MODELS AS MEDIATORS

Perspectives on Natural and Social Science

EDITED BY

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CHAPTER 1

Introduction

Margaret Morrison and Mary S. Morgan

Typically, the purpose of an introduction for an edited volume is to give the reader some idea of the main themes that will be explored in the various papers. We have chosen, instead, to take up that task in chapter 2. Here we want to simply provide a brief overview of the literature on models in the philosophy of science and economics, and to provide the audience with a sense of how issues relevant to modelling have been treated in that literature. By specifying a context and point of departure it becomes easier to see how our approach differs, both in its goals and methods, from its predecessors.

The use of models in scientific practice has a rich and varied history with their advantages and disadvantages discussed by philosophically minded scientists such as James Clerk Maxwell and his contemporaries Lord Kelvin and Sir George Francis FitzGerald. In fact, it was the use of mechanical models by British field theorists that became the focus of severe criticism by the French scientist and philosopher Pierre Duhem (1954). In Duhem's view models served only to confuse things, a theory was properly presented when cast in an orderly and logical manner using algebraic form. By contrast, mechanical models introduced disorder, allowing for diverse representations of the same phenomena. This emphasis on logical structure as a way of clarifying the nature of theories was also echoed in the early twentieth century by proponents of logical empiricism. This is not to suggest that their project was the same as Duhem's; we draw the comparison only as a way of highlighting the importance of logical form in philosophical appraisals of theories. The emphasis on logic is also significant because it was in this context that models came to be seen as an essential part of theory structure in twentieth-century philosophy of science.

It is perhaps not surprising that much of the early literature on theory structure and models in philosophy of science takes physics as its starting point. Physical theories are not only highly mathematical but they are certainly more easily cast into an axiomatic form than theories in other sciences. According to the logical empiricist account of theories, sometimes referred to as the received view or the syntactic view, the proper characterisation of a scientific theory consists of an axiomatisation in first-order logic. The axioms were formulations of laws that specified relationships between theoretical terms such as electron, charge, etc. The language of the theory was divided into two parts, the observation terms that described observable macroscopic objects or processes and theoretical terms whose meaning was given in terms of their observational consequences. In other words, the meaning of 'electron' could be explicated by the observational terms 'track in a cloud chamber'. Any theoretical terms for which there were no corresponding observational consequences were considered meaningless. The theoretical terms were identified with their observational counterparts by means of correspondence rules, rules that specified admissible experimental procedures for applying theories to phenomena. For example, mass could be defined as the result of performing certain kinds of measurements. One can see then why this account of theory structure was termed the syntactic view; the theory itself was explicated in terms of its logical form with the meanings or semantics given by an additional set of definitions, the correspondence rules. That is to say, although the theory consisted of a set of sentences expressed in a particular language, the axioms were syntactically describable. Hence, without correspondence rules one could think of the theory itself as uninterpreted.

An obvious difficulty with this method was that one could usually specify more than one procedure or operation for attributing meaning to a theoretical term. Moreover, in some cases the meanings could not be fully captured by correspondence rules; hence the rules were considered only partial interpretations for these terms.[1] A possible solution to these problems was to provide a semantics for a theory (T) by specifying a model (M) for the theory, that is, an interpretation on which all the axioms of the theory are true. As noted above, this notion of a model comes from the field of mathematical logic and, some argue, has little to do with the way working scientists use models. Recall, however, that the goal of the logical empiricist programme was a clarification of the nature of theories; and to the extent that that remains a project worthy of pursuit, one might want to retain the emphasis on logic as a means to that end.

[1] A number of other problems, such as how to define dispositional theoretical terms, also plagued this approach. For an extensive account of the growth, problems with, and decline of the received view, see Suppe (1977).

But the significance of the move to models as a way of characterising theories involves replacing the syntactic formulation of the theory with the theory's models. Instead of formalising the theory in first-order logic, one defines the intended class of models for a particular theory. This view still allows for axiomatisation provided one can state a set of axioms such that the models of these axioms are exactly the models in the defined class. One could still formulate the axioms in a first-order language (predicate calculus) in the manner of the syntactic view; the difference however is that it is the models (rather than correspondence rules) that provide the interpretation for the axioms (or theory). Presenting a theory by identifying a class of structures as its models means that the language in which the theory is expressed is no longer of primary concern. One can describe the models in a variety of different languages, none of which is the basic or unique expression of the theory. This approach became known as the semantic view of theories (see Suppes (1961) and (1967); Suppe (1977); van Fraassen (1980) and Giere (1988)) where 'semantic' refers to the fact that the model provides a realisation in which the theory is satisfied. That is, the notion of a model is defined in terms of truth. In other words the claims made by the theory are true in the model and in order for M to be a model this condition must hold.

But what exactly are these models on the semantic view? According to Alfred Tarski (1936), a famous twentieth-century logician, a model is a non-linguistic entity. It could, for example, be a set theoretical entity consisting of an ordered tuple of objects, relations and operations on these objects (see Suppes (1961)). On this account we can define a model for the axioms of classical particle mechanics as an ordered quintuple containing the following primitives $\mathscr{P} = <P, T, s, m, f>$ where P is a set of particles, T is an interval or real numbers corresponding to elapsed times, s is a position function defined on the Cartesian product of the set of particles and the time interval, m is a mass function and f is a force function defined on the Cartesian product of the set of particles, the time interval and the positive integers (the latter enter as a way of naming the forces). Suppes claims that this set theoretical model can be related to what we normally take to be a physical model by simply interpreting the set of particles to be, for instance, the set of planetary bodies. The idea is that the abstract set-theoretical model will contain a basic set consisting of objects ordinarily thought to constitute a physical model. The advantage of the logicians' sense of model is that it supposedly renders a more precise and clear account of theory structure, experimental design and data analysis (see Suppes (1962)).

Other proponents of the semantic view including van Fraassen and Giere have slightly different formulations yet both subscribe to the idea that models are non-linguistic entities. Van Fraassen's version incorporates the notion of a state space. If we think of a system consisting of physical entities developing in time, each of which has a space of possible states, then we can define a model as representing one of these possibilities. The models of the system will be united by a common state space with each model having a domain of objects plus a history function that assigns to each object a trajectory in that space. A physical theory will have a number of state spaces each of which contains a cluster of models. For example, the laws of motion in classical particle mechanics are laws of succession. These laws select the physically possible trajectories in the state space; in other words only the trajectories in the state space that satisfy the equations describing the laws of motion will be physically possible. Each of these physical possibilities is represented by a model.[2] We assess a theory as being empirically adequate if the empirical structures in the world (those that are actual and observable) can be embedded in some model of the theory, where the relationship between the model and a real system is one of isomorphism.

Giere's account also emphasises the non-linguistic character of models but construes them in slightly less abstract terms. On his account, the idealised systems described in mechanics texts, like the simple harmonic oscillator, is a model. As such the model perfectly satisfies the equations of motion for the oscillator in the way that the logicians' model satisfies the axioms of a theory. Models come in varying degrees of abstraction, for example, the simple harmonic oscillator has only a linear restoring force while the damped oscillator incorporates both a restoring and a damping force. These models function as representations in 'one of the more general senses now current in cognitive psychology' (Giere 1988, 80). The relationship between the model and real systems is fleshed out in terms of similarity relations expressed by theoretical hypotheses of the form: 'model M is similar to system S in certain respects and degrees'. On this view a theory is not a well-defined entity since there are no necessary nor sufficient conditions determining which models or hypotheses belong to a particular theory. For example, the models for classical mechanics do not comprise a well-defined group because there are no specific conditions for what constitutes an admissible force function. Instead we classify the models on the basis of their

[2] Suppe (1977) has also developed an account of the semantic view that is similar to van Fraassen's.

family resemblance to models already in the theory: a judgement made in a pragmatic way by the scientists using the models.

Two of the things that distance Giere from van Fraassen and Suppes respectively are (1) his reluctance to accept isomorphism as the way to characterise the relation between the model and a real system, and (2) his criticism of the axiomatic approach to theory structure. Not only does Giere deny that most theories have the kind of tightly knit structure that allows models to be generated in an axiomatic way, but he also maintains that the axiomatic account fails even to capture the correct structure of classical mechanics. General laws of physics like Newton's laws and the Schrodinger equation are not descriptions of real systems but rather part of the characterisation of models, which can in turn represent different kinds of real systems. But a law such as $F = ma$ does not by itself define a model of anything; in addition we need specific force functions, boundary conditions, approximations etc. Only when these conditions are added can a model be compared with a real system.

We can see then how Giere's account of the semantic view focuses on what many would call 'physical models' as opposed to the more abstract presentation characteristic of the set theoretic approach. But this desire to link philosophical accounts of models with more straightforward scientific usage is not new; it can be traced to the work of N. R. Campbell (1920) but was perhaps most widely discussed by Mary Hesse (1966).[3] The physical model is taken to represent, in some way, the behaviour and structure of a physical system; that is, the model is structurally similar to what it models. If we think of the Bohr atom as modelled by a system of billiard balls moving in orbits around one ball, with some balls jumping into different orbits at different times, then as Hesse puts it, we can think of the relation between the model and the real system as displaying different kinds of analogies. There is a positive analogy where the atom is known to be analogous to the system of billiard balls, a negative analogy where they are disanalogous and neutral where the similarity relation is not known. The kinds of models that fulfil this characterisation can be scale models like a model airplane or a mathematical model of a theory's formalism. An example of the latter is the use of the Langevin equations to model quantum statistical relations in the behaviour of certain kinds of laser phenomena. In this case we model the Schrodinger equation in a specific kind

[3] There are also other noteworthy accounts of models such as those of Max Black (1962) and R. B. Braithwaite (1953, 1954).

of way depending on the type of phenomena we are interested in. The point is, these physical models can be constructed in a variety of ways; some may be visualisable, either in terms of their mathematical structure or by virtue of their descriptive detail. In all cases they are thought to be integral components of theories; they suggest hypotheses, aid in the construction of theories and are a source of both explanatory and predictive power.

The tradition of philosophical commentary on models in economic science is relatively more recent, for despite isolated examples in previous centuries, economic modelling emerged in the 1930s and only became a standard method in the post-1950 period. In practical terms, economists recognise two domains of modelling: one associated with building mathematical models and the activity of theorising; the other concerned with statistical modelling and empirical work.

Given that mathematical economists tend to portray their modelling activity within the domain of economic theory, it is perhaps no surprise that philosophical commentaries about mathematical models in economics have followed the traditional thinking about models described above. For example, Koopmans' (1957) account can be associated with the axiomatic tradition, while Hausman's (1992) position is in many ways close to Giere's semantic account, and McCloskey's (1990) view of models as metaphors can surely be related to Hesse's analogical account. Of these, both Koopmans and Hausman suggest that models have a particular role to play in economic science. Koopmans sees economics beginning from abstract theory (as for example the formulation of consumer choice theory within a utility maximising framework) and 'progressing' through a sequence of ever more realistic mathematical models;[4] whereas for Hausman, models are a tool to help form and explore theoretical concepts.

In contrast to these mathematical concerns, discussions about empirical models in economics have drawn on the foundations of statistics and probability theory. The most important treatment in this tradition is the classic thesis by Haavelmo (1944) in which econometric models are defined in terms of the probability approach, and their function is to act as the bridge between economic theories and empirical economics. Given that economists typically face a situation where data are not generated from controlled experiments, Haavelmo proposed using models

[4] Recent literature on idealisation by philosophers of economics has also supposed that models might be thought of as the key device by which abstract theories are applied to real systems and the real world simplified for theoretical description. See Hamminga and De Marchi (1994).

in econometrics as the best means to formulate and to solve a series of correspondence problems between the domains of mathematical theory and statistical data.

The account of Gibbard and Varian (1978) also sees models as bridging a gap, but this time between mathematical theory and the evidence obtained from casual observation of the economy. They view models as caricatures of real systems, in as much as the descriptions provided by mathematical models in economics often do not seek to approximate, but rather to distort the features of the real world (as for example in the case of the overlapping generations model). Whereas approximation models aim to capture the main characteristics of the problem being considered and omit minor details, caricature models take one (or perhaps more) of those main characteristics and distorts that feature into an extreme case. They claim that this distortion, though clearly false as a description, may illuminate certain relevant aspects of the world. Thus even small mathematical models which are manifestly unrealistic can help us to understand the world. Although they present their account within the tradition of logical positivism described above, it is better viewed as a practise-based account of economic modelling in the more modern philosophy of science tradition seen in the work of Cartwright (1983), Hacking (1983) and others. Their treatments, emphasising the physical characteristics of models (in the sense noted above), attempt to address questions concerning the interplay among theories, models, mathematical structures and aspects of creative imagination that has come to constitute the practice we call modelling.

Despite this rather rich heritage there remains a significant lacuna in the understanding of exactly how models in fact function to give us information about the world. The semantic view claims that models, rather than theory, occupy centre stage, yet most if not all of the models discussed within that framework fall under the category 'models of theory' or 'theoretical models' as in Giere's harmonic oscillator or Hausman's account of the overlapping generations model. Even data models are seen to be determined, in part, by theories of data analysis (as in Haavelmo's account) in the same way that models of an experiment are linked to theories of experimental design. In that sense, literature on scientific practice still characterises the model as a subsidiary to some background theory that is explicated or applied via the model. Other examples of the tendency to downplay models in favour of theory include the more mundane references to models as tentative hypotheses; we have all heard the phrase 'it's just a model at this stage', implying that the hypothesis has not yet acquired the level of consensus reserved for theory. The result is that we have very little sense of what a model is in itself and how it is able to function in an autonomous way.

Yet clearly, autonomy is an important feature of models; they provide the foundation for a variety of decision making across contexts as diverse as economics, technological design and architecture. Viewing models strictly in terms of their relationship to theory draws our attention away from the processes of constructing models and manipulating them, both of which are crucial in gaining information about the world, theories and the model itself. However, in addition to emphasising the autonomy of models as entities distinct from theory we must also be mindful of the ways that models and theory do interact. It is the attempt to understand the dynamics of modelling and its impact on the broader context of scientific practice that motivates much of the work presented in this volume. In our next chapter, we provide a general framework for understanding how models can act as mediators and illustrate the elements of our framework by drawing on the contributions to this volume and on many other examples of modelling. Our goal is to clarify at least some of the ways in which models can act as autonomous mediators in the sciences and to uncover the means by which they function as a source of knowledge.

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