commitments. Also, the model should reduce the cognitive or computational cost of the activity of drawing consequences, which requirement is closely bound to its inferential enablings. Thus Donato and Zamora ask, rather provocatively from the traditional perspective, whether there are "any other criteria to judge a model *right* (or *probably true,* or *approximately true,* or *probably approximately true*) besides the fact that it leads us adopt conclusions which are corroborated by different means?" (2009, 107).

Taken together the above mentioned pragmatically inclined accounts imply a larger unit of analysis than the earlier interest in the relations between models and theory or models and their real world systems. Conceiving models as independent entities and construing their representational capacity on the basis of their inferential enablings paves the way for considering modeling simply as a form of extended cognition, as extended inference in which the relevant cognitive unit of analysis is the user-model pair. Kuorikoski and Lehtinen (2009) deny that any philosophical account of representation (or other semantic notion for that matter) can explain the epistemic value of models, since there is nothing to be explained: modelling is simply inference or argumentation using external cognitive aids (such as a formal language or a diagram).

Paying attention to the inferential nature of models leads us to approach models from a novel perspective: Knuuttila (2005, 2009a) argues that the traditional emphasis on representation places excessive limitations on our view on what kind of entities models are and how they function in scientific practice. She suggests that models should be thought of as epistemic artifacts through which we gain knowledge in diverse ways. Focusing on scientific models as multi-functional artifacts releases them from any pre-established and fixed representational relationships and stresses their intentional construction that allows for various kinds of inferences. From this naturalist perspective, informed importantly by the idea of distributed cognition, models simplify and modify the complex problems facing the scientists turning them into a workable and perceptual form by making use of various representational media (see also Knuuttila and Voutilainen 2003, Vorms 2009).

3. Unrealistic assumptions and idealization in social scientific models

One common property of the models in social sciences is their highly simplified and idealized nature, which might seem more problematical in the context of social sciences than in natural sciences. A usual complaint levelled against theoretical models in social sciences is the apparent unrealisticness of the assumptions they make concerning the behaviour of social actors. There are indeed three basic properties of social phenomena that prompt the question whether modelling them requires special modelling strategies or even whether modelling should be considered as a plausible epistemic strategy to begin with. First, social systems are heterogeneously constituted, open and constantly changing, which means that models have to rely heavily on abstraction and idealization. Second, social systems are constituted by human action and, in contrast to the natural sciences, social sciences need to take into account the reflexive dimension of both their subject matter (intentionality of the subjects) and the nature of their theorizing (performativity, see MacKenzie, 2006). Third, the special status of intentional action also means that, as social actors, we judge oursevels already to have a reasonably good pre-understanding of social phenomena, and this pre-understanding seems to contradict the usual idealizations made in theoretical modelling.

There are numerous ways to justify the idealizations, approximations and simplifications that are characteristic of modelling. A good overall view on this problematic is provided by the so called “realism of the assumptions” -issue in economics, which dates back to the beginning of mathematization of economics in the nineteenth century. While the classical economists often interpreted the basic assumptions of economics realistically as subjectively available self-evident truths concerning human nature (see e.g. Caldwell, 1982), especially later in the twentieth century the attitudes of economists and the general public alike became more critical towards the basic behavioural assumptions of economics. Thus the question became how to save them as the significant part of economic theory was based on them.

Several economists have, in their attempts to save economic theory, taken the seeming falsity of the basic postulates of economics at face value. Thus Milton Friedman famously defended economic theory on instrumentalist grounds, claiming that the “unrealism” of the assumptions did not matter since the goal of science was to develop hypotheses that gave “valid and meaningful” predictions about the phenomena (Friedman, 1953). Although Friedman’s classic statement has created a more extensive secondary literature than any other piece on economic methodology, in the recent discussion, economic models are considered to be valuable because of their explanatory function rather than due to their predictive success. This applies to other models in social sciences as well: although unrealistic, they are nevertheless considered to give us some understanding on social processes.

The main defences of the unrealistic assumptions used in social scientific models proceed through two lines. On the one hand economic models have been conceived of as surrogate systems through which we can obtain knowledge if they succeed in *isolating* or abstracting some causal mechanisms, factors or tendencies correctly (Cartwright, 1989, Mäki, 1992, this issue), while on the other hand it has been suggested that they are rather like pure constructions or fictional entities that nevertheless license different kinds of inferences (Sudgen, 2002, 2009, see also Knuuttila 2009b). Of course, there are overlaps between these two alternatives, but for the sake of exposition we keep them separate in what follows.

The main exponents of the isolation account, Nancy Cartwright and Uskali Mäki, both have derived from J.S. Mill the idea that models abstract causally relevant capacities, factors or mechanisms of the real world for the purpose of working out deductively what effects those few isolated capacities or factors have in particular controlled model environments. Cartwright's focuses on causal capacities, which are the ontologically primary causes of the regular associations between events. Regularities are produced when causal factors work together in particular configurations isolated from other disturbing factors. In models we study the behaviour of the causal capacities of interest by idealizing (or abstracting) away the workings of the other factors (Cartwright 1999a). While Cartwright writes variably and sometimes more or less interchangeably about abstraction, isolation and idealization, Mäki (2005) makes isolation the central concept of his account of modelling.

According to Mäki, theoretical models in economics are outcomes of the method of isolation, in which a set of elements is theoretically removed from the influence of other elements in a given situation (Mäki 1992, 318, see also Mäki 1994). For Mäki, abstraction is a subspecies of isolation: the isolation of the universal from its particular exemplifications. Idealizations and omissions, in turn, are techniques for generating isolations: idealizations being deliberate falsehoods, which either understate or exaggerate to the absolute extremes (Mäki 1992). The idea of isolation shows that unrealistic assumptions can even be the very means of striving for the truth, which Mäki puts as boldly as stating that "an isolating theory or statement is true if it correctly represents the isolated essence of the object" (1992, 344, see also Mäki in this volume).

However, the idea of isolation is beset with a couple of major problems: Firstly, the problem is that the "causal structure" of the real world is often such that the causes are not separable and thus may not vary independently as the method of isolation assumes (Boumans and Morgan, 2001, p. 16, Alexandrova 2008). More likely, rather than "sealing off" the disturbing factors, models assume simpler relations than the actual ones for causal interactions. In econometric work it is often found that the causes are not separable and so they should not have been be treated as independent of other previously included and omitted factors (see Morgan and Knuuttila forthcoming).

Secondly, idealizations in economic models are often driven by the requirements of tractability (see Hindriks 2006). This is why Cartwright has lately asked whether economic models are, in fact, "over-constrained" in terms of facilitating study of the isolated processes of interest (e.g., Cartwright, 1999b),. The specific problem with economic models is that many of their idealizations are not meant to shield the operation of the causal factor or tendency of interest from the effects of other disturbing forces. Rather, the model economy is often attributed very special characteristics so as to allow mathematical representation from which, given some minimal economic principles such as utility maximization, one could derive deductive consequences (Cartwright, 1999b; see also Alexandrova, 2006 for "derivation facilitators"). Thus the model assumptions do not merely neutralize the effect of the other causal factors. They do much more: they construct the modelled situation in such a way that that it can be conveniently mathematically modelled making the results derived model-dependent. In an attempt to overcome this problem Kuorikoski and Lehtinen (2009) advocate robustness analysis, the use of multiple models with different and independent tractability assumptions to derive the same conclusions, as a tool for assessing the model-dependence of modelling results and claim that much of modelling practise can be interpreted through such a rationale.

As opposed to the idea of modes as isolating entities, economic and other social models have been also defended on fictionalist grounds. An early fictionalist interpretation of economic theorizing was presented by Fritz Machlup who suggested that homo oeconomicus should be regarded as a Weberian *ideal type* (Weber 1904). As an ideal type homo oeconomicus is to be distinguished from real types. Thus economic theory should be understood as a heuristic device for tracing the predicted actions of imagined agents to the imagined changes they face in their environment. According to Machlup, economists are not interested in all kinds of human behavior related to business, finance and production: they are only interested in certain reactions to specified changes in certain situations: "For this task a *homunculus oeconomicus*, that is, a postulated (constructed, ideal) universal type of human reactor to stated stimuli, is an indispensable device" (Machlup 1978, 300). Yet Machlup reminds us that regardless of the artificiality of the ideal type -construct, the motivational assumptions attributed to it should be "understandable" in the sense that we could imagine reasonable people acting according to them at least on some occasions.

In his account on modeling Robert Sugden (2002) also reverts to fiction, although instead of "understandability" he invokes "credibility". He contests the idea that modelers proceed by first isolating causally relevant factors of the real world and then studying their consequences. In his view economic models should rather be regarded as fictional constructions, which instead of being abstractions from reality are *parallel realities*. A good example towards that end, according to Sugden, is Thomas Schelling's famous "checkerboard model", which he uses to explain segregation by color and by sex in various social settings (Schelling 1978). The model consists of a grid populated by dimes and pennies that either migrate or stay put depending on the number of immediate neighbours that are of the other type. The migration of dimes and pennies continues until all the coins are content. As a result, strongly segregated distributions of dimes and pennies tend to appear—even if the number of neighboring "others" tolerated were quite high.

According to Sugden, it seems rather dubious to assume that a model like the checkerboard model is built by presenting some key features of the real world and sealing them off from the potential influence of other factors at work: "Just what do we have to seal off to make a real city - say Norwich - become a checkerboard?" he asks (2002, 127). Thus, "the model world is not constructed by starting from the real world and stripping out complicating factors: although the model world is *simpler* than the real world, the one is not a simplification of the other." (131). Sugden treats model-world inferences as a species of simple induction, which is legitimate when the model describes a state of affairs that is *credible* given our knowledge of the real world, and in doing so it could be considered realistic in much the same fashion as a novel can. Even though the characters and the places in the novel might be imaginary, we could consider them credible in the sense that we take it to be possible that there are events that are outcomes of people behaving as they do in the novel.

4. The uses and types of models in the social sciences

Although economic modelling is the biggest game in town, it is not the whole story about formal modelling in the social sciences. The boundaries between the different social sciences have traditionally been drawn according to the scale and nature of the entities they study. Sociology studies the non-market driven societal or macro phenomenon in industrial and post-industrial societies, economics (arguably) phenomena governed by markets, social psychology interaction in relatively small groups etc. These traditional ways of defining the division of labour in the social sciences do correspond to some extent to the differences in their modelling practises. Economists' theoretical practices consist nowadays nearly entirely of modelling, with only a relatively limited set of modelling methodologies, whereas few sociologists rely on modelling, but those who do, use a more heterogenous set of model templates (Edling 2002).

However, modelling frameworks cross disciplinary boundaries and an argument could be made that the traditional way of dividing the disciplines should be, and is actually in the process of being, replaced by a division of labour according to the use of different modelling tools (Humphreys 2004, 71). Most models in social sciences are indeed more or less of the off-the-shelf type, i.e. abstract structures that can be applied with varying degrees of adjustment to systems with intuitively very different causal make-up - the principles of stochastic processes, network models or constraint optimization are similar regardless of who or what (individuals, groups, countries, ideas…) is doing the random walking, networking or maximizing. Therefore the following brief survey on modelling practices in use in social sciences is organised around different model templates, rather than according to traditional disciplinary boundaries. However, as will become apparent later, this does not mean that there would be no important discipline related differences in the ways in which these templates are applied. For example, sociologists and economists conceptualise, use and interpret network models in importantly different ways, which reflect the deep methodological and substantial differences in their approaches to social phenomena.

We do not treat computer simulation as a distinct modelling format, since computational methods can and are used in connection with each of the following modelling practises. We acknowledge that not all uses of computational methods are simulations in any interesting sense (Hartmann 1996, Lehtinen and Kuorikoski 2007a), and that computational methods in general, and computer simulations in particular, involve important philosophical issues. But these issues cannot be adequately addressed here. Many model-types can also be, and are in fact, solved by manipulating diagrammatic graphical representations rather than symbolic mathematics, but this difference in the way of solving the model does not (usually) entail differences in the types of inferences that the model makes possible.

What kind of model template is considered appropriate depends on the goals of modelling: some types of models are obviously better suited to some specific purposes than others. Social scientific models can be used to suggest explanations for certain specific or general phenomena; to carry out virtual experiments; to specify and even help to execute policies based on a model; to design new institutions; to make predictions; to conduct thought experiments using a model; to derive solutions to theoretical problems; to explore the limits and range of possible outcomes consistent with questions that can be answered using a model; to develop concepts and classificatory systems; or simply as a pedagogical aid.

Simple and analytically tractable models are usually taken to be good at conceptual elaboration, theory development and explanation. Among others, Boyd and Richerson (1987) argue that replacing unintelligible phenomena with unintelligible models does not increase our understanding and that simple models are thus appropriate for explanation. However, their uses can be limited: for example, Grüne-Yanoff (2009) argues that extremely simple or "minimal" models can only be used to disprove pre-theoretic impossibility intuitions (such as surely racial segregation cannot arise from non-racist preferences). Simple models (such as the famous IS-LM model in macroeconomics) are also usually well suited for pedagogical purposes, although complex simulations can also be used to provide illustrative examples. Relatively simple atheoretical associational models are often superior to more complex theoretical models in pure prediction tasks (*pace* Friedman). On the other hand, policy analysis is often conducted with the aid of extremely complicated and data-rich computer simulations that are used to predict the consequences of possible interventions (for example epidemiological models and computational models used by central banks).

One common misconception about modelling is that modelling automatically entails a preference for quantitative data or quantifiable issues over a more qualitative approach. Much of theoretical modelling in the social sciences is about qualitative features of the socials systems modelled and need not involve any explicit statistics. The function of the mathematics is not to relate numbers, but to facilitate secure derivations from theoretical principles and thus to enable reasoning about matters that are too complex for natural language (Simon 1957, ch. 6).

What follows is a simple typology of commonly used model-templates in the social sciences – rational choice, dynamical systems, network models and agent-based models – and some examples of how they are used. Our typology mirrors Cristofer

Edling's (2002) classification of sociological models into models of process, structure and purposive agent, with the crucial difference that ours is based on the model-structure rather than on the intended interpretation.

Rational choice and traditional game theory (purposive agent –models)

Although rational choice ideas are now widespread in many social sciences, many applications of rational choice are little more than applications of economic concepts such as incentives, commodities and prices to domains of social phenomena without explicit market institutions or immediately obvious common currency (such as rational choice theories of religion, see essays in Young 1997). Much of this reconceptualization is not (and need not be) backed up by substantial formal models. Perhaps the field with the longest tradition of true model-building is political science, in which rational choice models have been used to explore the properties of different kinds of voting rules and political institutions (see e.g. Morton 1999).

In conceptual terms, rational choice modelling begins with a postulation of a set of agents with preference orderings over a set of alternative outcomes and a postulation of a condition under which the simultaneous satisfaction of these preferences would be in some sense mutually consistent (the solution concept). In practise, the mathematical apparatus needed to build and solve this general analytic problem may vary, even quite radically. What is common is the importance of the solution concept or equilibrium, which allows the modeller to abstract away much of the fine detail of the modelled situation, most importantly the dynamics, i.e. an account of how and why the social system ends up in the final state.

If the social situation can be modelled as if it exemplified a competitive market, i.e. the outcomes concern what commodities the agents posses after the interaction, there is a common currency in which the commodities can be valued and the actions of any given individual are not significant enough so as to affect the market prices, the models can be formulated and solved using simple principles of constraint optimization and the corresponding solution concept is the market equilibrium. If the strategic element in the joint choice situation cannot be ignored, game theoretical methods have to be used: preference orderings and the possible outcomes are jointly defined as the payoffs and some appropriate solution concept chosen (most often the Nash-equilibrium), which is then used to derive a solution.

Much of the philosophical discussion concerning rational choice modelling is about the extent to which it is sensible to treat humans as rational agents. This discussion is often connected to conceptual issues in action theory or normative issues concerning the concept of rationality. Some rational-choice theorists themselves defend their approach by appealing to the alleged intrinsic intelligibility of rational action and that rational choice is therefore a "rock-bottom" explanatory theory (e.g. Boudon 1998; see also Ylikoski and Kuorikoski 2008). The question of the legitimacy of rationality assumptions can also be tackled by simply treating it as an instance of the general problem of idealization, that is, under which conditions literally false idealizing assumptions about agent-behaviour are fatal for the interpretation of the model or for the external validity of the model result. Approaching the issue from an action-theoretic viewpoint might also make one miss the fact that not all rational choice models rely on attributions of intentional states to the agents for their explanatory value. In some rational choice models the structural constraints of the choice situation carry the main explanatory weight, and sometimes even the behavioural assumptions (i.e., that individual agents act as-if maximizing some quantity) may be largely a matter of modelling convenience (Satz and Ferejohn 1994). It is thus misleading to talk about a single theory of rational choice, since what is assumed by any given model, in other words the actual empirical content of the model, varies according to how the model is construed and used. (Lehtinen and Kuorikoski 2007b)

However, this very flexibility of the conceptual and mathematical frameworks have subjected rational choice models to charges of triviality in that they can only deal with features of social situations in such an abstract level that such models only serve to reformulate things that were already well understood or that the results are of little practical or theoretical interest. For example models of voting behaviour demonstrating the prevalence of preference cycles have been used to argue that democratic institutions are somehow inherently in disequilibrium. These extremely abstract models have been met with scepticism regarding whether they say anything empirically interpretable in the first place. (Green and Shapiro 1994)

Evolutionary game theory and dynamical systems (models of process)

Evolutionary game theory can be seen as an attempt to answer two central problems facing the traditional game theory. First, the requirement of formulating explicit dynamics can be seen as an attempt to answer the problem of equilibrium selection arising from the fact that most games have multiple Nash equilibria and that the consequent equilibrium refinement literature failed to pick a clear favourite replacement out of the multiplicity of intuitively reasonable stronger solution concepts. That the fact that game theory could not always make a definite point-prediction was seen as a fatal problem perhaps indicates that game theory was indeed seen more as a substantial predictive or explanatory theory, rather than as a modelling framework. Second, specifically evolutionary dynamics can be seen as an answer to the accusation that traditional game theory attributes wildly unrealistic psychological capacities to the agents: since sets of evolutionary stable strategies are also Nash-equilibria, evolutionary game theory is sometimes interpreted as showing how selection eventually drives a population into a state in which the units of the population exhibit strategic best-response behaviour, regardless of whether the units actually carry out any strategic deliberation.

Models of evolutionary dynamics are a special case of dynamical systems. Mathematically, dynamical systems are usually defined as systems of differential or difference equations, but we can also throw in stochastic processes for good measure. For example, game theory becomes evolutionary when the payoffs are interpreted as fitness, which is in turn operationalized as (or analytically linked to) the relative frequency of a given strategy in the next generation (replicator dynamics). This allows the model to be built as a simple system of difference equations, which can be solved for equilibrium. The equilibrium is thus still an essential concept, now defined as a fixed point of a dynamical system, i.e. as a point in a trajectory in which the rate of change of the system in any direction is zero. In evolutionary game theory, a further constraint is usually imposed, according to which the equilibrium should also be stable under the introduction of invading alternative strategies. However, point equilibria are not the only outcomes of interest in dynamical systems, since many interesting social dynamics involve oscillations or other kinds of stable orbits. With certain assumptions, the stability properties of fixed points and orbits of relatively simple dynamical systems can be explored analytically (usually through the use of linearization). Since in most cases of theoretical modelling, empirical grounds for favouring particular functional forms over alternatives are hard to come by, rough estimates about the qualitative behaviour of a loosely defined dynamic systems can usually be obtained by graphically reasoning with a phase diagram. Not surprisingly, using computational methods to explore the properties of dynamical systems has become the norm rather than the exception.

Dynamical systems are most prevalent in economics: many macroeconomic models are explicitly dynamical and are fitted to data using complex statistical models built from stochastic processes. Theoretical uses of stochastic processes in sociology mostly derive from the models presented by James Coleman in his textbook on mathematical sociology (1964). Many philosophers have also encountered dynamical systems as a vehicle for studying the possible evolutionary scenarios leading to the emergence of altruistic behaviour. One of the earliest sociological applications is the famous dynamic model of interaction in social groups by Herbert Simon (1952). Simon builds a simple system of differential equations to explore the comparative statics implications of George Homans' three postulates concerning the relationships between aggregate interaction, friendliness, activity and externally imposed activity within a social group and then discusses their further extensions to clique-formation and regulatory enforcement. The model is a good illustration of how a formal model can reveal implications of theoretical postulates that would have been hard or impossible to reach by using only natural language as the medium of argumentation.

A well-known approach to using ecological model templates in the social sciences is Hannan and Freeman's tract on organization ecology (1989), in which dynamical population models are used to analyze field-level effects of organizations competing for scarce resources in a niche-space. Evolutionary models and other dynamic systems are also often used to model population-level effects of social or evolutionary learning and even gene-culture co-evolution. For example, Richard McElreath (2004) uses a simple analytic dynamic model to discuss how a level of between-group cultural diversity is sustained under imitation and migration due to the way individuals have to strike a balance between costs and benefits of individual learning (trial and error) versus social learning (imitation) in a changing environment. The value of the model is in the formulation of hypotheses concerning dependencies between different kinds of learning problems and cultural variation. These hypotheses were then checked against interview data gathered from East-African tribes with intra-ethnic cultural variation between pastoralists and farmers. The model thus provides a general (functional) explanation of the preservation of cultural variation in the face of immigration and imitation and implies hypotheses about responses to different kinds of learning tasks.

Network models (models of structure)

Social life is largely constituted by the relationships people have with each other. Not surprisingly, then, different kinds of network models form a large part of formal modelling in the social sciences (see e.g., Wasserman and Faust 1994). Much of this network modelling is data-driven. The point is often to collect or use existing data to statistically measure the number and strength of connections and interactions between agents (people, firms, countries etc.) or social positions. The beginnings of network modelling can indeed be traced to the idea of sociometrics, the measurement of interpersonal relations. However, there are also theoretical uses for network models. First, a theoretical network model can show that a given network structure can give rise to a certain phenomenon. Thus network models can be used to show how the social structure can give rise to some surprising social regularities. Second, a network model can be supplemented with additional theoretical content providing an account of how micro-mechanisms give rise to networks with certain structural properties.

Network models can be seen as applications of graph-theory, a mathematical theory linking diagrams to joint distributions of random variables. The models consist of nodes and vertices. The nodes represent units, usually individuals or social positions, and the vertices some relation(s) of interest that may obtain between the units. What is distinctive about most network models is that they employ essentially structural variables over and above variables representing properties of the units. For example, social connectivity can be treated as an attribute of an individual (as a predictor of occupational achievement, for example) or as a structural attribute of the whole network. The vertices are often conceptualized as resource flows or resource asymmetries between the units. This approach can be used, for example, to model structures of social power by defining power as a resource asymmetry between social positions (not individual people holding the positions).

Network models can be used to explain societal patterns by showing how the structure of the network constrains the joint distribution of the attributes of the nodes. For example the speed and shape of diffusion processes depend on the general structure of the network in which the diffusion takes place. Accordingly, network models can be used to explain certain characteristics of the spread of diseases, practises, ideas or party affiliation. Network models can thus be seen as a clear operationalization of what might sometimes be meant by the notoriously vague term "structural property". Moreover, social structure is also sometimes identified through the *absence* of social ties in a network and the strategy of focusing on "structural holes" to make inferences about the structural properties of social systems is an important part of theoretical network modelling.

Network models can also be supplemented with explicit models of unit-level behaviour or decision making. Thus the network structure can function as an *explanandum* as well as an *explanans*. Often this means adding a game-theoretical element to the model, but this is not necessary. For example Bearman et al. (2004) found out that the network-structure of romantic affiliations of adolescents in a US high-school did not obey the assumptions of standard disease transmission models. Using simulation techniques, Bearman et al. concluded that the observed network structure could arise from a norm prohibiting chains of length 4 (thou shall not date your old partner's current partner's old partner). Bearman et al. theorized that this "norm" is the result of a common aversion to possible status loss amongst peers, which overrides any other preferences in partner choice.

Agent-based models

Social sciences are about phenomena that arise out of the interaction of a number of people. Because of the demands of analytic tractability, most mathematical models are ill-equipped to do justice to the differences between people and instead have to directly relate aggregate or macro variables, or resort to using representative agent -constructs. However, aggregation, brute macro constructs and representative agent constructs are all subject to well-known problems and biases (see e.g. Kirman 1989).

Since the individual agent is in many ways the most natural ontological building block of social phenomena, models that are built directly upon these agents, models that show how simple decision rules governing the behaviour of heterogenous agents give rise to social phenomena, would seem an attractive methodological option. In such agent-based models, solving the model does not mean that an external consistency condition is imposed on the action of the agents (such as a solution concept) in order to derive a solution, but the agents are instead left to interact "by themselves" and the modeller simply observers how the system behaves.

Since computational methods can overcome the constraints of analytic tractability that would quickly become overwhelming for any truly agent-based model (which, in principle, should include a separate set of equations of behaviour for each individual), most agent based models are computer simulations (the chapter on artificial worlds and agent-based simulation in this book addresses in more detail this rapidly growing field of social modelling). In principle, however, the idea of agent based modelling is independent of the technology of computer simulation. One of the first and most famous agent based models is Schelling's checkerboard model of urban segregation (although the checkerboard may alternatively be considered to be a non-computerized simulation).

Agent based models cope well with two issues that are difficult to model analytically: heterogeneity and configuration of agents. By heterogeneity we mean that the agents not only have different preferences, but also behave according to (possibly qualitatively) different decision rules. Since the model is built from individual agents, the model builder can, in principle, freely postulate different kinds of agents. The ability to take agent heterogeneity into account also means that agent based models can investigate distributional effects. By configuration, we mean properties or behaviour of agents that is dependent on an agent's relative distance to other agents according to some metric. This distance can often, but not necessarily, be interpreted as a spatial distance. Many agent based models (such as cellular automata, of which the checkerboard is an example) are based on a grid, in which the agents' behaviour is dependent on only on the behaviour of their immediate neighbours.

Conclusion

In this chapter we have discussed the general philosophical perspectives on modelling, which we have then related to the special problems of social sciences and the distinctive modelling practices that are in use in the social sciences. Whereas the philosophical discussion on modelling used to be about the general structure of all scientific knowledge, a general trend toward more practice-oriented accounts taking seriously the various uses of models in specific sciences can be discerned in the prevailing philosophical discussion on modelling. Models are seen as mediating between theory and observations, but this mediating role requires models to incorporate content that is not directly derivable from the theory making models autonomous. Model-based reasoning is also surrogative in that it essentially involves manipulation of the model, thus making modelling to some extent analogous to experimentation. Since models are not linguistic entities, the concept of truth has been largely replaced by the concept of representation as the criterion of epistemic achievement. However, it is not clear whether the concept of representation could be used to *explain* this epistemic value.

To this philosophical discussion modelling in the social sciences provides an interesting and challenging problematic of its own. It does not presuppose quantitative orientation to the modelled phenomena or adherence to any kind of nomothetic ideal of science in general. The value of theoretical modelling lies in keeping our reasoning about complex phenomena tractable and open to rigorous scrutiny. Theoretical modelling comes on its own in situations in which natural language and informal reasoning lose their traction, and many social phenomena are undoubtedly of such kind. Models of social phenomena face difficulties arising from openness and heterogeneity of social systems, the lack of experimental controls and paucity of data. However, all models are idealized and a model is good or bad only with respect to a particular modelling goal. Social sciences employ a number of different formal model templates and there are no reasons to suspect that the nature of social phenomena would make such modeling frameworks infertile, quite the contrary.

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