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How simulations can help economics to overcome two of its weaknesses

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1. Two weaknesses of economics

The science of economics has two weaknesses. It aspires to study both how economic agents (individuals, families, enterprises, etc.) use their resources to satisfy their needs and reach their goals (microeconomics) and how aggregate economic variables at the level of the entire economic system vary with each other and with time (macroeconomics) but it fails to describe and explain how this dynamics of aggregate economic variables actually results from the behavior of economic agents. Microeconomics and macroeconomics remain separated and there is really no account within economics of the interactions between these two levels of economic phenomena. This seriously limits the capacity of both microeconomics and macronomics to really understand even the economic phenomena that each subdiscipline chooses to study.

A second weakness of economics is that it is a science with a very limited interface and interaction between theory and empirical reality. The "facts" of economics are a very restricted subset of all the economic phenomena of a (modern) society. They are in practice only the observed values of a number of aggregate economic variables and how these values change over time. This is truly too little given the enormous richness, variety, and complexity of economic phenomena that can be observed in a modern society and that could be used to empirically test economic theories. The very restricted empirical basis of economics is another weakness of the discipline since science is both theory and empirical facts and, especially, a tight dialogue between theory and empirical facts.

In this chapter we argue that these two weaknesses of the science of economics could be at least in part eliminated by adopting computer simulation as an new tool for doing scientific research in economics. Traditionally, science seeks to know and understand reality by observing empirical phenomena and by formulating theories and models that try to explain the observed empirical phenomena. Computer simulations try to know and understand reality by reproducing reality in a computer. Computer simulations are being progressively adopted by all scientific (and technological) disciplines and also by economists (see, for example, Tesfatsion, 2001). In this chapter we discuss how computer simulations can help economics to establish a stronger link and interaction between microeconomics and macroeconomics and to strenghten and enlarge the empirical basis of the discipline.

2. Studying the interaction between microeconomic and macroeconomic phenomena

A well-known problem which has historically afflicted the social sciences and which the social sciences have never succeeded in solving satisfactorily is whether social phenomena should be studied at their own level, by explaining social structures in terms of other social structures and socially aggregated variables in terms of other socially aggregated variables, or social phenomena should be explained by stepping down one level and explaining social structures in terms of the behavior of the individuals that constitute them and socially aggregated variables in terms of variables pertaining to individuals.

Economics tries to solve the problem by dividing into two: macroeconomics and microeconomics. Macroeconomics is the study of economic phenomena at the aggregate level; microeconomics at the level of the behavior of individuals or other economic agents such as families, enterprises, etc. However, this is at best a partial solution. What is expected from a well-behaved social science is not only a recognition that both the aggregate/social level and the individual level are real and a separate study of each of the two levels in its own terms but a (detailed) account of how the two levels interact, that is, how the behavior of many individual gives rise to social structures and phenomena and how social structures and phenomena influence the behavior of individuals. Such an account economics has never succeded in providing. There is no attempt within standard economics to explain how economic phenomena at the aggregate/social level emerge from the behavior of individuals, that is, to identify and describe the mechanisms and processes that lead from the behavior of sets of interacting individuals to the appearence and functioning of economically relevant social structures. And the influence of the social/economic environment on economically relevant individual behavior is largely ignored by economics since economics tends to assume a model of individual behavior in which most of the variables are either given and fixed (e.g., the ordering of preferences in the individual) or completely idealized (e.g., the individual has perfect knowledge and perfect inferential capacity).

Many different reasons may explain why economics is unwilling to tackle the problem of describing and explaining the interactions between economic phenomena at the macro and micro levels. But even if economics were willing to consider the study of these interactions as an important research task for the discipline, it would be unable to do so because both the conceptual and the methodological tools which are available to the discipline are completely inadequate to the task.

Conceptually, economics embraces the traditional scientific view of reality as made up of “simple” systems, that is, systems which can be analyzed and understood in terms of one or more independent variables affecting some particular dependent variable. In contrast, if one is interested in studying the interactions between phenomena at the level of individuals and phenomena at the level of society one has to move to a different view of reality as made up of “complex” systems. Complex systems are systems made up of a large number of elements which, by interacting locally (i.e., each element of the system interacts only with a limited subset of other elements), determine the emergence of global properties and phenomena at the level of the entire system which cannot be predicted or deduced from even a perfect knowledge of the single elements and of the rules that govern their interactions.

Complex systems tend to have properties that are opposite to those of simple systems. Simple systems tend to be predictable and to change in predictable ways. They can be isolated from the environment (context) in which they normally exist without seriously compromising their functioning and our understanding of their functioning, and they react to external influences in ways which are commensurate to the size of the external influences (small influences have small effects, large influences have large effects). On the contrary, complex systems behave and change in ways which are not very predictable. They cannot be detached from the environment in which they exist because they tend to adapt to the environment and to change the environment. They develop in ways which are very sensitive to initial conditions and they respond to external influences in ways which tend not to correspond to the size of these influences (large influences may be absorbed by the system without apparent change, small influences may have catastrophic effects).

Furthermore, complex systems tend to be organized in hierarchical structures, with many interacting elements at one level resulting in a single element at the next higher level, with higher level systems constituting the environment for lower level systems.

Economic phenomena at the aggregate level are complex systems. The elements of the complex system are individual human organisms and the local interactions among individual human organisms generate such emergent social structures as organizations, markets, states, and other social structures which have a role in economic phenomena at the aggregate level. Economic phenomena tend to be hierarchical complex systems, with individual humans at the bottom of the hierarchy and a succession of ever larger organizations at the higher levels. (They are also heterarchies since one and the same individual can belong to different organizations.) Hence, if economics has to seriously address the problem of studying and explaining the reciprocal influences between economic phenomena at the macro level and at the micro level it must abandon its traditional scientific orientation which tends to view reality as made up of simple systems and embrace a view of reality as made up of complex systems (Anderson, Arrow, & Pines, 1988; Arthur, Durlauf, & Lane, 1997) - or at least combine the two views.

But the conceptual shift toward a complex systems view of reality must be accompanied by a parallel shift in the methodological tools with which economics conducts its researches. Traditional science not only views reality as simple systems but, predictably, uses methodological tools which are appropriate for studying simple systems. One of these tools is the traditional mathematics of equations, and this is the tool adopted by economics. An equation states how one variable depends or changes as a function of one or more other variables. Economic variables are aggregate variables at the social level. Economics assumes that the values taken by these variables are the collective result of the behavior of many individuals but does not consider it necessary or possible to actually investigate how the behavior of many interacting individuals results in the observed values taken by the economic variables. This is why macroeconomics and microeconomics remain separate. Now, it is certainly important to determine and to capture in a precise and quantitative way, i.e., via equations, how aggregate economic variables are linked together. This is certainly one level of explanation of aggregate economic facts. But one would like to ask economics to go deeper and not only determine that one aggregate variable is linked in some particular way with one or more other aggregate variables (or with time) but also discover why the two variables are connected in the way they are connected. However, if one wants to do so one must leave the higher level of aggregate variables, go to the lower level of individual behavior, and show how many individuals by interacting together give rise to the observed connections among economic aggregate variables captured by the equations. But to make this move equations are not particularly useful.

The other important methodological tool of traditional science which also reflects a view of reality as simple systems is the laboratory experiment. Macroeconomics cannot do laboratory experiments with aggregate economic variables for the obvious reason that aggregate economic phenomena cannot be physically brought in the experimental laboratory. Standard microeconomics also does not use laboratory experiments to study the economic behavior of individuals because, as is well known, it adopts a very abstract and idealized model of individual behavior as perfectly rational behavior and is not very interested in ascertaining empirically if this model corresponds to the actual way in which human beings behave. More recently, a certain number of economists have looked at the experiments done by psychologists on how individuals actually behave or they have even begun to do experiments themselves. (But the experiments done by psychologists and by economists are somewhat different. Cf. Hertwig and Ortman, 2002.) However, the adoption of the method of laboratory experiments does not even begin to solve the problem of studying how the micro and the macro level of economic phenomena interact together. Even if, by doing experiments on actual persons, what economists assume about the behavior of individuals can become less idealized and less obviously empirically ungrounded, it remains to be determined how the behavior of very large numbers of individuals gives rise to macro level economic phenomena. And this is physically impossible to study in the laboratory.

But laboratory experiments are not very appropriate as tools for studying the interactions between macro and micro economic phenomena for another, more fundamental, reason. Like equations, laboratory experiments are appropriate for studying simple systems, not complex systems. In the experimental laboratory the researcher typically isolates some phenomenon of interest from the actual context in which it normally takes place, examines and manipulates one variable or a few variables at a time, and observes the consequences of his or her manipulations for the phenomenon under study. This is perfectly appropriate for simple systems but not for complex systems. As we have noted, complex systems cannot be detached from their environment and they are the global result emerging from the highly nonlinear interactions among many different elements which it makes no sense to manipulate one at a time. Hence, laboratory experiments cannot be used for studying complex systems.

What then is the metodological tool which is appropriate for studying complex systems and, more specifically, for studying how aggregate economic variables and socio-economic structures and phenomena emerge from the many interactions among large groups of human beings? The answer to this question is: computer simulations. What are computer simulations, and why they are the appropriate method for studying how the macroeconomic level and the microeconomic level interact together?

Simulations are a new way of expressing scientific theories. Traditionally, science expresses its theories, i.e., its hypotheses about the causes, entities, mechanisms, and processes underlying the observed phenomena and explaining the observed phenomena, either verbally, using the familiar, ordinary language, or using mathematical symbols (equations). Simulations are theories expressed in a new medium: computer programs. The program runs in the computer and the simulation results, the simulated phenomena observed on the computer screen, are the empirical predictions which are derived from the theory incorporated in the simulation. If these results correspond to the actual phenomena observed in reality, the theory/simulation is confirmed. If not, it has to be modified or abandoned.

In addition to being theories expressed in a novel way, simulations are also virtual experimental laboratories. As in the real laboratory, the researcher observes the simulated phenomena in controlled conditions, manipulates the factors and the value of the parameters affecting the phenomena, and determines the effects of his or her manipulations. But, as we will see, as virtual experimental laboratories simulations have a number of advantages over real experimental laboratories.

Simulations are more and more frequently used in almost all scientific disciplines but they are also used outside science for constructing technological artifacts and for finding solutions to practical problems. From the point of view of basic science simulations are a new way of knowing and understanding reality. Traditionally, science attempts to know and understand reality by observing, directly or indirectly (i.e., using instruments), empirical phenomena and by constructing verbally or mathematically expressed theories of these phenomena. Simulations are attempts at understanding reality by reproducing reality in a computer (and, in some cases, in physical artifacts such as robots). If we are able to reproduce reality, we must possess some appropriate understanding of how reality is structured and functions that we have used in creating the simulation of reality. But once we have constructed pieces of reality that resemble actual reality for the purposes of science we can also construct pieces of reality that do not necessarily resemble actual reality (even if they are based on the same general principles) but can help us solve practical problems. This is the use of simulations for the purposes of technology and as tools for identifying and trying out solutions to our practical problems. Since economics is as much an applied science as a pure science, this aspect of simulations is also of interest for economics.

Why simulations are the chosen tool for studying complex systems and, more specifically, the interactions between macro and micro economic phenomena? In a simulation one can set up a large number of individuals (simplified human beings), each with its individual properties and with input and output capacities, that is, capacities for receving information and resources from the external environment and for affecting the external environment by generating information and transferring resources to other individuals. These individuals live together in the same environment and, therefore, the environment for each individual is constituted by other individuals in addition to natural resources and technological artifacts. The individuals interact among themselves using their input and output capacities, and their interactions are local, that is, each individual interacts only with the individuals with which it is connected in the sense that it can affect and be affected by those other individuals. From these local interactions emerge social-level structures and phenomena such as private and public organizations, markets, social networks, money, prices, interest rates, etc. These global structures and phenomena have all the properties that characterize complex systems: their emergence cannot predicted or deduced from a knowledge of the individuals and of their local interactions, they are sensitive to initial conditions, they exhibit properties of path dependence and lock-in, they tend to react to external influences in unpredictable ways, they tend to be organized in hierarchies. Each individual lives in an environment which contains not only other individuals but also these social structures and its individual properties and behavior are affected by these social structures.

If simulations are the appropriate tools for studying the reciprocal influences between phenomena at the macroeconomic level and phenomena at the microeconomic level, they can eliminate one of the weaknesses of the science of economics which consists in keeping microeconomics and macroeconomics separate. What cannot be captured by equations can be observed on the screen of a computer in which a simulation is currently running. One can literally see what social structures and global phenomena emerge from the many interactions of individuals and what are the consequences for the individual of living in an environment which contains social structures and global phenomena in addition to other individuals.

Furthermore, as virtual experimental laboratories simulations have all the advantages of the real experimental laboratory without its limitations. In a simulation, the researcher can control the conditions under which the (simulated) phenomena are observed with even more degrees of freedom than in the real laboratory. He or she can manipulate the variables and the value of parameters that affect the phenomena of interest and observe (measure) the consequences of these manipulations. But the phenomena studied in a simulation need not be isolated by the context (environment) in which they normally take place because one can simulate both the phenomena and their context. Moreover, while many phenomena of interest to an economist cannot be directly observed in reality and cannot be brought in the real experimental laboratory because they are too big or last too much or are long past, virtually all phenomena can simulated. Of course, the simulated phenomena, the results of the simulation, must correspond to the phenomena actually observed in reality but simulations can suggest new empirical phenomena that have not been observed yet and induce the researcher to look for these phenomena in reality.

3. Enlarging and strengthening the empirical basis of economics

Two rules govern the progress of science. The first rule is: Science is at its best when there is a strong interaction between theories and empirical facts. Theories, i.e., hypotheses about the causes, mechanisms, and processes underlying observed phenomena and explaining those phenomena, should generate specific empirical predictions which can be compared with specific empirical facts, and viceversa, observed empirical facts should be constantly illuminated by theories that try to explain them. Such a constant and tight dialogue between theories and facts characterizes the natural sciences but is much rarer in the social sciences. Among the social sciences there are disciplines such as history which are almost completely deprived of theories and are mostly restricted to describing and narrating facts and events, and other disciplines such as sociology which have both facts and theories but little dialogue between them. Theories in sociology are often ambitious and very general and abstract but they rarely make specific empirical predictions and therefore they typically are the object of never-ending discussions and arguments rather than empirical verification. On the other hand, empirical facts in sociology are often accurately collected and quantitatively analyzed to discover regularities existing in them but they remain empirical facts and do not become empirical evidence that verifies or disconfirms some theory aimed at explaining them.

There is also a third type of disciplines, exemplified by economics and formal linguistics, which succeed in establishing a tight interaction between their mathematically (economics) or formally (linguistics) formulated theories and empirical facts but they pay this trait of a mature science with innatural and very rigid restrictions on the empirical phenomena that they take into consideration. Empirical facts in economics mostly consist in the observed values of aggregated economic variables and how these values change with time, while the “facts” concerning the behavior of individuals are so idealized that they simply are not facts (as laboratory experiments easily show). Empirical facts in formal linguistics basically are the linguistic intuitions of the native speaker, i.e., his/her judgments on such properties of expressions of his/her mother tongue as their acceptability, ambiguity, and paraphrase relations with other expressions. For both disciplines the very rich empirical phenomenology of, respectively, economic and linguistic reality appears very distant and, in practice, absent. And both disciplines tend to capture reality in terms of equations (economics) or principles (linguistics) while sharing a tendency not to inquire into the actual mechanisms and processes that may explain these equations and principles.

The insufficient or inadequate interaction between theories and empirical reality that characterizes the social sciences is one of the reasons which explain why these disciplines often seem to be intrinsically incapable to make real progress and to provide us with a kind of knowledge and understanding of the phenomena they study which have the same cumulative and persuasive character of the results of the natural sciences. A second reason derives from the second rule which governs the progress of science. This rule is: One should not give too much weight to disciplinary divisions. One certainly can understand the existence of disciplinary divisions in science since reality is so complex and it includes such a range of very different phenomena that it does not make sense to suppose that only one big discipline can explain the whole of reality. However, reality is not actually divided up into the distinct categories of phenomena which are separately studied by the different scientific disciplines. In reality every category of phenomena is connected with all other categories, it influences and is unfluenced by the other categories, it explains and is explained by the other categories. Therefore, science advances when it connects one category of phenomena with another category, when it looks for explanations for the phenomena which are studied by one discipline in another discipline, when it connects and unifies, not when it separates.

Disciplinary subdivisions exist in both the natural and the social sciences. However, the natural sciences, i.e., physics, chemistry, and biology, have available to them a shared conceptual and methodological framework. Conceptually, all the natural sciences believe that everything is the physical effect of some physical cause and everything has an ultimately quantative nature. Methodologically, they all use the laboratory experiment. Therefore, they can explain biological phenomena in chemical terms and chemical phenomena in physical terms, and make crucial progresses when they are able to do so.

The situation is very different for the sciences of human behavior, at both the individual and social scale. The disciplines that study human behavior and human societies do not have a single, shared, uniformly accepted conceptual framework, and each of them has its own empirical methodology. Therefore, explaining the phenomena studied by one discipline in terms of the phenomena studied by another discipline is always controversial and rarely accepted by the first discipline.

Economics is both conceptually and methodologically separated from all the other disciplines that study human behavior, and the inadequate interaction, the restricted interface, between theory and empirical reality which characterizes economics is to a large extent a result of this disciplinary isolation which explains why economics has been called an "autistic" science (cf. the electronic journal Post-Autistic Economics Review, http://www.btinternet.com/~pae_news/join.htm). Although economists recognize that the phenomena they study are produced by the behavior of human beings, "neo-classical economics has defined itself as explicitly ‘anti-behavioral’. Indeed, virtually all the behavior studied by cognitive and social psychologists is either ignored or ruled out in a standard economic framework” (Mullainathan and Thaler, 2000). But the problem goes well beyond the relationhip between economics and psychology, i.e., the science that considers human behavior as its general object of study. Economics ignores not only psychology (and biology, if human behavior is studied using biologically inspired theoretical models such as artificial neural networks) but also other sciences of human behavior such as cultural anthropology and history. Almost all the behavior exibited by a human being (skills, beliefs, needs, values) is culturally transmitted, that is, it has been learned from others and from the artefacts produced by other. Economics ignores this origin of human behavior and how the process of cultural transmission transforms human behavior both at the individual and at the generational scale. Furthermore, economics studies economic phenomena as they manifest themselves in a restricted subset of human societies, i.e., modern Western-type societies. Economic phenomena of non-modern, non-Western-type societies are not taken into consideration by economists, do not influence their models, are not taught to economics students (Schneider, X). In the education of economists there is no space for economic anthropology, there is always less space for the past history of economic phenomena in Western societies, and even for the past history of the discipline itself. This empirical “myopy” of economics, which sees only what is very near, may compromise its ability to understand what is very near.

Another aspect of the very limited interface between the science of economics and empirical reality concerns the type of model of human behavior which is used in economics. Standard economics uses a model of perfect or absolute rationality which is clearly nonempirical. But also the more empirically justified model of limited or bounded rationality which emerges from the experiments of psychologists and economists captures only one form of human behavior: explicit, conscious, intentional, (boundedly) rational behavior. Human beings behave not only by explicitly considering what their goals are and what they know about themselves and about the environment in which they live, and by inferentially generating new explicit knowledge, even if with limitations and errors. They also, and perhaps more frequently, behave purely reactively, from habit, under an impulse or an emotion, because other people behave in the same way, because other people do not behave that way, because they are unable to behave differently, and so on. There is no reason to believe that if human beings normally behave in this large variety of different ways, they abandon this variety of ways of behaving when they generate economically relevant behaviors in order to behave rationally.

But the “autism” of economics is also, and perhaps especially, revealed in the restricted view of the phenomena which are assumed to be of interest to the discipline. Economics mostly studies a single type of social transfer of resources, i.e., exchange (markets), and a restricted subset of all the different types of resources which are socially transferred in human societies. Instead, one would like to see a science of economics which studies <u>all kinds</u> of social transfer of <u>all kinds</u> of resources that take place in human societies. Let us clarify what we mean.

A resource is defined here as anything which an individual seeks to possess and to continue to possess. When we observe an individual who behaves in such a way that he or she tries to bring X (which may be anything) in his or her possession (freedom of use) or to avoid to cease possessing X, then we call X a resource. This is a criterion for identifying something as a resource but there is no need or possibility to provide a closed or fixed list of resources, not only because our definition is intentionally very general and abstract but also because resources change with the changing needs of the individual.

Resources are said to be socially transferred when an individual or organization gives some of its resources to another individual or organization. There are at least five different types of social transfer of resources:

(1) altruistic transfer of resources among genetically related individuals, often without reciprocation
(2) sharing of resources in small groups of individuals with delayed and uncertain reciprocation
(3) synchronous or, in any case, guaranteed reciprocal transfer of resources (exchange, markets)
(4) transfer of individual resources to a central structure which by using these individual resources is able to produce new resources which single individuals would be unable to produce (private and public organizations)
(5) forced transfer of resources (war).

Economics tends to study only some limited types of resources which are socially transferred in human societies, mostly those which are exchanged in markets, and to study only economic exchange (type (2) above) and, but only in part, centralization (type (4)) as types of social transfer of resources. (Some exceptions are Becker, 1991, and Buchanan and Tullock, X.) These restrictions are not really justified and they may even compromise our understanding of the restricted phenomena that economics chooses to study because all the different kinds of resource transfer which occur in human societies interact and influence each other and because there is constant change in human societies in what resources are socially transferred in which way.

Another empirical restriction of economics concerns what motivates economic behavior. Given our definition of a resource, something X is a resource only if there is an individual who behaves in such a way that he or she tends to come to possess X or to continue to possess X (where possession is to be free to use X without external interference). This clearly links the concept of a resource with the concept of needs or wants. An individual is said to need or to want X if he or she treats X as a resource. But of course needs change, and so do resources. Economics is not concerned with changes in needs because it considers the needs of an individual (the individual's preferences) as given and fixed. Economics justifies its position that considers the needs of individuals as given and fixed by pointing out that "economics as a social science does not examine what people ought to want, as distinguished from what they do want" (cf. the entry "Economics", in the International Ecyclopaedia of the Social Sciences, Volume 4, pag. 402). But this distinction between what is and what ought to be, between science and ethics or politics, obscures the fact that there is another entirely factual and scientific issue which is ignored by economics: why do people want what they do want? This is especially disappointing since in modern economic systems many behaviors of such economic agents as firms and sellers are aimed at changing what people want rather than at giving them what they want. Therefore, by failing to address the factual questions of why people want they want, how people's wants and needs change, and what makes them change, economics ignores important classes of strictly economic behaviors and an important part of economic reality. (But see Bowles, 1998.)

Of course, these very strong restrictions in the types of phenomena which economics considers as its empirical domain and the disciplinary isolation of economics are tightly connected and they explain each other. Economics fails to study many types of social transfers of many types of resources because they constitute phenomena which are studied by other disciplines. Type (1) (see above) social transfers of resources are studied by psychologists, type (2) by anthropologists and sociologists, types (4) and (5) by political scientists and historians.

We conclude, then, that economics is a science with a severely restricted empirical basis. The empirical basis of economics in practice consists in the observed values of a set of aggregate economic variables and how these values change as a function of time and of each other. The behavior of the individuals which ultimately determines the value of aggregate economic variables is not empirically examined, economic phenomena that are different from those which characterize non-Western modern societies are ignored, only a subset of social transfers of only a subset of resources are labeled "economic phenomena" and are taken into consideration.

Simulations can help economics to enlarge its empirical basis and they can promote new types of economic theories and models that generate a richer and more comprehensive set of empirical predictions, thereby strengthening the interaction between theory and reality in economics.

As we have already observed, theories in science are expressed either verbally or mathematically. Theories which are expressed verbally, i.e., using the common language, can be vague, insufficiently detailed, incomplete, and it may remain unclear which specific empirical predictions actually derive from the theory or if a given empirical prediction which is said to derive from the theory actually derives from the theory. Theories which are expressed mathematically, i.e., using equations, are precise and make very specific and clear empirical predictions but they tend to capture the relations existing among variables, not the mechanisms and processes which underlie the relations among variables and explain them.

Simulations are theories expressed as computer programs. Because they are expressed as computer programs simulations cannot incorporate theories which are vague, insufficiently detailed, or incomplete, in that these theories/simulations would not 'run' in the computer or would not produce the expected results. Furthermore, given a theory expressed as a computer simulation, it is completely clear what predictions are actually derivable or nonderivable from the theory expressed in the simulation because the results of the simulation are the predictions derived from the theory and they can literally be observed on the computer screen. And, normally, a simulation generates a very large set of different results (predictions) as consequences of the experimental manipulations of the researcher who treats the simulation as a virtual experimental laboratory. And, finally, unlike equations simulations tend to capture the underlying mechanisms and processes that explain the observed relations among aggregate variables, rather than just the relations themselves.

All these properties of simulations make it possible to envisage a new type of economic science which by adopting simulations as its research method realizes a much stronger and articulated interface between theory and empirical reality. Economic theories and models expressed as simulations can generate much larger sets of empirical predictions and therefore they can make contact with a richer range of different empirical phenomena.

Furthermore, simulations can help economics to give less weight to disciplinary divisions which, as we have seen, are another cause of the very restricted empirical basis of economics as we know it. A very practical but crucial reason that justifies the existence of separate scientific disciplines is that reality exhibits such a large number of very different classes of phenomena that it is completely unrealistic to imagine that there may be one single discipline that covers all of reality. The reason is that the limitations of the human mind make it impossible for a single person, a single scientist, to possess all the different competences that are necessary for studying so many different kinds of empirical phenomena. However, it is not only a problem of quantity of information but also a problem of information processing. A theory which would cover various classes of different phenomena normally studied by different scientific disciplines must be able to “compute” how very different categories of variables and entities interact to produce the observed phenomena. This is impossible if the “computing” must take place inside the mind of a human being. Interdisciplinary research is one way to solve this problem through the collaboration of the minds of different researchers belonging to different disciplines. But interdisciplinary research has many well-known intrinsic and sociological limitations, and in any case it can only solve the problem of putting many different disciplinary competences together, not the problem of "computing" the predictions or consequences of interdisciplinary models. This can only be done inside a single "system".

Simulations are the solution to this problem. With simulations scientific research becomes a collaborative enterprise between the researcher(s) and the computer. The computer has memory (storage) and processing (computing) abilites that greatly exceed those of the human mind. The computer can store many different categories of data normally treated and used by different scientific disciplines and, more importantly, it can compute the interactions among these different categories of data that generate the desired phenomena. A science of economics which uses simulations as its research tool can construct and test complex and detailed models of how many different types of entities, environments, conditions, and variables interact to generate phenomena of many different forms of social transfer of many different types of resources that may happen in populations of artificial individuals that behave in a variety of different ways.

Finally, simulations may make it easier for economics to interact with the other disciplines that study human behavior and human societies because, conceptually, simulations represent a sort of "lingua franca" for all these disciplines which is based on a shared conception of social reality as a complex system, and methodologically, they are a single method for conducting research which may be adopted by all these disciplines and may have the same unifying consequences for the behavioral and social sciences which the experimental method has for the natural sciences.

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