Chapter 1: On the Usefulness of Imperfect Models

I. Less than Perfect Models

Many advanced economic texts give students the impression that economics is a field of applied mathematics and that its conclusions and predictions are as precise as those associated with pure logic and mathematics. They forget to mention that there is a difference between pure mathematics—which does not make claims about the world beyond the intangible sphere of that field of study—and science, which makes claims about the world. Mathematical results are true in the logical sense of being generated by the rules of logic. Some propositions have relevance for the quantifiable parts of the real world, but many do not. Economists use models that are believed to reflect essential features of real-world choice settings as an aid to better understanding how well-functioning markets operate. If the models used are "perfectly realistic," then the inferences drawn from them will all be present in the real world. However, if the models are less than perfectly realistic—but nonetheless characterize important features of the choices being made—then many, but not all, of the inferences drawn will be evident in the world.

In both cases, the inferences drawn, if they have been carefully undertaken without mistakes, are true in the logical or mathematical sense, but economic deductions may or may not be evident in the real world. The models used are never perfect. They are not the world; they are models of the world.

It is generally understood that many features of the world have been left out of all such models, including those used in other fields of research. Thus, the results are often said to hold ceteris paribus—other things being unchanged. That caveat, however, covers a lot of ground that is rarely discussed in economic classes.

Most models intentionally leave out many details so that particular aspects of the phenomena of interest (as with market prices) can be better understood. However, other factors are unintentionally left out because the theorist does not know all the factors that might influence choices in the settings modeled—some of which may change frequently or very among persons or social settings. The latter implies that all models are imperfect. It also implies that the "other things being equal" part of many economic conclusions is untestable—a dodge rather than an analytical result. The universe is always in motion.

Nonetheless, imperfect models can be very useful. Even imperfect models can increase our understanding of economic and other relationships, and also of their consequences for larger scale phenomena such as a solar system or well-functioning markets. The degree to which a model is "good" or not or "useful" is partly an empirical question (how well it explains the phenomena of interest) and partly a matter of judgement (does it increase our understanding of fundamental relationships in a manner that seems plausible). With respect to markets, a good model's implications should accord well with what is already known about the phenomena of interest (such as the purchase and production of goods and services). It should also have implications that are a bit novel—which imply previously unnoticed or unknown relationships. A useful model may make it easier to understand the phenomena of interest, even if its implications are not always borne out. It may also point out important relationships that would otherwise have been missed, given the complexities of many real-world settings.

Indeed, insofar as models are known to be less than perfect, one expects differences between their logical implications and the real world—the phenomena being modelled. Thus, differences, per se, cannot be used to reject a model, unless it also fails to advance our other interests in clarifying underlying processes and increasing our understanding.

The inferences drawn from mathematical models may be logically correct, but less than perfectly true, without being worthless. For example, a model may account for half of the variation in a variable of interest (as with prices, outputs, rates of innovation, etc.), rather than all of it—a common result for statistical estimates of the core neoclassical models. However, that a relatively simple model of consumer and firm choices can account for even half of the variation in prices through time is actually remarkable, and often quite useful—especially when no more accurate or general models are available. "Useful" models shed useful light on the phenomena of interest.

The understandings generated often facilitate the development of better models—models with logical and mathematical implications that better accord with the real world. They may also be used to make decisions in settings where even greater uncertainty would exist about the consequences of particular choices. A good model might, for example, account for the average or typical result rather than all the unusual ones.

Simplified models are also useful as a method of getting general ideas across to students—because if the assumptions and reasoning is clear, students can get a rough understanding of a broad range of phenomena far more easily than possible with a catalog of special cases.

Having mastered a relatively straightforward model often facilitates the next step in their learning--mastering more sophisticated models.

All the models developed in this text are "good" in the above senses. They are engines of analysis, whose logical implications are reasonably faithful to the phenomena modelled. They provide relatively clear understandings of the choices and processes that generate market outcomes, without being perfectly accurate in all cases. They are not trivial. They are products of hard work by hundreds of talented persons over the past three centuries who were interested in improving our understanding of the most important factors that determine how market networks operate.

The models and their implications should be taken seriously by economics students, not because they are perfect or will never be improved, but because they increase their understanding of markets, provide points of departure for more sophisticated models, and also provide logical foundations for empirical tests of economic propositions and predictions.

They also provide the logic behind the most commonplace intuitions of economists who are not themselves actively engaged in theoretical research—e.g., not themselves model builders.

II. Science as Model Building

It bears noting that the use of models is not exclusively a feature of economics or social science, but of all sciences. Specialization within all scientific fields implies that all models are somewhat incomplete, because the influences of phenomena studied in other fields are normally left out of their research. And, perhaps naturally, experience has shown that they are all imperfect in their ability to perfectly account for the past or perfectly predict the future course of events. Anomalies always exist and their predictions may be accurate but nonetheless remain imperfect. Models are models, and even the best of today's models is likely to be improved in the future—indeed some of the readers of this textbook will be engaged in doing so for much of their careers.

Scientific work attempts to determine general properties of various subsets of phenomena in the world or universe. To do so, both individual scientists and teams of scientists use combinations of models, logic, and empirical evidence to determine what is (approximately) true. Because the real world is complex and interconnected in many ways, all scientists abstract from many features of the world in order to focus on the subset of characteristics and relationships thought to be most important for the aspects of the universe being studied.

Physicists, biologists, and economists, for example, focus on completely different aspects of the world and universe. They create quite different models of relationships of interest to their own groups of specialists, which they believe help us to better understand particular subsets of the phenomena of our universe. They largely ignore any interdependencies with fields other than their own that might exist.

The existence of separate fields of research such as astronomy, physics, chemistry, geology, biology, economics, political science and so forth implies that every model is a bit incomplete—because work in other fields is not fully taken into account. Thus, unless the problems addressed are completely independent of one another, all sciences have developed models or relationships of factors that help them to understand phenomena of interest. For example, astronomers neglect features of human nature (as with the senses) that partly determine how the universe is perceived and measured, and which studies are supported with subsidies and which are not. Economists, likewise, generally neglect the effects of astronomy and geology on the nature and distribution of the Earth's resources.

Yes, the neglected factors sometimes are important. For example, astronomical observations vary with technologies, such as telescopes and photography, which are partly determined by economic phenomena and partly generated by innovations in other fields. If and when a distant phenomenon is observed is thus partially caused by market developments. Similarly, astrological and geological factors affect the location of many natural resources, and thereby the demands and supplies of goods and services, which in turn affect the types of market networks that have emerged through time.

Biologists, arguably, do a bit better on integrating such effects into their theories after Darwin's theory of biological evolution was proposed and refined, but relatively few biologists focus on the very long run, and those that do not also tend to neglect the effects of astrophysics and economics on the distribution and nature of the species that exist today. As every economics student should know, there are advantages to specialization, but also costs.

It is far easier to think about subsets of relationships than to simultaneously take all possible factors into account. (Indeed, the latter may be impossible.) Which is, of course, one of the reasons that science has become so specialized and why imperfect models are commonplace.

Limitations of Simple Causal Models

Models rarely, if ever, account for everything of interest. For example, the simple theory of gravity attempts to explain why and how objects fall. In many cases, this is fairly easy, and models that ignore everything except gravity can explain quite accurately how an object, such as an iron ball or rock, falls. However, there are cases in which other factors, such as wind, air resistance, and aerodynamics, matter. It is much easier to predict how a rock falls than how a leaf falls. Although both fall because of gravity, a leaf's path is often quite complex because of wind and its own aerodynamics. The "average" leaf may fall straight down, but leaves will be distributed widely around the spot that a rock would fall to because of the interactions of air and aerodynamics that the simple gravity theory of falling ignores.

That does not make the simple theory of gravity useless; rather, it means that it does not and cannot account for the path of every object on earth. It is more applicable in a vacuum and thus does a better job of accounting for the movements of planets in their orbits than in predicting the path of a leaf falling from a tree in autumn. On Earth, it is a model rather than reality. Fortunately, even models that only partially account for some phenomenon can be very useful. Gravity accounts for much of the phenomenon of interest (falling) and also provide a basis for developing more inclusive theories (ones that include the effects of air, wind, and aerodynamics).

Trying to explain the path of a volitional, self-propelled object such as an insect, bird, or person is even more challenging. Clearly, more than physics will be required to account for where a bird or person goes after leaving a high branch of a particular tree. In a few cases, they may fall straight down, but that is not the most common case. Neither a bird nor a person is likely to wind up and stay at a place directly below the branch they initially occupied until another external force acts upon them. When a bird leaves a branch, it does not immediately fall to the ground—because they can fly and make choices about where to go—unlike a rock or leaf. Birds may fly off to their nests in other trees or to another place where food is available. Similarly, a person may descend to the ground in a manner that avoids the worst effects of gravity (falling and hurting oneself), but rather than staying where he or she lands, he or she may reclimb the tree (despite gravity) or "simply" walk home for lunch and reflection about the nature of trees, apples, and falling, as Isaac Newton is reputed to have done.

Such paths are influenced by gravity, but not fully determined by it. Because of gravity, humans climb down from trees and walk, rather than jump or fly. However, gravity has a relatively small effect on the paths followed. Although gravity remains part of the causality behind such activities, it does not account for the most important features of the path of humans or other animals. (Animals are, of course, beings that are "animated," e.g. self-propelled, and thus the "self" cannot be ignored). Their interests and intents provide a more complete explanation of the paths that they follow than do gravity, wind, inertia, and friction.

Entirely different and more complex models are required to account for the effects of volition. The nature of volition itself has to be modelled. In models of volition, gravity may be largely ignored, rather than given centrality, because it is far less determinative of the paths of interest than it is for inanimate things.

Modeling Volition

The simplest models of volition assume that the beings of interest have goals that they try to advance through their actions. A geneticist might, for example, argue that all living beings try to maximize the probability that their genes are transferred to the next generation. Those that do so, or behave as if they did so, have genes that will appear in successive generations. Those that do not, do not. Those that do, thus, ultimately determine most of the species we observe—all but the new ones.

This simple model explains a good deal about the nature of the living things that we observe—even those for "replicators" that lack volition, such as viruses. They have methods of transmitting their DNA to their successors and have behaviors (some of which are genetically determined) that make their species' survival more likely.

However, that genetic theory does not explain exactly how a given member of a species maximizes the probability that its genes will be passed on to the next generation, although it does provide a plausible model of the survival of all creatures with a biological nature.

This model, like the gravity model, has some relevance for humans. If humans are to survive as a species, the genes of individual homo sapiens have to be transmitted to future generations of humans, which requires individuals to procreate and nurture their children.

However, that model seems to imply that humans would all attempt to maximize the number of their descendants. Such a prediction conflicts with behaviors that contemporary humans routinely engage in that reduce the likelihood that a particular person's genes will be passed on to the next generation. Examples include choosing to have very small families, vows of chastity, and other lifestyles that make procreation unlikely, youthful suicides, engaging in risky activities such as reckless driving, participation in warfare, and so forth.

Although procreation is necessary for human survival, and child rearing does take up a good deal of adult time and attention, they are not the only activities that contemporary humans devote their time and attention to. And, maximizing family size is not always, or perhaps even usually, their main focus. (There would be many more donors to contemporary sperm and egg banks than there are, were their main goal.)

A still more general model is required to characterize human volition. The one that most economists have adopted has utilitarian roots going back to Jeremy Bentham's writings in the late eighteenth century, which in turn has roots that go back at least as far as Aristotle, who wrote in 350 B. C. This line of reasoning argues that all persons have a single unified goal that they pursue; namely, they attempt to maximize utility or happiness.

> **So far as the name goes**, **there is a pretty general agreement**: for happiness both the multitude and the refined few call it, and "living well" and "doing well" they **conceive to be the same with "being happy;"** but about the nature of this happiness, men dispute, and the multitude do not in their account of it agree with the wise. (*Nicomachean Ethics*, p. 26)
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> Happiness is manifestly something final and self-sufficient, being the end of all things which are and may be done. (*Nicomachean Ethics*, p. 34) … As for the life of money-making, it is one of constraint, and **wealth manifestly is not the good we are seeking, because it is for use, that is, for the sake of something further.** (*Nicomachean Ethics*, p. 29)
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> **Nature has placed mankind under the governance of two sovereign masters, pain and pleasure.** It is for them alone to point out what we ought to do, as well as to determine what we shall do. On the one hand, the standard of right and wrong, on the other the chain of causes and effects, are fastened to their throne. **They govern us in all we do, in all we say, in all we think: every effort** we can make to throw off our subjection, will serve but to demonstrate and confirm it. *(An Introduction to the Principles of Morals and Legislation*, KL: 3474–78)

Bentham and other utilitarians replaced the word "happiness" with the word "utility" in the early nineteenth century. This accounts for the name of their school of philosophy, utilitarianism. A subset of utilitarians were among the leading economists of the nineteenth century, which accounts for the use of the term utility in economics and for the characterization of human volition as utility-maximizing behavior.

The utility-maximizing model is the dominant analytical model of human volition in economics for several reasons. First, the notion of utility is all-inclusive. If individuals all pursue happiness, however they conceive it, then sensible persons will attempt to use their resources to maximize happiness. By leaving the sources of happiness open-ended, it allows all sorts of behavior to be characterized in that way. Second, there are several mathematical tools that can be used to characterize the maximum of any systematic relationship. Thus, internally consistent models of choices can be developed fairly easily, as demonstrated in every microeconomic text and in the next chapter (and several others) in this textbook. (The same models are used in game theory and in "rational choice" strands of political science, sociology, and anthropology.)

Third, since nearly all of us are interested in happiness (or avoiding its opposite), the activities that produce utility can be verified—at least to some degree—by reflection. "I get satisfaction or utility from X, so it is plausible that many (or most) others do as well." Activities to be avoided may similarly be imagined, "Activity Y makes me worse off (reduces my happiness or utility) and therefore will be avoided by me—and others like me."

This model of human volition, although very broad and useful, nonetheless, was criticized as being too narrow, too broad, or unrealistic.

In response to such criticisms, Paul Samuelson (1948) developed the revealed preference theory of utility. He demonstrated that if an individual makes decisions that are internally consistent (e.g., if A is preferred to B and B is preferred to C, then A is preferred to C, etc.), then one could assign numbers to A, B, and C such that A gets a number higher than that for B and B higher than C. After doing so, one can use this pattern of "revealed preferences" as utility numbers and model individuals "as if" they maximized utility. Such behavior, whether a conscious effort to maximize satisfaction or not, is consistent with a model that assumes that they do. Thus, the model is useful—even if it is not entirely realistic.

One does not have to assume that all people consciously pursue happiness or satisfaction to gain useful insights from the utility-maximizing model of human volition. Al that is necessary for economic models to be useful characterizations of human volition is internal consistency in one's choices.

Nonetheless, the assumption that most folks do attempt to maximize utility or happiness is consistent with a good deal of experience. As Aristotle observed long ago, most humans would agree that happiness is their ultimate end in both the short and long run. Thus, there is no harm in using that ancient model of humankind—even if all that is necessary for the utility-maximizing model to be a useful model of volition is internal consistency.

III. Improving Models and Theories

In economics and most other areas of active research, there are often two or more models that provide roughly equally accurate and informative explanations of the phenomena of interest. This makes choosing among the models challenging, because one cannot always simply pick the model that provides the most accurate account of the phenomena of interest. In some of these cases, there is also a somewhat less accurate model that is far easier to communicate with others, or to use as a basis for estimation. For example, models taught in principles of economics clearly differ from those taught in intermediate microeconomics and advanced microeconomics courses, although they are not entirely different. Similarly, within empirical research, single-market estimates may be followed by models that take better account of interdependencies among markets or the effects of government policies.

All "useful" models account for well-known relationships, and most also have implications about unknown or ignored relationships that are not intuitively obvious. In such cases, models serve as frameworks or points of departure that help scientists and other experts identify previously unknown relationships and facts. Many of these relationships would not have been predicted or imagined without the first relatively simple models that allowed core relationships to be understood.

Exceptions to the predictions of such models, in turn, often stimulate the development of more inclusive models. In some cases, refinements in one of the existing models will cause it to become "the" model of choice. In other cases, entirely new theories may be required to achieve a consensus among experts.

As noted above, Newton's theory of gravity provides a good approximation of how inanimate objects behave when falling, but for some objects, such as leaves or sheets of paper, the effects of wind and aerodynamic shape are also important. Relatively few analyses of falling or rocketry would neglect aerodynamics these days. Similarly, models of perfect competition that were developed in the late nineteenth and early twentieth centuries were subsequently extended to take account of less than perfectly competitive circumstances, as with monopolized markets or competition among a few firms selling identical goods (oligopoly). These models, in turn, were extended to take account of the effects of informational problems, government policies, and culture.

The evolution of models in every field of science is a joint product of logic (model building), observation (empirical testing), and reflection about the results, and subsequent refinements in models, experiments, and measurement. There is a nearly endless cycle of model building (hypothesizing), empirical testing, refinement, retesting, and so forth in every active area of science (a process is sometimes called bootstrapping). Ideas that look obvious in retrospect often take a century or more to be worked out and accepted.

Through this process our understanding of the world gradually improves and is, in a sense, gradually perfected. Even after several thousand years of efforts to understand the universe, some aspects of the world and universe are understood far better than others. Thus, some models are better than others—more precise, more encompassing, or better at facilitating one's understanding of key relationships.

Even somewhat imprecise models often allow one to discover and understand relationships among phenomena far better than human intuition alone can. And, such models often stimulate the development of new hypotheses that can be tested and refined.

IV. The Often Very Slow Progress of Science

In contrast to the fields of logic and mathematics, all fields of science have "truths" that they pass on to their students and expect others in the field to have mastered, but which they also acknowledge may change in the future. These "truths" or "facts of nature" should be regarded as "relatively absolute absolutes." Which is to say, they can be taken to be true or accurate for many purposes—even though most experts anticipate that future refinements will improve on the models or theories considered "true" today.[1]

Past truths are sometimes discarded—as when Newtonian physics replaced Aristotelian physics in the seventeenth century—but more often models are simply adjusted in various ways to take account of new ideas, data, and results. Newton's theories are still used for most day-to-day physics and engineering today, but they have been replaced by Einstein's theories in cases in which the objects of interest travel very rapidly (approaching the speed of light). Still other theories are used to analyze changes in atomic structure. Similarly, the core neoclassical models of micro-economics worked out in the late nineteenth and early twentieth centuries continue to be applied in the twenty-first century, although they have been modified in various ways to address issues neglected in the original models such as the importance of information problems and innovation.

Such refinements often take decades or centuries to be worked out. One can see evidence of this in the language that we use to describe some common events. For example, an example of a current model that most educated persons accept is that all sunrises on Earth are caused by the Earth's daily rotation in combination with light generated by its nearest star—the sun. After Copernicus introduced the heliocentric model of the solar system in the sixteenth century and was refined induced by Newton's theories and Galileo's observations in the seventeenth century, this explanation for our daily cycle of light and darkness has been the model accepted by all educated persons. Nonetheless, our normal English expressions for the point at which the earth spins around enough so that the sun becomes visible is called sunrise, rather than sun approach or the beginning of sun sight. Similarly, the end of that period of direct illumination by the sun is called sunset rather than the end of sun sight or the beginning of shadow time. Our language is still based on the earlier and more intuitive flat-earth theories of daylight. The sun does not move (much) relative to the Earth; it is the Earth that moves relative to the sun.

Note that there is some ambiguity about the meaning of sunrise and some measurement error in measuring the exact moment of sunrise or sunset at a given place on earth. Perhaps surprisingly, although we have lots of data about sunrise, the exact moment is more difficult to determine than one might expect. Is sunrise when the light of the sun first appears, or is it when the transition to daytime is completed? What factors cause the observed variation in the time at which lightness occurs? Does it matter whether one is on top of a mountain, on an ocean, or in a deep valley?

In practice, the first light and sunrise numbers published on meteorological websites tend to neglect the effects of mountains and weather on the times when first light and last light occur. They are, in a sense, approximations—numbers that would be accurate if the world were a level plane and the sky always clear and cloudless—even though they are not. Similar ambiguities exist in most physical and social sciences for similar reasons.

Nonetheless, exact times for sunrise and sunset are widely published and useful for planning purposes, although they are rarely exactly correct. Refinements that include all the "ifs" are possible and many have been worked out, but the approximations are easier to remember and have clearer (if often slightly wrong) implications than their more precise counterparts. The competitive model remains a useful first approximation of how prices and profits are determined in markets where there are numerous buyers and sellers engaged in the voluntary exchange of familiar products produced using familiar techniques.

The models developed in Part I of this book can be thought of as economic counterparts to the simple theory of sunrise and sunset. They are useful and provide many insights that are relevant for planning and public policy, but are not always, or perhaps ever, perfectly precise.

The models developed in parts II and III introduce some of the most important refinements of the core neoclassical models of price determination developed in part I. Most were worked out during the twentieth century. Some, but not all, were associated with the mathematization of the older models. Others incorporated factors that were neglected in the original verbal and geometric models.

V. A Short History of the Use of Mathematical Models in Social Science

Economics has a long history, it is essentially as old as voluntary exchange is, because trading always involves coming to terms about how much of this will be traded for how much of that—and theories about a "good deal" or "bad deal" must have emerged at basically the same time. The logic of supply and demand in their own markets would have been "intuitive" to most firm owners for thousands of years before general models of price determination were worked out.

Theoretical explanations of equilibrium prices go back at least as far as Aristotle, who proposed a theory of the origins of money that remains largely in place today (as an index and store of value that can nonetheless decline in value through inflation). Aristotle also developed a theory of equilibrium fair prices that he worked out to illustrate his theory of proportional justice. The first truly encompassing work on economics is Adam Smith's *Wealth of Nations*. It was published at roughly the time of the American Revolutionary War. He used tightly reasoned prose to develop economic theories and supported them with many examples and numerical data. He noted the advantages of specialization, factors that tend to induce prices and exchange rates to move toward long-run equilibrium values. He also noted factors that can disrupt an existing equilibrium.

The use of mathematics for modelling human behavior arguably started in political science at roughly the same time as Smith was writing, just before the French Revolution, when Condorcet and Borda used rational choice models to analyze the properties of different voting rules. Many of their results are still of interest today. Condorcet's analysis of majority rule identified the ideal of a dominant option (now referred to as a Condorcet winner) that is majority preferred to every other and Borda's suggested alternative for voting (the Borda count method) remains of interest to scholars of voting processes. The economic department at WVU has used the Borda count method to select among job candidate finalists for many years. However, very few political scientists adopted their analytical approach to understanding the effects of elections on public policies.

Mathematical models of economic decision making and their consequences were developed in the late nineteenth century and extended throughout the twentieth and twenty-first centuries. Many of the first persons to do so were members of the philosophical school referred to as utilitarians. Their notion of "utility" turned out to be a very useful way of thinking about choices, gains to trade, and the normative area of economics called welfare economics. It also turned out to be a useful foundation for mathematical models of volition as discussed above.

At first, this mathematical strand of economic research was a minor part of the overall research program of the group of scholars and practitioners who studied how markets operate. Most published research used prose and a diagram or two to convey their theories and tables of numbers as empirical support, when it was deemed necessary to do so. About fifty years ago, mathematical modeling (and statistical evidence) rapidly became the main method used to model (and test) equilibrium prices and networks of exchange and production. Prose, geometric representations, and tables of numbers largely disappeared from leading economic journals in the mid 1970s.

In the 1980s, models that used calculus (and to a lesser extent differential equations and more advanced mathematics) to analyze economic relationships became the most common methodology for "theory" papers published in mainstream economic journals such as the *American Economic Review* (AER), *Quarterly Journal of Economics* (QJE), and *Journal of Political Economy* (JPE). Other, more mathematically sophisticated analyses were published in more specialized journals such as *Econometrica* and the *Journal of Economic Theory* (JET). Very few prose or geometric-based theory papers were published in leading economic journals after 1980.

Most mathematical and geometric models imply that results worked out for a particular product or market can be generalized to essentially all markets. That is to say, there are commonplace relationships that exist within all markets for particular products, and these can be modelled in a general way that has implications for both existing prices in other similar markets.

This allows the inferences drawn from models of single markets to be applied to many other markets and also to phenomena that resemble voluntary exchanges and other choices that appear to be instances of constrained optimization. Microeconomics can provide a very broad understanding of social phenomena, although one that is often useful and insightful, but rarely perfect. (The latter is, of course, why progress continues to be made.)

The mathematization of microeconomic theory accounts for the mathematization of most graduate economic programs. Some background in mathematical model building (and its limitations) is necessary if one is to be able to read and understand most contemporary research.

VI. Methodological Individualism as the Foundation for Microeconomics

What distinguishes microeconomics from macroeconomics is both the widespread use of partial equilibrium models and an approach to social science referred to as methodological

individualism. Microeconomics also tends to be less directly public-policy oriented than most macroeconomic research tends to be.

Methodological individualism regards all social phenomena as consequences of individual decisions and actions. This includes such phenomena as markets, politics, norms, and social networks. That approach requires market outcomes such as prices and the pattern of goods and services produced for sale to be characterized as consequences of a large number of individual decisions. This approach, for example, is the basis for the theory of price determination in competitive markets, where prices are jointly determined by the decisions of thousands (or millions) of individual consumers and thousands of individual producers and their input providers. These, in turn, may be affected by the legal setting in which they take place and other factors such as the effects of mass education and policies that tend to encourage or inhibit various types of market activities.

This approach maintains that individuals are the prime movers, the choosing agents, through which all social phenomena emerge. Thus, many of these non-economic choice settings can also be analyzed using similar models.

"Organizations," "Networks," "groups," and "societies" are all composed of individuals making independent decisions in particular choice settings. The properties of "governments," "networks," "groups," and "societies" emerge from the choices of the individuals in those governing organizations, networks, groups, and societies. In lean models, the decisions reached by individuals are determined jointly by each individual's particular circumstances (constraints) and partly by their aims in life (often characterized as maximizing utility).

Most lean models assume that individuals make their choices without taking account of the effects of their actions on others. The choices are simple self-interested choices, ones that maximize their own utility. However, in more complex models, that assumption may be modified to take account of sympathy and hostility among individuals and groups that may exist. Such models may also explicitly take account of various rules and norms that an individual has internalized, some of which may have to be followed to maintain membership within a firm, group, or society.

Lean models of economic decision making also implicitly assume that the decisions made are inhibited by a well-functioning system of laws, by personal inhibitions or by combinations of that are sufficient to largely rule out non-market transactions. The individuals modeled do not steal or use threats of violence to gain what they want—rather, they engage in various forms of voluntary exchange. That is one of the fundamental "rules" or constraining principles of market networks. More general approaches include possibilities for theft and violence, and so must take explicit account of how such possibilities affect the scope of trade and innovation. Such approaches may also take into account why some institutions and internalized norms can promote economic development.

Rationality as Internally Consistent Behavior

Microeconomic models use "rational choice" models to characterize the kinds of choices made by individuals in a wide domain of possible circumstances. It is such models that allow methodological individualism to serve as the foundation for microeconomics. A wide variety of tastes and circumstances can be included in such analyses. In many economic settings, market-level activities such as demand or supply are simply sums of individual consumer or firm decisions. In others, more complex, less linear effects emerge from the choices of individuals as with respect to externality and commons problems.

However, it bears keeping in mind that economists use the word "rational" in a manner that is different from its ordinary use in English. In normal usage, "rational" means "based on or in accordance with well-informed reason or logic." This suggests that individuals who are "rational" are dispassionate, well-informed, analytically competent, and sane. Economists regard such persons to be rational.

However, many others who are less than well-informed or dispassionate are also considered to be rational. That term is also used to describe any individual whose choices or rankings of alternatives are internally consistent. If A is preferred to B and C is preferred to B, and C is also be preferred to A for all possible A, B, and Cs of interest, then the individual is said to be rational.

Note that myopic or even insane persons may behave in a manner that is internally consistent, and thus would be regarded as rational in the economic sense, although their behavior would not be considered well-reasoned or reasonable.

Whether well-reasoned or not, if individual choices are locally rational in the sense of internal consistency, it implies that their behavior can be modelled as if it is the result of a process of optimization—the maximization of utility subject to various constraints.

Local rationality is sufficient for economic models of individual choice, because, as Samuelson (1948) demonstrated, in that case, choices can be characterized as if they were outcomes of utility maximizing choices.

Microeconomic models normally characterize only a subset of the choice settings that individuals confront, so internal consistency with respect to market-relevant choices is sufficient for most economic modelling.

The ability to characterize preferences with numbers allows geometry and calculus to be used to characterize choices. Once "mathematized," mathematical deduction can be used to infer the effects of changes in constraints or preferences on the actions that a rational individual will undertake.

Other aspects of choice settings, as with payoff functions in game theory, determine the joint consequences of the choices made by groups of interdependent individuals.

The models used by economists, game theorists, and the rational choice strands of research in political science, sociology, and anthropology are all very similar to one another in spirit, in that they nearly all assume that people are basically rational in the circumstances of interest.

Microeconomics tends to focus most of its attention on the various economic features of the choice settings that individuals confront. However, it does not always ignore other factors that influence the decision-making process. For example, a model may explore the effects of biased expectations, mistakes in the processes used to evaluate the consequences of the choices that can be made, or the extent to which human computational power and informational limits affect the choices made.

VII. A Short Overview of the Organization of this Book

The book is organized into three parts. Part I reviews the basic logic of neoclassical price theory. The first three chapters of Part I use geometry, concrete functional forms, and abstract functional to model the choices of consumers, the output choices of firms and the production methods used to produce their goods and services. These provide the foundations for the neoclassical theory of price determination explore in Chapter 5. Part II reviews extensions of the competitive model to settings where time and uncertainties exist. Among the topics reviewed are entrepreneurship, the nature of the goods sold, and the strategies of multi-product firms. Part III reviews extensions of the rational choice model to non-market settings that are relevant for economics and other social sciences. Law, politics, and prevalent norms within a given society all have effects on the extent of markets within those societies and both intra-firm decisionmaking and incentive structures.

The main attraction of the models developed in this text is that they provide general results from relatively straightforward analyses. Without generalizable results, the best that economists could accomplish would be a catalog of special case results. This is not to say that such catalogs are never useful, nor that general results are the only types of research published in the last half century. But it is to say, or at least assert, that exploring such a catalog is not the best way to introduce students to advanced microeconomics.

Although the book may appear to focus narrowly on the calculus of commerce, its main purpose is to expose students to a broad subset of the most well-known ideas and generalizable models and results that emerged from rational-choice-based research in economics and related fields during the period after World War II. It is the idea base for most contemporary research and for most economic intuition.

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Appendix I: Axiomatic Choice: Fundamental Concepts and Definitions from Mathematics used in Neoclassical Price Theory

A. When the rules of logic are applied to numbers the result is mathematics.

- Most of the mathematics we have been taught can be deduced from a few fundamental assumptions using the laws of logic.
- (See the postulates of Peano, an Italian mathematician (1850 - 1932).)

Some mathematical economists are very attracted to the axiomatic approach (See Debreu's book for an early example). This appendix shows how that approach can be used to model human choices.

B. Some fundamental properties of preference orderings:

- DEF: Relationship R is **reflexive** in set X, if and only if aRa whenever a is an element of X.
- DEF: Relationship R is **symmetric** in set X if and only if aRb then bRa whenever a and b are elements of set X.
- DEF: Relationship R is **transitive** in set X if and only if aRb and bRc then aRc when a, b, and c are elements of set X.

Recall that within the set of real numbers, there are several relationships that are symmetric , reflexive, and transitive. The equality relationship has all three properties. Greater than, less than, greater than or equal than, less than or equal than are transitive, but not reflexive or symmetric.

In economics, there is one relationship that is assumed to possess all three properties, and others that are assumed to exhibit only transitivity. Strong and weak preference orderings are transitive, while indifference is transitive, symmetric, and reflexive. In general, economists assume that "rational" preference orderings can be constructed on indifference and strong and weak preferences that have these properties..

C. The indifference relationship, I, can be defined in terms of the weak preference relationship R.

- The weak preference relationship R means "at least as good as."
- Note that if aRc and cRa, then aIc.
- Similarly, the strong preference relationship, P, can be defined in terms of the weak preference relationship. The strong preference relationship means "better than."

- Note that if aRb but b~Ra then aPb.
- Rationality in microeconomics is often defined as preferences that have a transitive weak preference ordering
- If every possible combination of goods can be ranked, then preferences are said to be complete.

D. On the Mathematical Foundations of Utility Functions

- DEF: A **function** from set X to (or into) set Y is a rule which assigns to each x in X a real number, f(x), in Y. Set X is called the domain of function f and set Y its range.
- On most diagrams from math classes, the domain is the horizontal axis (X), and the range is the vertical axis (Y).
- However, most textbook diagrams in economics have the domain of the function on the vertical axis (P) and the range of the function on the horizontal axis (Q). For example, demand functions go from P (prices) into Q (quantities a consumer is prepared to purchase).
- This is evidently Marshall's fault, who decided that the diagrams were easier to draw this way—possibly because of the use of blackboards back in the 1890s. For blackboard diagrams, it is very useful to have price (P) on the vertical axis.
- DEF: A **utility function** is a function from set X into the real numbers such that iff aPb then U(a) > U(b) and if aIc then U(a)=U(c) for elements of the set X.
- In diagrams, indifference curves are simply graphs (plots) of all combinations of two goods that generate the same utility.

Note that when a utility function can be developed that is complete, it does not necessarily characterize satisfaction, but does require transitive preferences, because equality and greater than are transitive relationships within the space of real numbers. Nonetheless, if you think of utility as "satisfaction" or closeness to some "goal," your intuition about the choices that will be made as one's opportunity set changes will be correct.

Note also that the assumption that a utility function exists is equivalent to the assumption that individual preferences are transitive (within the domain of interest).

The assumption that all feasible combinations of goods can be evaluated with the function implies that preferences are **complete**: each bundle (combination of goods and/or "bads") has a unique rank. Every bundle of goods generates either more or less or the same utility level as other goods.

(Some theorists make a distinction between complete and incomplete utility mappings from X to R, but this distinction is not important for the analysis of 'routine' decisions, because of constraints on the domain of possibilities. Completeness is only important within the domain of feasible combinations of the good of interest.)

E. Some useful definitions and concepts from Set Theory.

- DEF: An infinite series, x_1, x_2, ... x_n is said to have a **limit** at x* whenever for any d >0, the interval x* d, x* + d contains an infinite number of points from the series. (That is to say, x* is a limit point of a series if there are an infinite number of elements of the series arbitrarily close to x*.)
- DEF: A set is **closed** if it contains all of its limit points.
- Def: A set is **bounded** if every point in A is less than some finite distance, D, from other elements of A.
- Def: A set is **compact** if it is closed and bounded.
- Most opportunity sets in economics are assumed to be closed and bounded.
- Def: A set is **convex** if for any elements X_1 and X_2 contained in the set, the point described as $(1-d)X_1 + dX_2$ is also a member of the set, where $0<d<1$.
- Thus, a convex set includes all the points directly between any two points in the set.
    - That is to say, any convex (linear) combination of two points from the set will also be a point in the set.
    - Thus, a solid circle, sphere, or square-shaped set is a convex set but not a W-shaped or U-shaped set.
    -

To see this, draw one of these figures, pick representative pairs of points and connect them with a line interval (cord). Every line interval within a circle, triangle, or square, for example, will lie entirely in the set. They are convex. However, this is not true of a doughnut-shaped set or a set with a wavy outer edge.

- What other common geometric forms are convex?

- Example from economics: “better sets" are usually assumed to be convex sets. That is to say, the set of all bundles which are deemed better than bundle “a” is generally assumed to be a convex set.
- Another example is the budget set; the set of all affordable commodities given a fixed wealth and fixed prices for all goods that might be purchased.
- Why do a series of convex combinations trace out a cord? Because as d varies from 0 to 1, the “point” characterized moves along a line from one point (X_1) to the other (X_2).

Convexity and compactness assumptions are widely used in calculus and graphical models of human volition because they make differentiable functions (and lines) possible. Opportunity sets and production possibility sets are nearly always assumed to be convex and compact.