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Prologue: Model building yesterday versus today

> An econometrician's job is to express economic theories in mathematical terms in order to verify them by statistical methods, and to measure the impact of one economic variable on another so as to be able to predict future events or advise what economic policy should be followed when such and such a result is desired.
>
> This definition describes the major divisions of econometrics, namely, specification, estimation, verification, and prediction.
>
> *Specification* has to do with expressing an economic theory in mathematical terms. This activity is also called *model building*. A *model* is a set of mathematical relations (usually equations) expressing an economic theory. Successful model building requires an artist's touch, a sense of what to leave out if the set is to be kept manageable, elegant, and useful with the raw materials (collected data) that are available.
>
> Stefan Valavanis [1959, p. 1]

As beginning economics graduate students soon discover, most of their time will be spent learning about model building. As James Heckman observes, 'Just as the ancient Hebrews were "the people of the book", economists are "the people of the model"' [2000, p. 46]. But, students will also discover that there will be little explicit talk about how best to go about building models. Instead, they are seemingly expected to learn inductively by example. Over the last fifty or sixty years of educating modern economists, most things have not changed much. However, what one is supposed to think constitutes a model and what one is supposed to think a model can or should do has changed dramatically. Originally, the idea was that common principles of economics could be illustrated with physical models, but later it was that they could be represented by mathematical models.[1] Representative models were

[1] See, for example, Stefan Valavanis [1959].

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spearheaded mostly by the work of Jan Tinbergen in the 1930s.[2] In the last two or three decades, the representative notion of models seems to have been lost. Today, models are objects of research on their own, without explicit recognition of any underlying principles that someone might wish to discuss without reference to a specific model. Stated another way, models today are easily viewed as simple instruments to be used to measure the economy and hopefully to learn about the economy in a trial-and-error manner.[3] Unfortunately, by viewing models as mere instruments, students have been cut off from the origins of ideas underlying the models and hence from an opportunity to learn about those ideas.

1. Representative models of yesterday

Until the 1980s (or in some cases, the late 1970s), almost all graduate students were taught to think of models as particular representations of more general theories – for example, the ISLM model of John Maynard Keynes's *General Theory* or Paul Samuelson's models of Ricardian economics. That is, models were always models *of a theory*. The mechanics of such representations involve three separate decisions that the model builder would have to make: (1) choose the basic behavioural principles or theory that one is going to build a model of, (2) choose how each principle or element of a theory is to be represented (usually, this is a choice of the mathematical tools to use) and (3) choose how to specify or 'calibrate' the model's elements if it is to be applied to observable data.

1.1. Choosing basic principles or a theory

Before the 1980s, it was common for students at all levels to be assigned study and exam problems (or questions) in a verbal or literary form that required the students to begin by deciding how to translate the verbal problem into a mathematical problem to solve. In other words, they had to begin by building a model of the problem such that, should they obtain a solution to the model, they would thereby have solved the assigned verbal problem or answer the assigned verbal question. As such, the model *represented* the verbal problem or question. This way of looking at models was very common in other fields as well. In particular, economics students were being taught to look at models in

2 See Marcel Boumans [2005].
3 See Mary Morgan and Margaret Morrison [1999].

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the same way that most engineers used models. For example, designing an airplane or an automobile, the engineer might choose to build a scaled-down model to test in a wind tunnel. Doing so would necessarily involve selecting those attributes to ignore as being unimportant and those that are important (and usually, the latter are ones that also do not depend on size whenever it is a scale model). For wind tunnel tests, it is usually just a matter of accurately representing the shape. Today, of course, design engineers would more likely use a computer model and test it based on programmed physics principles. In either case, the test model involves simplification (e.g., using clay rather than metal in the case of wind tunnels). If carefully done, one can learn whether some new innovative idea has a chance of working and thus producing the desired aerodynamic results. No conclusions can be reached for attributes left out, of course.

In economics, things are usually more intellectual than mechanical, but models still involve selection and simplification. At minimum, the first step is to decide what variables in the theoretical explanatory principle are to be quantified and then which of those are to be endogenous (i.e., to be explained) and which are to be exogenous (i.e., not explained but considered to play an important role, perhaps as constraints).

Keeping things as simple as possible at this early stage – and in order to illustrate how model building was done in yesteryears – let us consider an elementary textbook example, one about explaining supply or, more particularly, the output of a single-factory firm that produces standard-size garbage cans. Let us say we are interested in the extremely simple explanatory principle that says the volume of output depends directly on how much labour it employs. To build a model, then, we first say that the daily output of cans will be represented with a scalar number X that stands for the number of cans that go out the door each day. Producing the cans, let us say, takes an input of a quantity of homogenous labour (no special skills possessed by anyone); this will be represented by the scalar L that stands for the number of man-hours worked each day. The simplest explanatory principle would be to say that these variables are positively correlated. Of course, there may be other factors that matter as possible constraints – such as the size of the factory, the number of tools available, and so forth. However, for the purposes of this very simple explanatory principle, these factors will not be explained but are still assumed to matter and hence will have to be recognized. The factory size will be represented by a scalar Z that identifies the square meters of the factory, and the number of tools will be represented by a scalar K. So far this is a fairly weak explanation since it only claims that the relationship is a positive correlation. However, it does claim

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implicitly that if the size of the factory or the number of tools available were to change, then output X could change without any change in the number of labour-hours utilized, contrary to our initial explanation.

Although it is not trivial, all that is said with such a simple behavioural theory of the daily supply of one firm is that *if* the factory size and the number of tools utilized do *not* change, we would expect the daily output to *not* change – but *only if* the quantity of labour employed does *not* change. Those wanting to say something more might choose to build a model of this behavioural theory or they might instead just recognize more variables. For example, ordinary labour is obviously not homogenous regarding skills; there can be more than one type of tool needed to produce garbage cans, and while factory size is important, the configuration of that size might matter, too. However, including these would involve adding more variables and would thus change our original explanatory principle – and as such, we would no longer be building a representative model of the original simple explanation. That is, it would not be just a different model; it would represent a different explanation. For now, let us stick with the very simple explanation with which we began.

1.2. Choosing tools of representation

If we do continue to keep things very simple (i.e., maintain homogeneous labour and one type of tool, etc.) and want to build a representative model, the usual first step is to express the basic input-output relationship as something like $X = f(L, K, Z)$ with $\Delta X/\Delta L > 0$ (a simple expression of a positive correlation). This would not say much more than the verbal statement at the beginning of this example, of course. To say more, we would need to add assumptions about the nature of the $f(\bullet)$. We could assume it is a simple linear function, such as $X = \alpha L + \beta K + \gamma Z$ with $\alpha > 0$. Most important, as long as every quantity recognized here is positive, it does still represent the verbal idea of the simple explanatory principle with which we started.

More interesting theories that one would more likely want to go about representing with models would usually involve many different relationships between the variables in question (e.g., simultaneous or lagged) and hence many more functions that would also have to be included in the representative model. For example, K could be considered an endogenous rather than exogenous variable and explained rather than taken to be a given. Going further, one might like to consider production technology to be a matter of choice. This choice might be a matter of changing the tools used or the way the tools are used.

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1.3. Specifying or calibrating the functional elements of models

One important thing to keep in mind about mathematical functions used to represent economic relationships – such as the one discussed earlier concerning the supply output of one firm – is that some of the quantities represent observable variables (e.g., X, L, K and Z) and others are not observable because they are mathematical artefacts of the type of equation used. That is, in the simplest case, the coefficients α, β and γ are there because we have assumed a linear relationship. Had we assumed the relationship to be quadratic, many more coefficients would have to be dealt with, even though the number of observable variables would be the same.[4] The coefficients usually represent presumed *parameters* of the relationship being modeled, and thus there is always the possibility that they are themselves either Nature-given or, in the case of the supply function, technology-given. If at some time in the future the technology dramatically improves, some of these parameters might increase or decrease.

Sometimes we have independent knowledge of the size of such parameters. Perhaps we know that, given K and Z, an individual worker will produce twenty cans in one day. At other times we do not know exactly the values of the parameters, but we can guess. In this case, depending on the purpose for building the model, we might make several observations of X and L over several days and try out our guess to see if it fits the observed data. Doing this amounts to a form of calibration [see Kydland and Prescott 1991, 1996] and is much like what is done in some branches of engineering where measuring instruments need to be calibrated. Sophisticated engineering aside, even more mundane cases would be the calibration that always has to be done to make sure a magnetic compass points to the real North Pole rather than the magnetic north pole, or the calibration of a thermometer by setting its 0°C where it reads when inserted into ice water and its 100°C where it reads when inserted into boiling water.

2. Theoretical versus empirical models today

In what follows I will restrict the use of the word 'model' just to empirical models based on data from an actual economy. Such models will often be distinguished from information in the form of what may be called theory. In this simplistic

4 For more on this, see chapter 6 of Boland [1989].

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> viewpoint a theory starts with a set of consistent assumptions and then produces logical consequences from them in a form relevant to economic questions. On some occasions this theory is best expressed using very sophisticated mathematics, 'best' here meaning the most rigorous and compact although not necessarily the easiest to understand. To have something easier to use and to interpret a simple version of the theory can be formed, an approximation, and this is sometimes called a theoretical model. However, I will call all such constructs just 'theory'. I will take the attitude that a piece of theory has only intellectual interest until it has been validated in some way against alternative theories and using actual data.
>
> Clive Granger [1999, p. 6]

So far I have been discussing how models were viewed before 1980 when students were usually expected to translate their verbal study questions into mathematical questions. Today, judging by the most popular theory textbooks, few students are expected to do such a translation (except, perhaps, those being trained in the old, 1960s–1970s Chicago School tradition). And so, all this so far might seem strange to some readers since, when opening articles in the major mainstream journals, there is often no discussion of non-mathematically presented explanatory principles.

What students today are taught is to distinguish between 'theoretical models' and 'empirical models'. Theoretical models (which will be discussed in Part I) are basically what one would get if one were to follow the step-by-step process discussed earlier, but usually for such models the process has not been explicitly stated – only the final result is revealed. How they were constructed is now rarely discussed. That is, a theoretical model is implicitly representative of some verbal explanatory theory, but that verbal theory is not at issue and so is rarely separately discussed.

Empirical models (to be discussed in Part II) can range from simple linear or log-linear single equations (where the coefficients are estimated with the available data) to more elaborate multi-equation models. While simple empirical models have been developed for more than seven decades, more elaborate versions began to appear in the 1970s and 1980s, which were focused on the readily available labour or financial data. Today there are many more sources for data and many different types of data available. Representative empirical models are usually designed to represent either some behavioural theory or just available data – rarely do they do both, but it is not impossible.

Today, representative empirical and theoretical models still have a common first step. Both begin with the identification (if only implicitly) of a list of relevant variables. Although the theoretical models will

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always have their list separated into those variables that are endogenous and those that are exogenous, some empirical models may let the question of exogeneity be determined with an appropriate test of the data. However, they can differ in terms of how the list of relevant variables is arrived at.

Representative theoretical models are already focused on or limited by one or more explanatory principle or behavioural theory that as such asserts causes and effects and thus identifies which variables are exogenous versus which are endogenous. Builders of representative empirical models need not be so limited. Their first step is usually to examine a body of data and then decide what to identify as relevant variables. This may be guided by *a priori* principles or theories but need not be. As Clive Granger [1999, pp. 16–17] puts it:

> One can find advocates at [two] extremes, some saying that theory contains the only pure truth and so has to be the basis of the model, even to claiming that all 'residuals' have to have theoretical explanations, leaving little place for stochastics, uncertainty, or exogenous shocks to the system. At the other extreme, some econometricians have thrown up their hands in despair when trying to find a use for theory and so build 'atheoretical' models based just on examination of the data and using any apparent regularities and relationships found in it. Most applied economists take a middle ground, using theory to provide an initial specification and then data exploration techniques to extend or refine the starting model, leading to a form that better represents the data.

He goes on to note [p. 18], however,

> If no theoretical basis is used and if a complex modeling situation is considered, with many possible explanatory variables and plenty of data, the possibility of 'data-mining' or 'data-snooping' becomes a problem, particularly now that computing is both fast and cheap. Clearly evaluation procedures need to be applied using data sets that were not involved in the model selection and estimation process, either 'out-of-sample' in cross-section or panel analysis, or 'post-sample' in time series. It is not sufficient to merely show a statistic that indicates that one model performs better than others; a correct hypothesis test is required. . .

What is important in any representative empirical model is to keep in mind the purpose for the model. Some empirical models are intended to help with forming policy formation. Others are intended to be tests of competing behavioural theories or principles. Some think the purpose of building empirical models is to learn inductively from the data, but if strictly interpreted, this notion is based on a false theory of learning.[5] In any

[5] For more on this, see chapter 1 of Boland [2003].

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of these ways of using models, it is easy to see them being used as research or policy instruments.

3. Models as instruments

> While theoretical principles . . . have to form a consistent system, instruments are built on the basis of a compromise of often incompatible theoretical and empirical requirements. Theories should be true, or at least not false, but models have only to fulfill their goal satisfactorily.
>
> Marcel Boumans [2005, p. 20]

While it is hard to deny that economic models can be used as instruments; whether that is profound is another matter. That models are often used as instruments does, however, seem to divorce them from the old (pre-1980s) view of the theory-model relationship. That is, today, models are no longer thought to be merely designed to be simplified representations of some given theories – instead, they might be designed from the start to be instruments. For this reason, such models will be of interest on their own, and behavioural theories may play what seems a secondary role in the design of the instrument-model.

3.1. Building models to serve as instruments

One does not build tools or instruments only for the sake of building tools or instruments; one must have a purpose or goal. But, of course, theoretical and empirical model-instruments will usually have different purposes. That is, which type of model one would build depends on one's purpose. Let me explain.

3.1.1. ***Theoretical models as instruments:*** Beginning in the mid-1970s (as I noted in the Preface), 'theoretical' became synonymous with 'mathematical'. Of course, it is easy to see that empirical models also use mathematics – so, today, 'theoretical' merely indicates that a model's intended purpose may not necessarily involve previously observed data – and in some cases, it may mean not having anything to do with observable data. There are many possible purposes or aims for building theoretical models. One suspects that in the early days, particularly after World War II, building theoretical models was done for purely mathematical reasons. That is, for the purposes of showing that, by mathematizing one's preexisting verbal theory, the theorist would be able to more easily prove the

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various theoretical claims being made with that theory regarding policy or simply being made for our understanding. Historically, perhaps since the time of Léon Walras and the later promotion of his general-equilibrium analysis in the late 1930s, there has been a continuing effort to prove that Adam Smith was right. Most of this effort involved building general-equilibrium models and proving the theoretical existence of an equilibrium set of prices [cf. Hahn 1973]. This involved so-called existence proofs that were based on the axiomatization of Walras's general-equilibrium analysis. In this case, the purpose of the model building would be to create a logical tool to perform the intended proof.

Today, an obvious purpose for building some theoretical models is to try out new mathematical techniques.[6] In many cases, the purpose is just to develop an alternative to an existing theoretical model using a different technique (perhaps one more aesthetic or less demanding or more rigorous, etc. to prove the same theoretical proposition). In recent years, the primary new mathematical technique has involved game theory. Fifty or sixty years ago, the new technique being promoted was ordinary set theory. Critics often complain that this changing of techniques is only an issue of the latest changing fads – but, of course, it need not be.

In a more practical way, some theoretical model building is done to figure out a policy for governments to employ to achieve desired aims. How can the government reduce unemployment, inflation, and so forth? What damage might be done with some proposed policies? What are the relevant constraints on any particular proposed policy? What are its limitations? Such questions have been at the core of economics since before the time of Adam Smith and long before theorizing was focused on building theoretical models.

A considerable literature has developed in recent years concerning the history of building models to serve as instruments for economic measurement.[7] The instruments can range from the theoretically simple consumer index number or national income accounts measures to the possibly more sophisticated measure of such a thing as the elasticity of demand for a particular product. The purpose in all cases is to have an autonomous (uncalibrated) instrument – that is, one that makes sense before being

6 See the survey results in my 1986 article with Herbert Grubel for how such use of mathematics was critically viewed then.

7 For example, see Mary Morgan [2001] as well as the remainder of the *Annual Supplement* to Volume 33 of *History of Political Economy* journal.

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applied to empirical data. Few graduate courses spend much time on the issue of developing measures – too often it is simply taken for granted.

Now, the most obvious use for theoretical models is as tools to simulate an economy for the purpose of deriving, say, optimal fiscal or monetary policies. In this case, one would, for example, represent notions of aggregate demand and supply functions – including notions about the labour market and demands for investment or liquidity preference, and so on. With such a model and its identification of significant parameters, one could try to calibrate these parameters so that one could plot the effects of various changes in the exogenous policy variables that a government might be able to control, such as the interest rate, the tax rates, and so on.

The common factor in all of these theoretical models is that their development usually comes before any consideration of data for the purpose of specification or calibration. Questions about what should be the optimal governmental policies need to be addressed before attempting to simulate an economy for the purposes of evaluating the policies. Obviously, calibration based on empirical data is the last step in the development of a simulation model that might be used for what Finn Kydland and Edward Prescott [1996] call a 'computational experiment'. One question that still might be asked is whether consideration of empirical data should come before or after one develops a theoretical model. On the one hand, some think one must always consider data before forming a theoretical explanation. On the other hand, theoreticians will counter that, even when looking at data, one will implicitly, if not explicitly, be presuming some existing theoretical model. I will not try to resolve this dispute here, but in Chapter 12 it will be used as a case study concerning how one goes about choosing a model-building method in macro-econometric studies.

3.1.2. *Empirical models as instruments:* Those who think consideration of empirical data should come before theory development have been around for a long time – perhaps going back to the seventeenth century, the days of Galileo or Francis Bacon. The basic notion is that one would examine the available data and look for patterns and then form a conjecture as to the causes of the pattern. For some, it is merely a matter of identifying patterns. Critics, however, point out that one can be a little too selective in identifying patterns and see only what one wants to see. Or, in a similar vein, one could just be engaging, as Granger said, in 'data mining' – perhaps to justify one's prior prejudices.

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