A MICROSIMULATION MODEL OF THE HEALTH CARE SYSTEM

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I. An Overview of the Model

This paper reports on the conceptualization of a simulation model of the health care system which deals explicitly with the microanalytic behavior of the individuals and institutions comprising the system.[2] The scope of the model includes all aspects of the production and utilization of personal health care but excludes environmental, mental, and dental health, as well as drugs and biomedical research. Even with these limitations the system under consideration is extremely complex and rich in structural and institutional detail, involving, as it does, many different participants, typical institutions, and complex multi-party transactions, etc.

To cope with the complexities of the health care system we have employed a modular approach, organizing the system into three modules--health services, health manpower, and health professions education. These particular modules were chosen because interactions within each are manifold, while interactions among them are fewer and simpler. The modules and interactions, which summarize the conceptualization of the complete model, are displayed in the block diagram below. In this particular conceptualization there are five simulated populations. Three of the populations are composed of people namely: individuals, health manpower, and students. The remaining two populations are composed of institutions, namely: health services institutions and health professions education institutions.

The individuals and institutions in each of the simulated populations are described by certain attributes or characteristics. The characteristics for the population of individuals include age, sex, residence, ethnic group, family income, health insurance status, etc. The population of health manpower is subdivided into physicians, nurses, and allied health manpower, and individuals in each of these subpopulations are characterized by age, sex, length of training, specialty (for physicians), marital status and number of children (for nurses), etc. The population of students is characterized by age, sex, ethnic group, previous education, and marital status. With respect to the institutions, the population of health service institutions is divided into hospitals, nursing homes, outpatient clinics, and physicians' offices--each of which are, in turn, described by a variety of characteristics such as size, ownership or control, nature of payment, length of stay, etc. Similarly, health professions education institutions are divided into medical, nursing, and allied health personnel schools--each of which are described by size, university affiliation, ownership, accreditation, etc.

Each module contains markets corresponding to that particular sector of the health care system; and these markets are influenced by the simulated populations as illustrated in the block diagram. Thus, in the health services module the demand for health services is generated by the population of individuals, and the supply of health services is generated by the population of health service institutions. In the health manpower module the demand for health manpower is obtained from the population of health service institutions. It is derived from the underlying demand for health services. The supply of health manpower is obtained from the population of health manpower. Finally, in the health professions education module, demand for health professions education is generated from the population of potential students, while the supply is generated from the population of training institutions.

The markets in each of the modules are characterized by widespread and persistent disequilibria. This is reflected in the model by variations in waiting time, and allocations of shortages and surpluses according to the nature of the disequilibrium.

Perhaps the best way to describe the set of interactions that take place among the five populations is to summarize the events occuring in a typical simulation run. For this purpose we will refer to the linkages indicated above by the number given to each on the Block Diagram. The basic solution sequence is presented in Figure 1. Major clusters of these linkages are enclosed in the boxes lettered A through G.

Before simulation begins each of these five populations is generated, and initial conditions are specified for values of the lagged variables.

A. We begin with an individual from the general population, assign a diagnostic condition to him (1), determine his needs for patient visits (2) and bed days (5), then adjust his needs for patient visits by the prices he faces, giving his demands for patient visits (3). The demands for patient visits are then aggregated over all individuals to give market demands for outpatient services (4). The determination of bed days demanded is slightly more complex than that of patient visits demanded due to the usual requirement that a physician be seen before admission to a hospital is granted. The quantities needed are transformed into demands by taking account of prices and financial constraints (8), as in the case of patient visits. Additionally, estimates of the patient visits to be received are employed (7) to

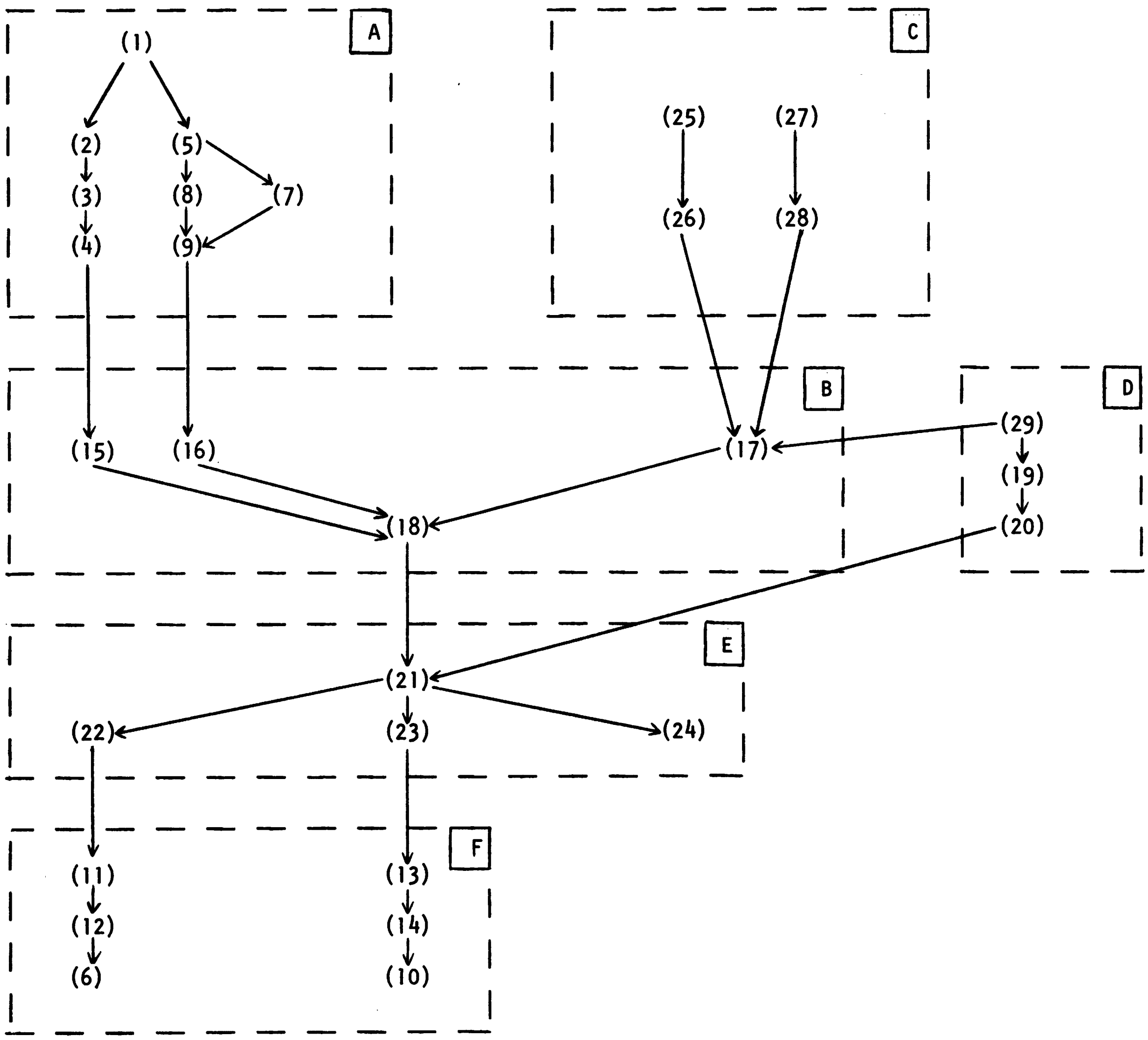

Figure 1: The Solution Sequence For One Period
(Numbers refer to linkages on the Block Diagram)

adjust further for the physician approval aspect of hospital admission. That is, if fewer patients manage to see physicians, then fewer patients will demand care from hospitals. Bed days demanded by individuals are then aggregated (9) to yield market demands for inpatient services.

B. On the basis of the demands faced by service institutions, demands for health manpower are derived separately for the various types of inpatient institutions (15) and outpatient institutions (16). These are aggregated to give part of the market demands for health manpower. Additional health manpower demands come from educational institutions for faculty (17). The demands for manpower from all three sources--outpatient, inpatient and health professions education institutions--are aggregated to give market demands for each category of health manpower (18).

C. The demands for faculty are derived by the following sequence of steps. First, the demand for health professions education by individual students is generated (25), then these demands are aggregated to yield market demands (26). Independently, the supplies of openings at individual institutions are developed (27), and aggregated to provide market supplies (28). If market demands for education exceed available openings, as is to be expected for physicians' education, then the scarce openings are allocated to the students. If the number of openings exceeds the number of qualified applicants, as is expected in nursing programs, then the vacancies are allocated among the programs. Demands for faculty by educational institutions (17) are derived from the numbers of students educated. Eventually students graduate (29) and enter the various pools of health manpower.

D. Having generated the manpower demand side in B, we turn next to the supply side. Hours of work supplied by each individual in the manpower pool are developed (19) and aggregated over all similar types of individuals to obtain market supplies, in terms of hours of work offered, by all types of health manpower (20).

E. The demands and supplies for health manpower interact in the health manpower market to determine wage adjustments, shortages, and the actual allocations of manpower to the various types of institutions (21), with corresponding feedbacks to the populations of outpatient service institutions (22), inpatient service institutions (23), and educational institutions (24).

Following this key solution step, the forces in motion branch outward again, with the manpower markets' influences on the outpatient, inpatient, and educational institutions proceeding to move through separate channels.

F. Outpatient institutions have now received the inputs which (through the production function) limit their capacity to provide patient visits to individuals. The next step determines the amounts of patient visits these institutions will seek to supply to individuals in the various diagnostic classes (11). These supplies (12) interact with demands in the outpatient services market to produce changes in prices and waiting times, and to result in allocations (6) of physician visits (if shortages occur) to the different categories of patients.

A similar pattern develops for inpatient service markets. The allocation of manpower to these institutions (23) sets limits on the amounts of bed days (13) they will seek to supply to individuals in the various diagnostic classes. These supplies (14) interact in the inpatient markets to generate changes in prices and waiting times, and, further, to produce allocations (10) of bed days (if shortages occur) to the various types of patients.

This completes the steps through a given simulation solution for one period. Additional periods would normally be run by updating all populations by the growth functions, and then repeating the above solution steps.

The foregoing conceptualization is, of course, highly simplified by contrast to the enormously complex real world system. Nevertheless, we feel that it represents a major step in the direction of adequately modeling the real system. Previous studies have focused on only one small part of this conceptualization looking at, for example, the demand for health services or "shortages" of physicians in isolation from the rest of the system. Such a partial equilibrium approach is obviously less desirable than a general equilibrium approach, which is the ultimate goal of our health care system modeling efforts.

Perhaps the most important reason for considering the entire health care system is that models of the complete system could be of tremendous value in designing and evaluating policy with respect to national health programs. Experimenting with the real world system is prohibitively expensive, both in terms of both costs and human suffering. In this regard, Medicaid, the major Federal program for providing health care services to low income families, has been criticized on the grounds that it amounts to an extremely expensive unsuccessful experiment which now should be replaced.

With a running microsimulation model of the health care system it would be possible to experiment on the model rather than on the real world system. Alternative policies could be studied by simulating the real world system modified to allow for these policies, and a particular policy or set of policies could be adopted on the basis of an examination of the simulated outcomes. An example is national health insurance. Several alternative plans have been proposed and a number are under active consideration by the Federal government.

These include: Federal payment of a certain stipulated percentage of hospital and physician costs; Federally sponsored major medical insurance which would pay for all health expenditures above a stipulated percent of family income lowering of the eligibility age for Medicare and, possibly, also covering preschool children under this program; and numerous other. These could all be analyzed using the model we have developed. The first impact typically would be in the health services market. The demand for such services would shift outward, increasing the amount of services supplied and prices of these services. In order to produce the increased services provided, the health service institutions would shift outward their demand for health manpower. The next impact would be on the health education module, shifting outward the demand for health professions education. The last impact would, in the long run, eventually result in an increase in the size of the manpower pool. All of these impacts, and their complex interactions, could be analyzed quantitatively using a running version of our microsimulation model.

II. Specific Features of the Model

In designing the model described above, we adopted a micro rather than a macro approach because of the requirement that the model be capable of simulating both the aggregate behavior observed in health care markets and the individual behavior of the many participants in these markets.[3]

A macro econometric model may be capable of predicting the gross magnitudes of certain indicators of health care activities--and it would clearly be less complex to operate and less expensive to build. However, such a model yields little or no information about the distribution of health care, yet the distribution as well as the total level of health care is of manifest policy concern. Medicare for the aged and Medicaid for the indigent are two important illustrations of programs designed to alter the distribution of care among types of consumers.

A microsimulation model is ideally suited for estimating the distributional, as well as the aggregate, impacts of major policy changes. However, there is a problem in moving from a macro approach to a microsimulation approach in building this type of model--namely, the temptation to focus narrowly on one component of the health care system in order to make microsimulation replicate as closely as possible, the intricacies of the real system being modeled. This effort to simulate intricate details almost necessitates a drastic restriction of the scope of the model, since to model many components, and to simulate each in great detail, becomes totally unmanageable. It is especially important to guard against this danger in the design of a model of a highly interdependent system in which changes in one sector have vital ramifications with respect to the variables in other sectors of the system. In the health care system, for example, changes in medical and hospital insurance for the aged will affect not only the utilization of services covered by insurance, but also services not covered. Additionally, the utilization of inpatient and outpatient care by the rest of the population is affected as a result of fee increases, longer waiting times, and, possibly, shortages in these markets. The challenge in developing a microsimulation model, therefore, is to balance the desire for comprehensive systems analysis against the temptation to reach for too much detail and intricacy in modeling individual behavior. Although recent technological advances, in the form of better computer software and hardware, greater data availability and more refined mathematical techniques, have enormously expanded capability to move in both directions, there still remains a tradeoff which, in the last analysis, cannot be avoided in constructing a microsimulation model of the complexity we have undertaken. In this regard, we feel that the terms "micro" and "macro" suggest a false dichotomy whereas, in reality, there exists a continuum of degrees of detail and aggregation. For example, we simulate the behavior of each patient and physician, yet the two interact only in aggregate markets. That is, the behavioral variables associated with individual patients and physicians are treated as "micro" in nature; but the fees for physician services are "macro" variables insofar as they are determined not for every pair of interacting patients and physician but only for the overall markets relevant to the various categories of physicians. This is illustrative of a large number of problems where we tried to design an optimal mix of detail and generality. As a consequence of the approach chosen our model is considerably more aggregative than is true of most previous microsimulation models, while, at the same time, it is much more finely disaggregated than any existing macroeconometric model of the health care system.[4]

The device of having populations not interact on a specific individual to individual basis has been used generally in our model.[5] That is, a patient is not matched with a specific physician, and sent to a specific hospital. Rather, aggregate demands for physicians services and hospital services interact with aggregate supplies. To have included multi-party matching would have yielded little in detailed information by comparison to the loss in not treating the types of variables that can be included using the adopted approach of interacting aggregate supply and demand equations. This approach has made it feasible to employ several populations simultaneously in our microsimulation model--which would have been prohibitively expensive if we had followed the lead of others and maintained multiparty matching.

In addition, the decision to use aggregate interactions between populations resulted in significant data storage and processing simplifications, since microsimulation data can then be stored according to what we have called the "cell", instead of the more typical "file", approach. In a file, each of say 20,000 individuals is represented by a set of variables characterizing that individual. The first file entry will, for example, contain an individual's age, marital status, sex, etc. In the cell approach one uses a complete joint distribution exhausting all possible types of individuals. While the cell and the file approaches are fully equivalent in terms of information contained, in the sense that except for an arbitrary permutation of file entries one can transform a data set organization from one into the other, their processing consequences are not the same. First, the cell approach is very sensitive to the subdivision of attributes and, thus, is ideal for coarse divisions. On the other hand, it is completely invariant to the sample size, which is, of course, a definite strategic advantage in the effort to control sampling error. By contrast, the file approach is invariant to the degree of subdivision of attributes, but very sensitive to the number of individuals in the population. Second, the cell approach has the advantage that a random number, drawn from the distribution of the sum of random events for a given set of individuals, can be used instead of the sum of many random drawings, one for every individual. It is clear that no essential information is lost in microsimulation by aggregating over individuals of identical characteristics. Furthermore, a certain amount of aggregation may be extremely efficient, giving rise to little loss of detail yet reducing the size of the simulation task significantly.

Other unique characteristics of our model result from the inclusion of salient institutional features of the health care system, rather than considerations of operational feasibility and efficiency. One such characteristic is the widespread use of non-price rationing when shortages occur in most, if not all, of the relevant markets. That is, in such situations we employ a two-price system, using variations in waiting time to ration services when (or for as long as) pecuniary price adjustments are insufficient to accomplish this task. Thus, for example, in the services market of our model admissions to hospitals are based partly on priorities which give preference to the critically ill when there are not sufficient beds to satisfy the total demand. By the same token, since it is apparent that prices (i.e., tuitions) are not set so as to clear the market for medical school openings, we developed an allocation mechanism which distributes the shortage of such slots among the demanders. A similar mechanism distributes the surplus of first-year openings in nursing schools among the suppliers.

Still another aspect of our model which represents a marked departure from its predecessors has to do with the specification of input-output relationships. Specifically, our model recognizes that many factors of production are employed in producing each of the major categories of health services. In this connection the popularly used production functions (e.g., the n-factor CES function) have a characteristic that is manifestly absurd if applied to the analysis of such finely subdivided input categories. This characteristic is the constancy of the partial elasticity of substitution (however defined) between all pairs of inputs. This means that if any two factors are made close substitutes then all factors must be close substitutes. Thus, for example, if registered nurses are estimated to be very close substitutes for licensed practical nurses in some institutional settings, the form of these production functions will force one to the further implication that RN's are very close substitutes for physicians. In order to overcome this problem, we have employed a multi-level CES function which permits tractable variation in the partial elasticity of substitution.[6] In this form of the production function, the direct partial elasticity of substitution between factors in the same subset is constant and easily variable. The Allen partial elasticity of substitution between factors not in the same subset is also constant and also easily variable. Thus, the multi-level CES production function permits certain factors to be close substitutes for each other while, at the same time, being poor substitutes for factors not in the same subset.

Finally, in order to handle the heterogeneous nature of the "outputs" produced by both outpatient and inpatient institutions, a similar modification was made with respect to the output side of the production functions employed in our model. That is, we have employed a multi-output production function with mathematical properties relating the various outputs that are similar to those relating inputs. Thus, output substitutability is also specific to pairs of outputs and can vary between diagnostic types of patients by institutional setting.

III. Implementation of the Model

The brief report presented above has, of necessity, been limited to a broad overview of the model, and a few remarks regarding its most unique features. A complete description of the model we are now seeking to implement is contained in the forthcoming proceedings of the National Conference on Health Manpower Simulation Models. It is our hope that within two to three years we will have an operational prototype of the model. Once the model is actually running it will be progressively modified by the addition of new relationships, and the respecification of those now included, until it has been judged acceptable as a forecasting tool by health planners and other public officials charged with responsibility for establishing and administering national health programs.

Footnotes

1. M. D. Intriligator and L. J. Kimbell are also on the faculty of the Department of Economics, UCLA.

2. This project was supported in part by Contract No. PH-108-69-69 from the Bureau of Health Professions Education and Manpower Training, National Institutes of Health. A more detailed description of the model is given in our final report ("The Development of a Microsimulation Model of Health Manpower Demand and Supply"), forthcoming in the Proceedings of the Conference on Health Manpower Simulation Models, August 31-September 1, 1970, Bethesda, Maryland.

3. The pioneering research on microsimulation models was performed by Orcutt and his associates. For a detailed description of their work see: Orcutt, G. H., Greenberger, M., Korbel, J., and Rivlin, A. Microanalysis of Socioeconomic Systems: A Simulation Study. New York: Harper & Brothers, 1961.

4. For examples of macroeconometric models of the health care system see:

   Feldstein, M. S. "An Aggregate Model of the Health Care Sector," Medical Care, V (November-December, 1967), pp. 369-81.
   Feldstein, M. S. "An Econometric Model of the Medicare System." Discussion Paper No. 103. Cambridge, Massachusetts: Harvard Institute of Economic Research, Harvard University, January, 1970. (Processed.)
   Feldstein, P. J., and Kelman, S. "A Framework for an Econometric Model of the Medical Care Sector," in Empirical Studies in Health Economics, Klarman, H. E. (ed.). Baltimore: The Johns Hopkins Press, 1970, pp. 171-90.

5. Investigators at the Research Triangle Institute compared the relative efficiency of "open" and "closed" microsimulation models, and concluded that "open" versions are much more efficient for purposes such as ours. A detailed description of their recent research is presented in the forthcoming Proceedings of the Conference on Health Manpower Simulation Models, August 31-September 1, 1970, Bethesda, Maryland.

6. The multi-output, multi-level CES production function takes the form:

$$\left((y_1^{\delta_1} + y_2^{\delta_1})^{\frac{\delta}{\delta_1}} + (y_3^{\delta_1} + y_4^{\delta_1})^{\frac{\delta}{\delta_2}}\right)^{\frac{1}{\delta}}$$

$$= \left((x_1^{\rho_1} + x_2^{\rho_1})^{\frac{\rho}{\rho_1}} + (x_3^{\rho_2} + x_4^{\rho_2})^{\frac{\rho}{\rho_2}}\right)^{\frac{1}{\rho}}$$

This function can be called a two level CES production function in both inputs and outputs.

BLOCK DIAGRAM OF A MICRO-SIMULATION MODEL OF HEALTH MANPOWER SUPPLY AND DEMAND