AD 690584

ECONOMIC PROBLEMS OF INFORMATION AND ORGANIZATION

Progress Report: April 1968-August 1969

Nonr-222(77), NR 047-029

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1. Introduction

Research on the present contract during this period falls under the the following headings:

Dynamic and uncertainty aspects of resource allocation

Stocks and flows of U. S. manpower with college and university degrees

Decision rules for warning systems with noisy signals

Non-linear regression theory

Summaries of results obtained and of work in progress under each heading are presented in the following sections. The next-to-last section describes publication plans, and the last section lists the Technical Reports, Working Papers, and reprints of publications issued during the report period.

2. Dynamic and Uncertainty Aspects of Resource Allocation

2.1. An Algorithm for Dynamic Programming of Economic Growth

This paper studies the computational properties of an algorithm for optimal resource allocation over time, and applies the algorithm to a model of the U. S. economy. The algorithm is applicable to multisector models with differentiable production and objective functions, and uses a method of successive approximation by linear-logarithmic functions, in which the recursive features of dynamic programming are combined with exact formulas for optimal solutions in the linear-logarithmic case. Memory and computing requirements go up approximately linearly with the number of state variables, and experience indicates that the algorithm can handle a model with 10 sectors and 50 time periods in a few minutes on a machine like the IBM 7094. The algorithm is applied to a four-sector empirical model of the U. S. economy, and various optimal paths are compared with the observed path of the economy from 1910 to the present. The sensitivity of the optimal solution to the parameters of the system is studied in some detail. A horizon of 50 gives a good approximation to the solution for an infinite horizon; this can be improved by suitable approximations for the value of final stocks. (Ref: Tech. Rept. No. 28)

2.2. Allocation of a Scarce Resource under Uncertainty

This paper applies the analytical techniques of the theory of teams to the evaluation of alternative information structures for the allocation of resources under uncertainty. In particular, we try to throw new light on the information role of "prices" and "demands" in the theory of allocation. T. A. Marschak (1959) and L. Hurwicz (1960) have emphasized the role of prices and demands as "messages" in a given allocation mechanism. Now a message is not "informative" unless it tells the receiver something he didn't know before; hence the study of the value of an exchange of messages (e.g., between enterprise managers and resource managers) presumably presupposes that before the exchange the various agents had incomplete and different information about the relevant variables, and therefore could properly be said to be uncertain about them. In the application of the theory of teams to this situation, we assume that this uncertainty can be expressed in terms of probability distributions, and that the several agents have a common goal, namely the maximization of (expected) output.

Furthermore, in the previous literature on allocation and price adjustment mechanisms it is usually assumed that the adjustment mechanism (an iterative procedure) is allowed to run until an equilibrium is reached, and in most cases the object of the analysis is to show that such an equilibrium is a solution of the problem of optimal allocation. In the present example we emphasize the situation in which there is not sufficient time for equilibrium to be reached before decisions must be made, and the environmental variables take on new values. In this case, even after some exchange of messages, the economic agents will have to take decisions on the basis of incomplete and different information, although this information will be more complete than it was before the exchange of messages.

The results of our example suggest that information in the form of "prices" and "demands" may be quite efficient even if the adjustment process is not allowed to reach equilibrium. The results also suggest that even though "demands" are calculated by the enterprise managers to maximize accounting profit, using the "prices" transmitted to them by the resource managers, the same definition of profit cannot be used to calculate the optimal <u>decisions</u> of the enterprise managers, based on the information provided by <u>the "price"</u> messages. (Reference: Working Paper No. 248)

In further work, which however has not yet been included in any paper, it has been possible to generalize the foregoing paper to the case of an arbitrary number of scarce resources, under the assumption of a quadratic payoff function. It can be shown that (1) a single step of the "classical" price-demand adjustment process is as efficient as providing the central resource allocator with complete information about the parameters of individual production units, and the individual production units with complete information about the supplies of the scarce resources; (2) if the number of production units is large, with no dominant units, then a single step of the price-demand adjustment process is approximately as efficient as complete exchange of information among all of the economic agents. It can also be shown that these results hold to a first order of approximation if the payoff function is differentiable.

2.3. <u>First-Order Certainty Equivalence</u>

Given any problem of decision under risk to which the expected utility hypothesis applies, one may associate to it first a riskless problem in which random disturbances are replaced by their expected values, and second a class of intermediate risky problems with decreasing degrees of uncertainty. In this class the optimal decision depends in principle on the degree of uncertainty, but turns out to be independent of it, to the first order of approximation, in the neighborhood of the riskless problem. The first-order certainty equivalence explains why it is so difficult to characterize the situations in which an increase in the degree of uncertainty requires a decrease in the allocation of resources to the risky projects. (Reference: Technical Report No. 27)

This work has been extended to the case of a term, for use in the study described in Section 2.2.

2.4. Simulation of Alternative Decentralized Planning Procedures in Deterministic and Stochastic Environments

Following the "Decentralized procedures for planning," by E. Malinvaud (Reprint No. 64), Malinvaud and T. Hogan elaborated several new decentralized procedures for planning resource allocation. These procedures promised to be more consistent with the availabilities of information in actual economic planning than the standard decomposition methods of linear and non-linear programming. They also involved the transmission of "quantity" as well as "price" messages from the center to the individual production sectors. These procedures have been simulated on 2- and 5-sector models, and their efficiency compared under various parameter configurations. For a deterministic environment, efficiency is measured in terms of closeness to the optimum achieved with a given number of iterations, or of number of iterations required to achieve not more than a specified error.

A novel feature of the simulation is the comparison of these decentralized procedures under a stationary stochastic environment. The parameters of the model are generated by a stationary auto-regressive process (discrete time). One iteration of the procedure in question is performed per unit time, and we compute the average difference between the sequence of "solutions" generated by the procedure and the corresponding optimal solutions for each time unit. (Reference: Technical Report No. 32.)

3. Stocks and Flows of U. S. Manpower with College and University Degrees

3.1. Educational Planning for Labor Force Needs: A Review

It is well recognized that highly educated manpower represents at least as vital a resource for the U. S. economy as do our various non-human resources (primary commodities, physical plant, etc.). Labor force and manpower planning are typically thought of in terms of occupations and/or industries, whereas educational planning is developed in terms of degrees and specialties. This paper reviews the attempts that have been made to relate the labor force and educational categories. These attempts range from econometric and linear programming models to human factors and personnel management studies.

Whether or not education should be a planned industry was decided in the days of Smith and Mill on social and political grounds, but economists did not concern themselves very much with general education on economic grounds until a search for the determinants of growth in the period from 1950 on helped focus their attention on it.

A 1957 article by Solow concluded that a large percentage of U. S. growth in this century could best be explained by the concept of neutral technical change. This gave scope for believing that the increased education of the labor force had been an important determinant of growth. The work of Denison, Schultz and Becker, heavily dependent as it is on the assumption that labor inputs grouped according to educational attainment receive wages equal to their marginal productivity, is the principal quantitative reason for believing that there is substantial benefit to be gained from planning general education for labor force needs.

In educational planning as in other areas of long-term planning, planning procedures have not been devised to handle substitutability very well. Consequently, recourse is had to a formulation of the planning problem in terms of activity vectors. Two educational planning approaches to plan for labor force needs which use this technique are the manpower requirements approach and the optimization approach.

The basic procedure of the manpower requirements approach is to convert a sectoral employment forecast into an educational requirements forecast through the use of technical coefficients. Thus, the basic idea of the approach is that a certain mix of employee educational development is required for production. Despite this rigidity, the manpower requirements approach is the most promising approach to educational planning for labor force needs because it easily links up with models of the education sector at a level of disaggregation as fine as desired.

The occupational input variant of the manpower requirements approach, which is based principally on work by Parnes, Eckaus and Scoville, suffers doubly from the no-substitutability assumption, since one assumes an occupational as well as an educational requirement. The direct-educational input variant, which starts from work by Tinbergen and Correa, while naturally subject to the rigidity of the manpower requirements approach, can be given a less rigid interpretation than the occupational input variant. A projection using direct-educational input vectors can be seen to project present practice rather than economic necessity.

The optimization approach, represented by work by Bowles, Bernard, and Adelman, attempts to build criteria for the labor-force worth of educated people directly into integrated models of education and the economy (Adelman, Bernard) or into simple models of the education sector (Bowles). This approach can be criticized on the ground that the allocational value of the models does not outweigh the disadvantages of a low practical level of disaggregation and a limited ability to convincingly handle the social and consumption demand for educational services. While the optimization models may not be practical as yet for actual planning, the integrated models of education and the economy can probably play a part in planning by helping to delimit the set of feasible educational outputs.

The concepts of job, occupation and education do not have self-evident meanings at a basic level of analysis. Concepts of "role set," "role repertoire," and "role set-repertoire gap" are used in this paper to construct a framework for expository purposes. The occupational analyses of Scoville and U. S. Bureau of Employment Security, for instance, can be usefully appraised in this framework.

Scoville's work which develops a new occupational classification can be criticized on the ground that summarizing job content along a single dimension such as skill or, in his case, "level of job content," obscures basic information which is needed to forecast how jobs will change (how technical coefficients will change) in the future. The BES work, a large and interesting start toward job role set specification, does not give sufficient detail for those key job desiderata which are related to general personal capability.

The work of Bloom et. al., a group of university examiners, is a quite successful attempt to develop a classification system for intellectual behavior, and, therefore, sheds light on the limitations of the work of Scoville and the BES. The Bloom group's work demonstrates that there is an important affective component of intellectual behavior which can only be separated from the cognitive component for purposes of classification. An accurate description of a job's role set cannot, consequently, be restricted to skill roles, but must be specific about all the significant areas of human functioning which will be used on the job.

The effect of firms' demand for educated labor on the formation of the capabilities (role repertoires) which young people bring to the job is probably limited to a short-run effect on skill roles and a medium-run effect on the quantity of educational output in the various specialty and level categories. A full-blown qualitative as well as quantitative effect in the long run can undoubtedly be expected from economic institutions, but at that far-off horizon, theory on decision-making processes in the firm must give way to general social theory. What firms want probably becomes a dependent variable.

If firms are not easily identified as the qualitative determinants of capabilities in children, home, school, and community can be so identified. The determinants of which children succeed in school and thus continue, and of their traits are quite complex, reflecting the interaction of character formation processes in schools with broader social class determination processes. Thus a firm's ability to secure the role repertoires it needs or desires in its beginning employees is limited by processes which have an important locus outside the firm in schools. In a discrete world, this may be an important consideration for economic development and a justification for educational planning.

Within the firm, it is possible to conceive of a gap-closing process, based on a firm's efficiency drive and its desire to stockpile human capital, which does important work in the allocation of human capital. In this view, the action of the labor market and wages is the first crude approximation of allocation with the gap-closing process the fine-tuning mechanism.

3.2. Stocks of Terminal Degree Holders

In this study, which is still in progress, we develop a data series on the stocks of educated persons in the teaching and non-teaching labor force. The stocks are in terms of degrees, academic specialties, age, and sex. Although scattered surveys have given partial data on these variables, no comprehensive time series covering the entire U. S. population have been compiled thus far.

The stock and flow data being developed here refer to terminal degrees; that is, the numbers in any category do not include those persons who subsequently received a higher degree. Annual degree award data from the Office of Education are combined with life tables and information on the distribution of time between degrees. The resulting figures are further adjusted in the light of aggregate census data (which do not include information on advanced degrees or specialties) and a special sample survey conducted by the National Opinion Research Corporation. Adjustments will also be made for migration and labor force participation. The resulting figures will then be disaggregated by sector of employment, including teaching as one sector. Preliminary figures, by degree level, age, and sex, have been developed for 1930, 1940, 1950, 1960, and 1967.

4. Decision Rules for Warning Systems with Noisy Signals

This study analyzes a class of models of warning (detection) systems with noisy signals. These systems are treated as stochastic sequential decision problems, in which the criterion of optimality is the minimization of total discounted expected cost.

Although the literature contains several studies on the subject, few have attempted to analyze a multiple signal system. On the other hand, most detection and warning systems used in industrial and military systems have multiple signals. In an attempt to fill this gap, five models of single and multiple signal systems are studied here, and the characteristics of the optimal decision rules are derived. In the multiple signal case, the optimal decision rules do not have a simple form.

In the single signal case, the optimal decision rules do have a simple form: respond to the "warning" as soon as the warning signal has been "on" a certain critical time, where the critical waiting time is to be chosen optimally. This suggests the following generalization of the "critical waiting time rule" to the case of several signals: for each subset of signals there is a critical waiting time; respond to the warning as soon as for some subset of signals all of the signals in that subset have been "on" for at least the critical waiting time corresponding to that subset. Indeed, if one adopts the procedure of at each date making a maximum-liklihood-ratio test of the hypothesis that the system is still "good" against the hypothesis that the system has "changed" (i.e. that the warning is justified), then one is in fact led to a critical waiting time decision rule.

However, it can be shown, for the multiple signal models that we consider, that the sequential decision rule that minimizes total discounted expected cost is generally not of the critical waiting time form. Numerical computations are performed to measure the expected loss due to using a critical waiting time rule instead of the optimal rule. For the case of two signals, the optimal decision rule can be characterized in terms of the current "posterior" probabilities of a change in the environment. (Reference: Working Paper 249 and Technical Report 31)

5. The Consistency of Non-Linear Regression

A sample of T observations on the variables x, $z_1, z_2, \ldots z_m$ has been generated according to the model:

$$x_t = g(z_{1t}, z_{2t} \ldots z_{mt}; \alpha_1, \alpha_2, \ldots \alpha_p) + \varepsilon_t, \quad (1)$$

in which x_t, z_{1t}, $z_{2t} \ldots z_{mt}$ designate the values taken by the variables in observation t ($t=1,2\ldots T$), $\alpha_1, \alpha_2 \ldots \alpha_p$ are p unknown parameters to be estimated ($k=1,2\ldots p$), ε_t is an unobservable random variable with zero expected value and g is a known function of its m+p arguments. By a regression on model (1) we mean the computation of estimates $\hat{\alpha}_1, \hat{\alpha}_2 \ldots \hat{\alpha}_p$ that minimize the mean square deviation of x from g:

$$\frac{1}{T} L_T(\alpha) = \frac{1}{T} \sum_{t=1}^{T} [x_t - g(z_{1t} \ldots z_{mt}; \alpha_1 \ldots \alpha_p)]^2. \quad (2)$$

The regression is said to be linear if the function g is linear in the vector α with components $\alpha_1, \alpha_2, \ldots \alpha_p$, a situation extensively explored in the literature. This paper gives alternative sufficient conditions for the least squares estimates to be consistent in the case of nonlinear regression, i.e., without the assumption of linearity of g with respect to the parameters α.

6. Publication Plans

The book, Economic Theory of Teams, by J. Marschak and R. Radner, is in press and is scheduled for publication in 1970 by the Yale Press, as part of the Cowles Commission Monograph Series.

The book, Decision and Organization (A Volume in Honor of Jacob Marschak), edited by R. Radner and C. B. McGuire, is in the final stages of manuscript preparation, all the chapters having been completed. A publisher has not yet been chosen. It is hoped that the volume can appear during 1970.

Detailed outlines of both of these volumes appeared in the previous Progress Report.

7. Technical Reports, Reprints, and Working Papers

Technical Reports

No. 27 First-order certainty equivalence. E. Malinvaud, April 1968.

No. 28 An algorithm for dynamic programming of economic growth. S. I. Friedmann, June 1968.

No. 29 The consistency of nonlinear regressions. E. Malinvaud, October, 1968.

No. 30 Normal backwardation, forecasting, and the returns to commodity futures traders. Charles S. Rockwell, February 1969. (Issued in combined form with Reprint No. 68.)

No. 31 Warning systems with noisy signals. T. Y. Hans Tjian, August 1969.

No. 32 Simulation of alternative decentralized planning procedures in deterministic and stochastic environments. Terry Hogan, August 1969.

Reprints (IPER/CRMS Reprint Series in Economic Theory and Econometrics)

No. 44 Roy Radner, Équilibre des marchés à terme et au comptant en cas d'incertitude, Cahiers d'Econometrie, No. 9 (1967), pp. 30-47. (TR No. 24, April 1967)

No. 53 Roy Radner, A note on maximal points of convex sets in ℓ_∞, Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability, Vol. I, pp. 351-354, 1965-66. (TR No. 22, January 1966)

No. 55 Roy Radner, Dynamic programming of economic growth, in Activity Analysis in the Theory of Growth and Planning, M.O.L. Bacharach and E. Malinvaud, editors, Macmillan, London, 1967. (TR No. 17, February 1964)

No. 58 Roy Radner, Competitive equilibrium under uncertainty, Econometrica, Vol. 36, No. 1, January 1968. (TR No. 20, April 1967)

No. 64 E. Malinvaud, Decentralized procedures for planning, in Activity Analysis in the Theory of Growth and Planning, M.O.L. Bacharach and E. Malinvaud, editors, Macmillan, London, 1967. (TR No. 15, November, 1963)

No. 68 Charles S. Rockwell, Normal backwardation, forecasting, and the returns to commodity futures traders, Food Research Institute Studies, Stanford University Press, 1967. (Issued in combined form as Technical Report No. 30 and Reprint No. 68.)

Working Papers

No. 248 Roy Radner, Allocation of a scarce resource under uncertainty: an example of a team, March 1968 (Chapter 12 of Decision and Organization.)

No. 249 T. Y. Hans Tjian, A note on maximum-liklihood-ratio decision rules for simple noisy warning systems, April 1968.

No. 253 Douglas Adkins, Educational planning for labor force needs, May 1968.

No. 255 Roy Radner, Teams, June 1968 (Chapter 11 of Decision and Organization).

Sandra Schwartz, Activity analysis models of California public higher education, August 1969.