1-1963

Simulation in Economics and Business

Daniel Orr

Two Books on Simulation in Economics and Business
Author(s): Daniel Orr
Source: *The Journal of Business*, Vol. 36, No. 1 (Jan., 1963), pp. 69-76
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/2350454

TWO BOOKS ON SIMULATION IN ECONOMICS AND BUSINESS*

DANIEL ORR†

COMPUTER simulation is a specialized form of modeling that has been used for many years in the testing of certain physical systems, for example, airframes. Much more recently, this technique has been applied to economic and social systems. If the promise is great, as some believe, the problems are great as well, and the flow of results has so far been small. The two volumes under review have little else in common beyond their use of large computer simulation to deal with business and economic problems; the novelty of simulation in these areas and the opportunity to appraise the technique in two dissimilar applications are the justifications for this joint review.

At least two aspects of any simulation may be of interest: the value of the model itself, with computer-related considerations recognized only insofar as they constrain the model-builder; and the layout aspects, that is, how efficiently does the simulation use computer capacity and computing time, and how readily can it be adapted to other (perhaps smaller) computers. This review will focus almost entirely on the first of these aspects.

GENERAL CHARACTERISTICS OF THE STUDIES

The Forrester volume is concerned with normative microeconomics (the discovery of improved operating policies for the firm); the Orcutt *et al.* book deals with descriptive macroeconomics (the study of activity on an economy-wide level). Interestingly, the techniques employed by Forrester have traditionally been associated with research in macroeconomics (he relies heavily on linear difference equations as a vehicle of representation), while the Orcutt group sets out to analyze macroeconomic phenomena in a model that preserves the identity of the individual decision-making units. This reversal of normal role is consistent with the exploratory nature of these two studies. (*Microanalysis* is offered as a progress report describing completed work on a small portion of a project that will ultimately (it is hoped) simulate the entire economy; *Industrial Dynamics*, however, is regarded by its author as describing a research tool that is finished, proven, and ready for use.)

To an extent, both studies are a product of two ancient methodological controversies in economics and business. It has long been held by many writers in these fields that the ability to perform

* Jay W. Forrester, *Industrial Dynamics* (New York: M.I.T. Press, 1961), pp. xv+464; and Guy H. Orcutt, Martin Greenberger, John Korbel, and Alice M. Rivlin, *Microanalysis of Socioeconomic Systems: A Simulation Study* (New York: Harper & Bros., 1961), pp. xviii+425 (referred to hereinafter as "*Microanalysis*").

† Assistant professor, Graduate School of Business, University of Chicago. This review article was completed during the summer of 1962, while I was a participant in a Ford Foundation program on mathematical models and computers at the University of Chicago. I am greatly indebted to Martin Shubik for our discussions of simulation, and of specific points regarding the two books here reviewed. These discussions were made possible by the Ford Foundation program. In addition, discussions with George Hadley originally stimulated my interest in this area. I alone am responsible for all errors of description or interpretation found in the next few pages.

controlled experiments, and to analyze models richer in empirical detail than the standard ones, would lead to an ultimate upgrading of the scientific "quality" of research in these disciplines. There is little controversy regarding the criterion by which a model is judged, the reliability and accuracy of predictions that it yields; however, it has often been said that the ability to perform experiments on highly realistic models would enrich our comprehension of why a model delivers accurate and reliable predictions, as well as assure greater reliability and accuracy.

Computer simulation is probably the first widely available large-scale technique that permits experimentation; simulation also permits a higher degree of realism than was heretofore accessible, in the form of non-linear dynamic models comprising large numbers of relationships. Both the studies with which we are concerned are heavily committed to experiment and realism, although they set about the task of performing more realistic experiments in virtually opposite ways. Forrester plots the dynamics of a single enterprise in an environment rich in challenges: for example, he asks whether a production system, as it is realistically represented in the model, can cope with an exponential delay in production response and a demand series represented by a sine wave; or, if not, what changes can be made to nullify the adverse effects of these environmental conditions? Operating rules that make the computer model perform satisfactorily in the face of extraordinary stress should, he feels, benefit the real firm's operations under ordinary conditions.

The experiments of Orcutt and associates are aimed at accurate short-run forecasting of aggregative economic data. Forces that determine the changes in status of the individual microeconomic decision units are summarized in a few linear equations: these equations give the probability of changes of various types, and "lots are drawn" to determine the new status of the decision unit. Behavior of the entire economy is studied as an aggregate of the behavior of the individual decision units. The type of realism sought in this approach is freedom from another methodological bugaboo, the loss of accuracy that stems from the aggregation of data. However, in order to make experimentation feasible, it is necessary to sacrifice richness of detail in the mechanism that determines changes in the status of the individual decision units. Otherwise it is uneconomical to deal with those units in large numbers.

Thus, the two volumes represent approaches that are extremes of the available possibilities: a normative study of a single, interaction-free economic unit operating in a rich environment versus a descriptive study of many economic units that interact in an otherwise sparsely structured environment.

"INDUSTRIAL DYNAMICS": AN APPRAISAL

J. W. Forrester is an electrical engineer who has achieved great distinction in computer and systems design and has found economic and business problems challenging. His approach to these problems, which he calls industrial dynamics, has been incorporated into the curriculum of the MIT School of Industrial Management, and has received a cordial reception in the popular business press.[1] In this section we will attempt an appraisal of the achievements and promise

[1] "New Way To Spot Company Troubles," *Business Week*, November 4, 1961, pp. 158–60; "Advertising: A Problem in Industrial Dynamics," *Harvard Business Review*, March, 1959; and "Industrial Dynamics: A Major Breakthrough for Decision-Makers," *Harvard Business Review*, July, 1958.

of his approach, based on the methodological discussions, research reports, and examples found in his book.

Forrester treats a firm (or other socioeconomic system) as a set of interrelated networks: each network comprises flows and stocks of a critical variable. In the case of a firm, six networks are specified: materials, orders, money, capital, personnel, and information. (Capital and money are not, however, incorporated in any of the models specifically described in *Industrial Dynamics*.) These networks and their interactions are characterized by systems of bounded linear difference equations that are chosen on the basis of how well they represent the physical system. An exception is the order network, where certain conventional "loads"—for example, a step function, a sine wave, or a random signal—are used to represent the behavior of demands through time.

The most noticeable—and to many readers, no doubt a most offensive—attribute of Forrester's book is his insistence on the unique validity of his approach. He is violently critical of economic analysis and operations research. Even management gaming, a learning device not unlike simulation in its objectives and procedures, is scathingly attacked. He dismisses nearly all of this earlier research as "exercise in formal logic, rather than . . . search for useful solutions to real problems" (p. 3). To achieve more substantial results, "Mathematical models should incorporate all the factors that our judgment tells us are essential . . . no longer should we limit our attention to oversimplified analysis simply to achieve analytical solutions" (p. 361). Management science has fallen prey to "the misleading objective of trying only for an optimum solution [which] often results in simplifying the problem until it is devoid of practical interest" (p. 3). Industrial dynamics, on the other hand, makes use of "mathematical models that can . . . simulate the time sequential operation of *dynamic* systems, *linear* or *nonlinear*, *stable* or *unstable*, *steady-state* or *transient*. The model must be able to accept our descriptions of *organizational form*, *policy*, and the tangible and intangible factors that determine how the system evolves through time. Such models will be far too complex (tens, hundreds, or thousands of variables) to yield analytic solutions" (p. 52; italics in original). This new approach is proposed as the key to the most important and perplexing contemporary socioeconomic problems: "What, then, is the structure, the policy, the allocation of resources, the timing, the goals, and the aspirations that can lead to success [in economic development]? Here is an area for innovative model building. We need to combine the economic factors, the political, the educational, and the technological to obtain a better understanding of the dynamics of growth" (p. 361).

It will be interesting to see if the future course of computer simulation of economic systems is toward greater detail, as Forrester predicts, or whether simulation evolves toward truly thorough exploration of the critical interactions among a few key variables, which has been the objective of all the best work in management and economics to date. There is certainly no question that simulation permits more "realistic" representations—use of models that were formerly too cumbersome for ordinary analytic methods. However, it has yet to be shown that such enhanced representations are of value.

The results obtained thus far by Forrester's modeling device give little support to his glowing forecasts. *Indus-*

trial Dynamics presents two major illustrations of the technique as an aid to policy design; in each case the sources of difficulty could to a large extent have been understood and dealt with on the basis of analytic work preceding industrial dynamics. An approach through previous techniques would also be cheaper: Forrester's two examples are not characterized by the uncompromising incorporation of "tens, hundreds or thousands of variables," but they are nevertheless costly in terms of skilled analytic labor and computer capacity.

One example discussed at length by Forrester is a basic model of a retail-distribution-manufacturing system. Sales are represented by the three simple devices mentioned earlier—a step function, a sine wave, and a random signal. All three sales patterns show instability in the system as it is initially formulated: fluctuations in customer orders cause much greater percentage fluctuations in material flows and stock levels within the system. In this initial model, the time delay required to process and fill orders is not the source of instability; however, dramatic smoothness is attained by the removal of the wholesaler from the system. Forrester comments: "The foregoing raises an interesting question about industries having more than three distribution levels. For example, in the textile industry . . . there are often four or five distribution levels. . . . May not a good deal of instability be caused by the existence of so many levels?" (p. 33).

It happens that the distributor in Forrester's model controls his inventory according to a "*k* months' supply" rule, that is, he tries to keep on hand an amount proportional to his average demand over the past *k* months. (This rule may be a conscious policy measure, or it may be the net result of the interaction of several plausible procedures administered at several different control points within the firm.) It is well known that this sort of inventory policy frequently leads to amplification of fluctuations.[2] Contrary to the inference Forrester draws, the seat of the difficulty may not be the distributor himself: rather it may be the inventory control rule assigned him in the model. The problem examined in the example has been "solved" earlier by less cumbersome and less costly techniques.

The second major illustration of the efficacy of industrial dynamics is a case study that deals with a system characterized by fluctuations in employment and inability to fill customer orders within a stipulated delivery period. Oscillations observed in production and back orders were produced in the model by a *k* months' supply rule. It was also discovered that labor force layoffs were not made soon enough in the face of an upper turning point in sales activity; this latter factor was most important in conjunction with an oscillation-amplifying inventory requisition rule like the one built into the model. Appropriate corrections led to stable behavior, and the recommended changes are, according to the *Business Week* report cited earlier, achieving the desired results for the client. However, if part of the malady was in fact prior use of the *k* months' supply rule, some of the client's difficulties might have been eliminated quickly and comparatively cheaply. The stabiliz-

[2] A demonstration of this in the literature of management science is that of Harlan D. Mills, "Smoothing in Inventory Operations," *Navy Supply System Research*, Study I, Mathematica (Princeton, N.J., July, 1960). In addition, the fluctuation-magnifying effects of inventory accelerators like the one Forrester builds into his model have long been understood by economic analysts (see Lloyd Metzler, "The Nature and Stability of Inventory Cycles," *Review of Economics and Statistics*, August, 1941, pp. 113–29).

ing or destabilizing properties of various inventory policies have been ascertained from linear models; nevertheless, a rule that is capable of producing undesirable fluctuation when things are linear should be suspect despite delinearization of the model.

That simulation is currently very much an art is well conveyed by Forrester's "approach to enterprise design": "Identify a problem. Isolate the factors that appear to interact to create the observed symptoms. Trace cause-and-effect information-feedback loops that link decisions to action to resulting information changes to new decisions. . . . Construct a mathematical model. . . . Generate behavior through time as described by the model. . . . Compare results against all pertinent available knowledge about the actual system. Revise the model until it is acceptable as a representation of the actual system. Redesign, within the model, the organizational relationships and policies which can be altered in the actual system . . ." (p. 13). The example and case study cover with admirable thoroughness the process of setting up system equations but completely avoid the (seemingly inevitable) subsequent problem of revising them when they turn out to contradict "pertinent available knowledge about the actual system." Very little substantive help is available in carrying out these steps (a review of material on feedback control systems and exponential delays provides the exception), and criteria for judging the success that attends each of these operations are not yet available.

The problem of validation is particularly troublesome in conjunction with the artificially generated behavioral time series. A special compiler, DYNAMO, has been designed to facilitate the execution of these simulations. The compiler automatically prints out the simulated time series of critical variables as per cent deviations from starting levels or rates. Unfortunately, having achieved an extremely useful and simple output mode, Forrester suggests no standards by which to evaluate performance, other than the obvious one ("look for the smallest amount of fluctuation in all variables"). It is easy to think of cases for which damped fluctuation of all variables is inferior to amplified fluctuation of one variable with attendant greater damping of another. When eight or nine such variables are present, as in the case and example, determination of tradeoff among the variables on an *ad hoc* basis is quite a challenge. In standard optimization models, the loss function may be only the roughest sort of approximation to the unwritten "true" criteria, but it is unambiguous, and quickly leads to a "best" policy. Sensitivity analysis can then be employed to gauge the range of applicability of that policy.

One further consideration mitigates against industrial dynamics as an approach to macroeconomic problems, and attenuates its usefulness for dealing with multi-plant, multi-warehouse, multi-outlet microeconomic systems. The compiler DYNAMO makes no provision for *sets* of retailers, wholesalers, customers, etc., and as a consequence it must be extremely difficult to keep the individual members of these groups distinct.[3] Such interesting behavioral information as lengths of waiting lines at specific retailers is unavailable: only aggregate retail backlog can be determined. The industrial dynamics approach thus involves the study of "representative" systems, with different levels characterized not as sets but as single units.

[3] This specific point was called to my attention by M. Shubik.

COMMENTS ON "MICROANALYSIS"

The ultimate objective of Orcutt and his co-workers on the project reported in this volume is a scale model of the American economy. The representation is to comprise a set of interrelated but distinct decision-making units, which operate in a set of markets. The portions that have been both modeled and tested so far are only those that determine changes in the demographic characteristics of the family "decision units." Modeling work has been carried out on the demand for higher education, the labor force, and the impact of liquid assets upon consumption behavior.

By creating individual units and markets with a high degree of autonomy, the simulators hope to achieve a truly large-scale simulation; the various routines for each unit or group of units could be carried out independently, perhaps on different computers. The relevant output of a group of decision units or markets could be relayed to other locations and serve to determine partially the behavior of decision units simulated in those locations.

Thus, their plan is systematically to generate accurate sample data on the whole economy. The feeling underlying such an approach is that extrapolation of the readings on such a sample is a more promising way to obtain macroeconomic forecasts than is the usual approach of extrapolating the aggregates themselves. In addition, insights can be obtained regarding the impact of alternative policy measures on the mechanisms governing the period-to-period transactions of the individual decision units.

Because it is necessary to recalculate and tabulate the status of each of the microcomponents of population (4,580 families and 10,358 individuals) once each time period, it is only feasible to determine the changes in status of these units on the basis of a small number of linearly interacting variables. Four basic demographic "events" can befall a family in any period: marriage, childbirth, divorce, and death. The probability of each event is determined by one or more of the characteristics that determine the family's status: marital status; race, number, age, and sex of members; parity of married women; and interval since marriage. In addition to calculating probabilities of such events, the demographic model records an increase in the age of every family member once per "run."

Whether generating and tabulating the behavior of microcomponents is more promising than the alternative of using computing time and computer capacity to perform more elaborately structured extrapolations of the aggregates themselves is an open question. For example, in the study of consumption behavior one must decide whether an aggregation of four thousand families, with the consumption of each determined by its own simple linear function of current income, will provide a better estimate of aggregate consumption behavior than would an elaborate multivariate estimate of aggregate consumption, with such variables as "permanent" income and past peak income built into the forecast.

The status of the demographic sample is kept up to date in the following manner: during each period, the sample families are re-examined in succession. Probabilities based on the initial status of a family govern the expected outcomes of the random experiments that determine whether a demographic "event" befalls the family in the current period. When such events occur, they lead to revision of the family's status. Final status is stored on tape, in preparation for the next period's round of activity. This procedure is straightforward for dealing with birth, divorce, or death, but marriage presents some difficulty, since two persons are involved, and new members are not introduced *ad hoc* into the population for the purpose of consummating marriages. In the updating routine, one demand made on computer storage is to maintain a file of marriageable males and females. When the Monte Carlo process indicates marriage for a member of the population, the waiting list of the opposite sex is searched for a suitable partner: if nobody with appropriate characteristics is available, the new bride or groom designate is placed on the list to wait for a suitable future candidate.

The characteristics of the initial population were based on sample data obtained from the Survey Research Center, Ann Arbor, and were made to conform to the population of the United States in April, 1950.

Since the purpose of this portion of the simulation is to obtain an accurate representation of population movements from period to period, and since the small size of the sample can lead to misrepresentation when sample events are extrapolated to depict the condition of the population at large, the authors found it necessary to devise a tracking mechanism to prevent such cumulative and self-reinforcing errors. Two such mechanisms have been tried: the first controls errors due to sample size and errors due to misrepresentations built into transition probabilities; it uses data obtained from the population itself to increase the probabilities of future sample events when such events occurred too infrequently earlier in the simulation and vice versa. Assuming the availability of up-to-date data on the true population, this procedure yields useful extrapolations one period into the future; it also permits the testing of alternative sets of transition rules against historical series. The second tracking procedure controls only the errors resulting from the smallness of the sample. It prevents the cumulative number of simulated events such as births from wandering too far from the expected value. This second alternative enables forecasting without current data from the actual physical system: after aggregation it should yield almost the same results as would an extrapolation along a linear trend, with an expected deviation equal to some linear combination of past deviations from the trend line.

The tracking mechanism is probably the most controversial detail of the simulation reported in *Microanalysis*. It should be kept in mind that the population model is intended to serve as a source of the demographic data that are relevant to the behavior of the individual decision-making units; despite the major contribution the authors have made in synthesizing the relevant demographic literature on birth, death, marriage, and divorce, the population model is not represented as a source (or testing device) of demographic hypotheses. Given the intended purpose of the demographic simulation, some form of tracking device may well be justified in making the longer extrapolations. In making one-period forecasts, one wonders why it would not be better simply to feed in the most current available data from the true population, instead of requiring a synthetically generated sample to track those same data. The second tracking method is certainly more plausible; it is less easy to imagine a simpler alternative to tracking expected values as a way of controlling longer extrapolations; the procedure of Orcutt and co-workers keeps records of the individual microunits, while most of the simpler possibilities that come to mind do not. It also seems clear that some sort of control against errors due to limited sample size is necessary.

The use of such tracking mechanisms for maintaining control of the *status* of each microunit is one thing; however, the temptation to extend use of the tracking approach into future phases of the simulation should be resisted, since mechanistic correction schemes that affect the decision processes of the microunits, or the behavior of the several markets, are to be deplored. A good job of modeling these decision or market processes cannot be claimed if feedback control is exercised, unless the feedback model does a good job of describing the causal mechanisms that underlie decision or market behavior. In the absence of good modeling, the macroeconomic model serves neither as a reliable forecasting device nor as a trustworthy vehicle for testing the impact of policy changes. Again, the problem of validation is not an easy one: when is a representation good, and how can alternative representations be compared?

CONCLUSIONS

The constraints on modeling activity were once entirely technological: because very few results are available on systems of non-linear differential equations with non-constant coefficients, such systems (with their attendant flexibility and richer ability to represent a wide variety of relationships) have never been a fruitful device in modeling. Simulation, however, has pushed the technological barriers further back: a trial-and-error approach with a highly structured model is now within the realm of possibility. The constraints on modeling *cum* simulation are economic: the value of another structural equation or another iteration may be lower than their costs. The problem is further confounded by the difficulty of measuring these marginal costs and returns.

In view of these difficulties, it is interesting to reflect on the cost implied by a macroeconomic model containing more than fifteen thousand individuals and families in the household sector alone: unless this sector is to be the tail that wags the economy, the number of markets, firms, and decisions implied is truly astronomical. It is almost certain that major break-throughs in the technology of digital computers must attend the technical feasibility of the ultimate goal of this highly ambitious program: the question of its economic feasibility will still remain open long thereafter.

The same comments apply with equal force to the more completely developed and less far-reaching models Forrester had provided. His most significant contributions are undoubtedly his non-linear normative micro-models that embody feedback controls and time delays. Yet in the work that he has already made available, the question of his marginal contribution is a valid one. The linear predecessors of the models with which he deals are rich in results similar to his and are comparatively inexpensive sources of information. Thus both volumes here reviewed share the weaknesses of other well-publicized "great leaps forward": in different degree they outrun available skills and resources, and in different degree they throw away the many potentialities of present abilities.

It is, of course, very easy to raise questions regarding any pioneering work, as we have done regarding both of these volumes. Both are exciting in their objectives and ingenious in their methods: whether either will find definitive results for economics or management science is not yet settled.