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Modelling as a Method of Enquiry

PART I: CHANGING THE PRACTICE OF ECONOMIC SCIENCE

1. From Laws to Models, From Words to Objects

Two hundred years ago, political economy was overwhelmingly a verbal science, with questions, concepts, and a mode of reasoning all dependent on words. As a *science*, classical political economy of the eighteenth and early nineteenth centuries began with individuals, theorized their relations, and posited a few general laws that operated at a community level. One of the few laws that was expressed in mathematics was proposed by the Rev'd Thomas Robert Malthus, who claimed that the growth of population, driven by passions, increased in a way that would inevitably outstrip the more pedestrian growth of food supplies. So, he argued, there must also be checks at work in the world: the numbers of people were kept in

check either through the vices of disease, famine, and war, or by virtue of celibacy or delayed marriage. While such laws might indeed have an iron grip on economic life, it was not thought easy to perceive these laws at work amongst the complicated changing events of everyday life. This created difficulties for the *art* of political economy, namely fashioning policy in line with an understanding of those scientific principles of political economy.[1]

Economics is now a very different kind of activity. From the late nineteenth century, economics gradually became a more technocratic, tool-based, science, using mathematics and statistics embedded in various kinds of analytical techniques.[2] By the late twentieth century, economics had become heavily dependent on a set of reasoning tools that economists now call 'models': small mathematical, statistical, graphical, diagrammatic, and even physical objects that can be manipulated in various different ways. Today, in the twenty-first century, if we go to an economics seminar, or read a learned scientific paper in that field, we find that economists write down some equations or maybe draw a diagram, and use those to develop solutions to their theoretical conundrums or to answer questions about the economic world. These manipulable objects are the practical starting point in economic research work: they are used for theorizing, providing hypotheses and designing laboratory experiments, they are an essential input into simulations, and they form the basis for much statistical work. Economics teaching is similarly bounded: students learn by working through a set of models: some portraying decisions by individuals and companies, others representing the behaviour of the whole economy, and for every level in between. The use of economic models has become habitual in government policy making, in trading on financial markets, in company decisions, and indeed, anywhere that economic decisions are made in a more technocratic than casual way. In economics, as in many other modern sciences, models have become endemic at every level.

The significance and radical nature of this change in economics is easily overlooked. The introduction of this new kind of scientific object – models – involved not just the adoption of new languages of expression into economics (such as algebra or geometry), but also the introduction of a new way of reasoning to economics. And having moved from a verbal to a model-based science, economists no longer depicted their knowledge in terms of a few general, though unseen, laws,

1 Nineteenth-century economists often used the term "principles" in the titles of their treatises on political economy. This term denoted both their theories and analysis of law-like elements in the economic system as well as the appropriate means of good governance (which might have an ethical, even moral, quality). For example, Malthus' laws of population were almost laws of nature (they were based on individual instincts of passion and the need for food, empirical data on population growth, and hypothesized claims about likely growth of food output), while his policy arguments were designed around his understanding of these laws (for example, he was against social security schemes which, in the process of supporting the poor, would interfere with the natural checks on population growth operating within the system see Malthus, 1803).

2 For the twentieth-century development of economics into a tool-based science, see Morgan (2003a).

but expressed it in a multitude of more specific models. As models replaced more general principles and laws, so economists came to interpret the behaviour and phenomena they saw in the economic world directly in terms of those models.[3]

Despite the ubiquity of modelling in modern economics, it is not easy to say how this way of doing science works. Scientific models are not self-evident things, and it is not obvious how such research objects are made, nor how a scientist reasons with them, nor to what purpose. These difficulties of definition and understanding are exhibited in a most concrete fashion in an example that may well be the first such economic model in the history of the field.

The *Tableau Économique* is a wonderful numerical object: a cross between a table and a matrix, it presents an accounting portrait of the French economy (Figure 1.1). It shows the classes of people in the economy (farmers, manufacturers, and landowners) and has a zig-zag pattern of horizontal and diagonal lines between them with numbers on them indicating the amount of goods or money being transferred between the groups of people. It was invented in the late 1750s by François Quesnay, an economist, and physician in the court of Louis XV and thus at the centre of French political life in the mid-eighteenth century.[4] He treated the *Tableau* as a research object, using it to conduct various numerical exercises to explore the possibilities for the French economy to grow via agricultural investment and the subsequent circulation of the surplus created from Nature around the classes of people in the economy. In these exercises, various numbers for the agricultural surplus and the amounts circulated in the zig-zags were inserted, and then added downwards to determine whether such an economy would grow in a stable, balanced way, or if there was some lack of balance in the relations.

The *Tableau Économique*, as one of the earliest models in economics, makes a fine example to introduce a book on models, for it is one of the most celebrated in the history of economics. It can be regarded as the great-grandfather of models in many different economic traditions even while its own content and meaning remain somewhat mysterious. Two hundred and fifty years later, most modern economic models lack the decorative borders (and the dot-matrix qualities that make it look like a needlework sampler hanging on the wall), but are otherwise not so different. Models in economics are still mostly pen-and-paper objects depicting some aspect of the economy in a schematic, miniaturized, simplified, way. The most important point to note about this object, however, is that it was not simply a passive portrait of the economy; rather, it had the internal resources for Quesnay to

3 So, by the early twenty-first century, we find, for example, an account in which financial traders acting on models make markets behave like those models (demonstrating the performativity of economic models; see MacKenzie, 2006), and we find economists in newspaper columns explaining the phenomena of ordinary life by verbally reinterpreting those events as examples of these small worlds depicted in economic models (e.g., Harford, 2008, or Levitt and Dubner, 2005 and their columns in the *New York Times* and the London *Financial Times*). I return to this point in Chapter 10.

4 Examples (for there are several) of Quesnay's *Tableau* are found in Kuczynski and Meek (1972) and in Charles (2003) who discusses the development of the diagram.

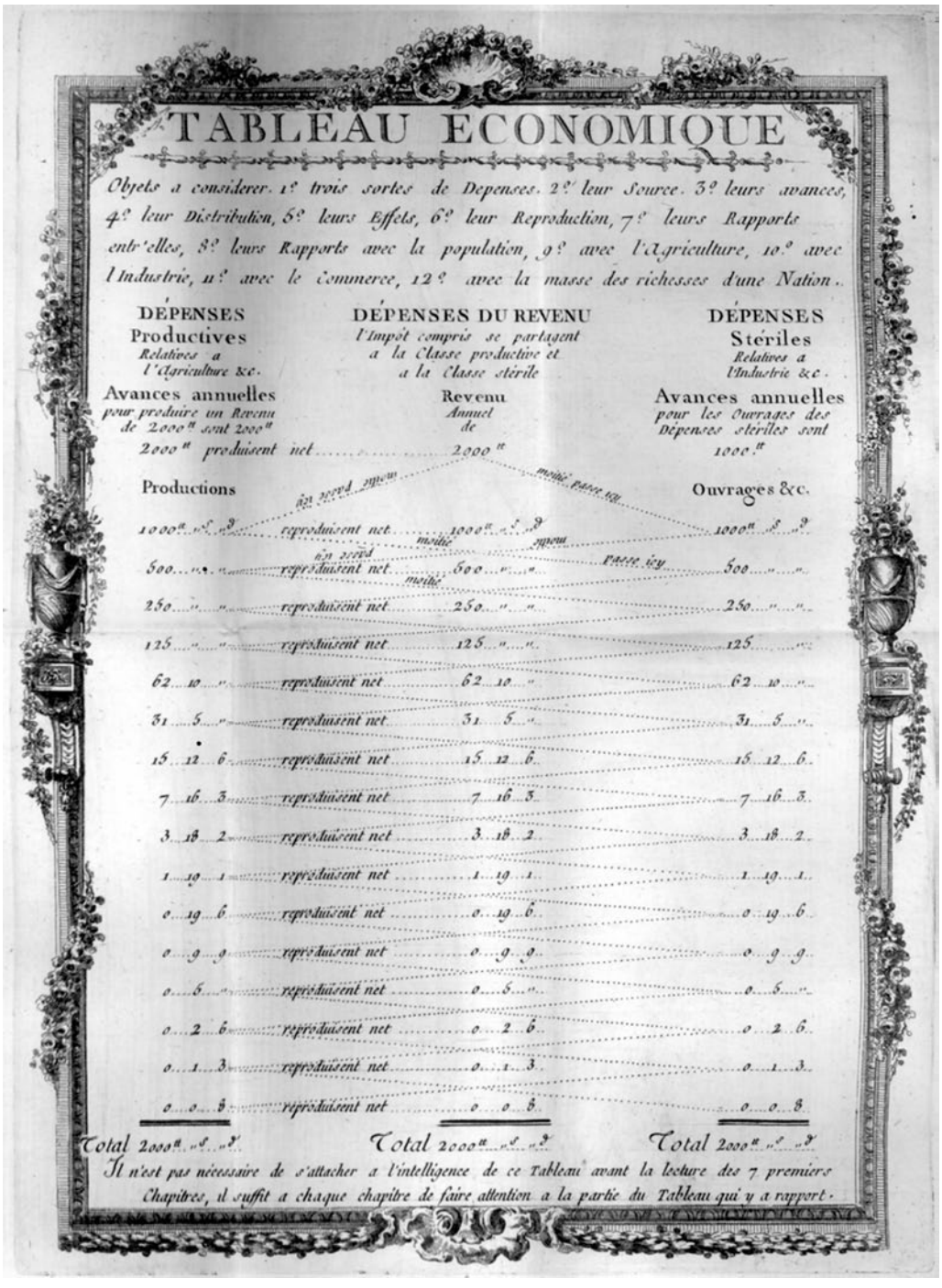


Figure 1.1. Quesnay's *Tableau Économique* (1767).

Source: Private collection. (Reproduced in Loïc Charles [2003] "The Visual History of the *Tableau Économique*". *European Journal of the History of Economic Thought*, 10:4, 527–50, 528.) Reproduced here with thanks to Loïc Charles.

investigate (by his arithmetic exercises) how such an economy as he depicted might work. It is this possibility for manipulation that turns such pictures into models for the economist.

It is also telling that Quesnay's contemporaries found the *Tableau* as difficult an object to interpret and use as do present-day economists. It is very hard for modern economists to understand how the different parts of the *Tableau* relate to each other, or to the economy he inhabited, and to reconstruct exactly how Quesnay reasoned using the object, without the evidence uncovered by historians to explain these things to us.[5] And if we think about how Quesnay might possibly have invented this research object, we can also appreciate that an imaginative and creative mind must have been at work. Such difficulties point to the cognitive and contingent aspects of models: they are objects that embed theoretical and empirical knowledge that later economists will not automatically be able to extract and articulate again, just as non-economists cannot read or use modern economic models without considerable training in the field.

Quesnay's *Tableau* is surely a special object, unique perhaps in its day, but its very specificity raises a number of questions that need answering. If such research objects are so specific to time and place, and if we need to know a great deal about their particularities to see how they work, then how can we characterize the scientific practice of modelling in a general way? This raises philosophical questions: How do economists create such research objects? What exactly is involved in scientific reasoning with such objects? How does working with such objects tell us anything about the world? That is: How should we characterize the making, using, and learning from models as a way of doing science?

The pioneer status of Quesnay's *Tableau* equally raises general historical questions. For while economists now find making and reasoning with such objects the natural way to do economics, we do not have a good account of how that happened, nor understand how it could make such a difference to economics as a science. Reasoning with models is a cognitive process by which economists acquire their knowledge and use it.[6] Sometime in the past, economists had to begin to think with such objects, and learn how to gain knowledge of economics with them, if later generations of economists were to come to reason easily with them and take it for granted as the method they should use.

That process of change: from economists reasoning with words to reasoning with models, is what this book is about. The historical and philosophical aspects of that change cannot be easily untangled. At the meta level, we can point to the considerable but gradual historical shift in the way economists reason, involving elements

5 For recent scholarship that investigates the likely sources of the *Tableau*, its various versions, and how it was used, see particularly Charles (2003) and Van den Berg (2002).

6 Nancy Nersessian (from her 1992 paper to most recent 2008 book) has been instrumental in connecting the literatures of cognitive science with that of the philosophy of scientific modelling. (See also, for examples of different approaches using this connection, papers by Gentner, by Vosniadou, and by Giere in Magnani and Nersessian, 2001.)

of both cognition and imagination that made a big difference to the epistemology of economics, that is, to how economists come to know things in economics. But to understand and appreciate fully the import of these changes, we need to look at the micro level, at the objects themselves. When we look at that level, we find we cannot understand how economists learn things from models without understanding how models are used, nor understand how they are used without understanding how they are built. But why a particular model is built, what questions it is designed to answer, and what uses it is put to, are historically contingent. History and philosophy cannot easily be pulled apart, and the cognitive and imaginative aspects of modelling prove equally sticky in figuring out how economists make and reason with models. These issues – philosophical and historical, involving elements of reasoning and imagination – are explored in the book through the investigation of a number of models of considerable significance, and long life, in the history of economics. It is by paying careful analytical attention to how these small objects are made and used in economics that we can understand the import of the big changes in economics. They provide the materials for both a naturalized philosophy of modelling in economics and a historical account of the naturalization of models in economics.[7]

2. The Naturalization of Modelling in Economics

Though the important historical and philosophical changes in economics are difficult to understand separately, a broad chronology for the historical development of modelling over the last 200 years can be outlined. There are three moments of time that are important. To begin with, we can find a few isolated examples of models in the late eighteenth and early nineteenth centuries and so call this period the prehistory. We then find, in the late nineteenth century, a first generation of modellers: a very few economists who regularly made and used such research objects. The second generation of modellers, the real developers of the method of models, emerged during the interwar period. Modelling then became widespread through economics only after the mid-twentieth century.

To make this history more concrete, and to get a real feeling for what these research objects are, I introduce a number of significant examples here. If we begin with the 'prehistory' of models, we find that not only does Quesnay's *Tableau Économique* exist as an object out of its time in the eighteenth century, but there

7 It is appropriate here to refer to three parallel investigations. Nersessian (2008) comes to the topic of 'model-based reasoning' from cognitive science and philosophy of science, and combines mental models, narratives, experiments, and reasoning in her account of the history of physics. Ursula Klein (2003) uses history and philosophy of science and semiotics to explore the nexus of paper tools, models, and experiments that created a shift of scientific reasoning and practice in chemistry (see also Klein, 2001). Their two accounts share many of the elements of my own project for economics, though we have put them together in somewhat different ways. Meli (2006), in another parallel, discusses how the science of seventeenth-century mechanics depended on reasoning with objects.

(a)

Now if no rent was paid for the land which yielded 180 quarters, when corn was at 4*l.* per quarter, the value of 10 quarters would be paid as rent when only 170 could be procured, which, at 4*l.* 4*s.* 8*d.* would be 42*l.* 7*s.* 6*d.*

20 qrs.	when	160	were produced, which at	£4	10	0	would be	£90 0 0
30 qrs.	.....	150	.....	4	16	0	.....	144 0 0
40 qrs.	.....	140	.....	5	2	10	.....	205 13 4

Corn rent[1] would increase in the proportion of { 100, 200, 300, 400 } and money rent in the proportion of { 100, 212, 340, 485 }

(b)

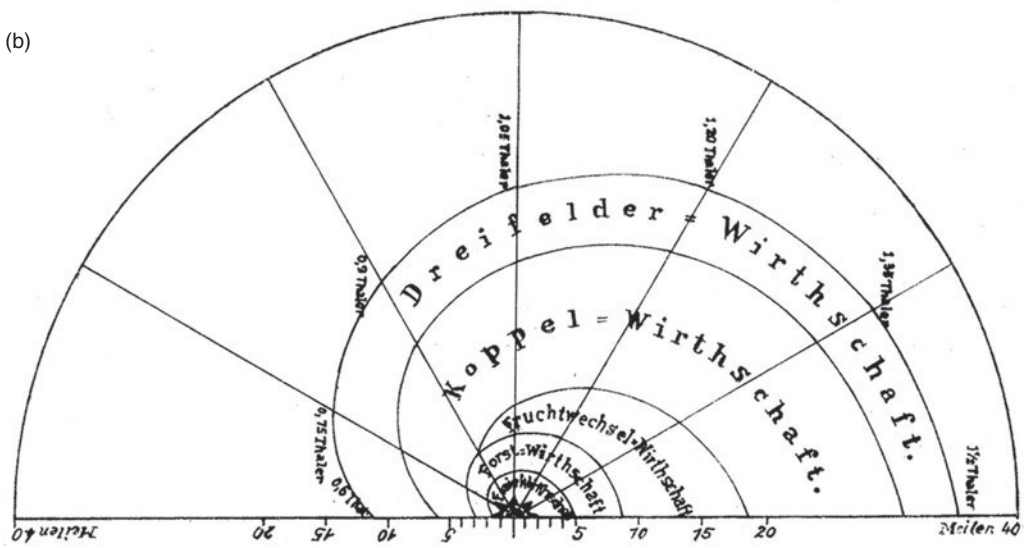


Figure 1.2. The Prehistory of Models.

(a) Ricardo's Farm Accounting (1821).

Source: Piero Sraffa: *The Works and Correspondence of David Ricardo*. Edited with the collaboration of M.H. Dobb, 1951–73. Cambridge: Cambridge University Press for The Royal Economic Society. Vol. I: *Principles of Political Economy & Taxation*, 1821, p. 84. Reproduced by permission of Liberty Fund Inc. on behalf of The Royal Economic Society.

(b) Von Thünen's Farming Diagram (1826).

Source: Johann Heinrich von Thünen, *Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie*, Hamburg, 1826. Reprinted facsimile edition 1990. Berlin: Academie Verlag, p. 275.

are also very few further cases in the early nineteenth century. One is provided by a table of farm accounts developed by the English economist David Ricardo (1821) to explain how income gets distributed in the agricultural economy (one element of his table is shown in Figure 1.2a). Another is the diagram (in Figure 1.2b) of farm prices in relation to distance from towns, drawn by the German agriculturalist Johann von Thünen (1826), depicting an idealized abstract, landscape but with numbers drawn from his experience of farming at his own estate of Tellow.[8] These three objects – the *Tableau*, the accounting table, and the spatial diagram with numbers – each designed to show how the agricultural economy worked, jut out awkwardly from the sea of words that surround them in this early period of economic science.

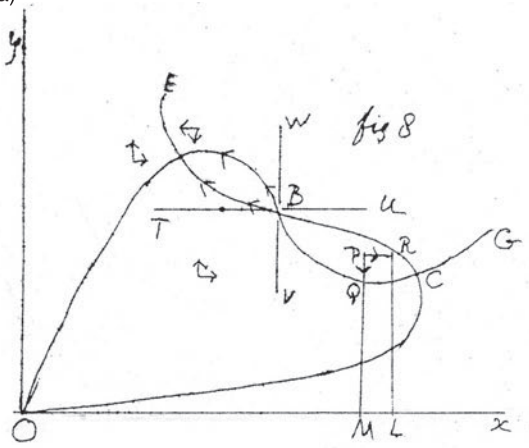
In the late nineteenth century, we begin to see more regular occurrences of these objects we are calling models, but we may also notice that the few economists involved felt they had to justify their creation and usage of these odd research objects that they had invented to help them in their analysis. They did not yet have the concept or label of models and were indeed quite self-conscious about this activity. Three important examples epitomise this first generation of models and modellers and their understanding of the role of models. In 1879, the British economist Alfred Marshall began to draw little diagrams to explain more clearly how two countries trade with each other, in this case the curves depicting the offers of German iron for English cloth and vice versa as relative prices change (Figure 1.3a).[9] Marshall thought that such diagrams were useful if they could be illustrated with examples from economic life (and then he often presented them in his footnotes), but that if such pieces of mathematics were not useful, they should be burnt! In 1881, the Irish economist Francis Edgeworth outlined a somewhat different diagrammatic perspective on exchange relations (Figure 1.3b) to figure out the range of possible contracts that Robinson Crusoe might strike with Man Friday to gain his help in cultivating their island economy. Not being sure how to refer to this way of reasoning, he labelled his analysis with the diagram as offering a "representative particular" argument (see Chapter 3). In 1892, Irving Fisher, an American economist, designed and constructed a hydraulic mechanism to represent, explore, and so understand the workings of a mini-economy, one with only three goods and three consumers (Figure 1.3c).[10] He accompanied this work with an outright

8 Von Thünen's original contribution appeared in 1826; an English translation of part of the study became available in 1966, with a useful introduction. On different interpretations of his modelling project, see Judy Klein (2001, pp. 114–6), who reproduces his diagram and discusses it as a measuring device, and Mäki (2004), who analyses it as a theoretical model.

9 This was the first appearance of these curves in the history of economic theorizing about trade relations, on which Humphrey (1995, p. 41) comments: Marshall "by crystallizing, condensing and generalizing earlier insights into a powerful yet simple visual image" was able to create an object that made these relations "transparent". Marshall's 1879 diagrams and discussion were finally published in an edition of his early works edited by Whitaker in 1975, and this diagram provided the logo for the Charles Gide conference at which some parts of this paper were first presented. Marshall's views of mathematics are discussed by Weintraub (2002).

10 Fisher's thesis of 1891 was published in 1892 and republished in 1925, displaying a photograph of the mechanism in the frontispiece labelled "model of a mechanism".

(a)



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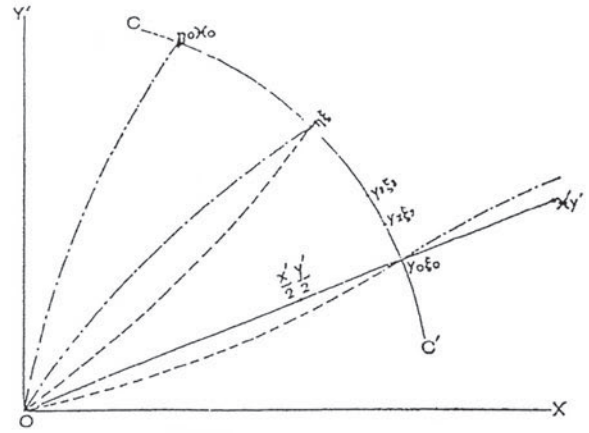

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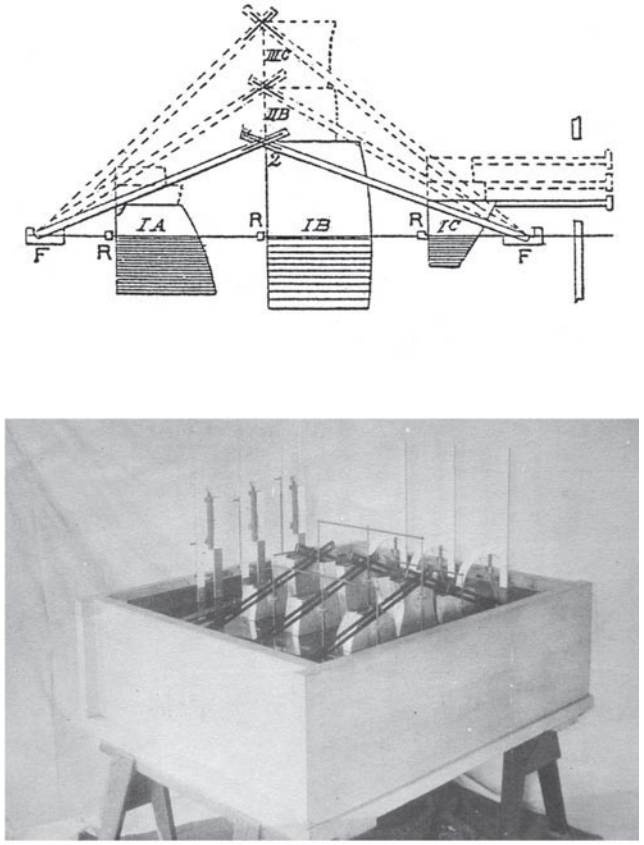

Figure 1.3. First-Generation Models.

(a) Marshall's Trade Diagram (1879).

Source: Alfred Marshall, "Pure Theory of Foreign Trade". Privately printed 1879, Figure 8, Marshall Library, Cambridge. (Reprinted, London: London School of Economics and Political Science Reprints of Scarce Tracts in Economics, No. 1, 1930). Reproduced with thanks to Marshall Library of Economics, Cambridge.

(b) Edgeworth's Exchange Diagram (1881).

Source: F. Y. Edgeworth, *Mathematical Psychics*. London: C. Kegan Paul & Co., 1881, Figure 1, p. 28.

(c) Fisher's Hydraulic Machine and Its Design (constructed 1893 from 1892 design).

Source: Irving Fisher, *Mathematical Investigation in the Theory of Value and Price*. Thesis of 1891/2. New Haven: Yale University Press, 1925. Frontispiece and Figure 9 on p. 39. Reproduced with permission from George Fisher.

defence of these research objects – mathematical, graphical, and real machines – that he designed and used for his economic analysis.

It seems reasonable to locate these three economists in the first real generation of model-makers, and their self-consciousness about their research objects as indicative of this moment of change. This late nineteenth century moment was noticed later on by Arthur Pigou in 1929, who cleverly understood the diagrams and equations we see in these examples as "tools", labelling Edgeworth as a "tool maker" and Marshall as a "tool maker and user". For Pigou, these objects were "pieces of analytic machinery", "thought-tools", or even "keystones".[11] And because economics is now dependent upon such research objects, all of these examples can today be understood as models, though, neither in the prehistory period, nor in this late nineteenth century moment, would economists have recognised them as such or used the label.

It was in the 1930s that economists really 'discovered' the idea of models. It was in that decade that these objects became conceptualized, gained the label 'model', and a fuller understanding of their usefulness developed. Two economists played an important role in this transformation, thus sparking the wider deployment of the label, notion, and usage of models in economic analysis. In 1933, in the depths of the Great Depression, the Norwegian economist Ragnar Frisch developed one of the first mathematical models of the business cycle. Because it had certain features, particularly the possibility to simulate a cyclical pattern, Frisch's "macro-dynamic system" created a new recipe for future business cycle models (see Boumans, 1999 and Chapter 6, this volume). As a recipe, it formed the basis for the first econometric model of a whole economy, built by the Dutch economist Jan Tinbergen in 1936 (1937), to see how to get The Netherlands out of the Depression. This object embedded a theory of the business cycle into the mathematical form, along with statistical information from the Dutch economy in the numbers (or parameters) of the equations. These two economists won the first Nobel Prize for Economics in 1969 for this model-based research; one of Tinbergen's model equations and a schema (from his slightly later US model of 1939) are shown in Figure 1.4a, while Frisch's model is shown later in Figure 1.6.

Tinbergen was also largely responsible for transferring the term 'model' in the early 1930s from physics, where it had usually referred to a material object, into economics to refer to the statistical and mathematical objects that he and Frisch were then developing.[12] So by the middle 1930s, the label 'model' had come into use,

11 See Pigou's lecture of 1929 (in his 1931), particularly pp. 2–8. Joan Robinson (1933) is more usually noted for introducing the notion of the "tool box of economics", but she was following Pigou, whose discussion, and prose, is more effective. Pigou's idea of tools was quite broad – it included not just models, but also the concurrent development of mathematical and statistical techniques. I return to the issue of "keystones" in Chapter 10.

12 Ludwig Boltzmann had defined the term 'model' in the sense of a material object model, in what has become one of the classic articles on models in the 11th edition of the *Encyclopaedia Britannica* (1911). Boltzmann there provides a good view of nineteenth-century scientists' sense of the word. Boumans argues that it was Ehrenfest who probably broadened the scope to apply to mathematical objects, and since Tinbergen was his assistant in the mid-1920s, this is a likely route for the transfer of the term into economics (see Boumans, 2005, chapter 2) though there are also scattered uses of the term by other economists in the 1920s.