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Input-Output and Activity Analysis in Industrial Concerns

Alan S. Manne

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by

Alan S. Manne **

Introduction

As followers of an ancient scholastic tradition, economists much prefer to talk about, rather than to measure economic relationships. Engineers and industrial managers are, for the most part, inhibited by a rather different sort of tradition: Producing something that is immediately practical. Given these customs, it is little wonder that much of the work on the actual measurement of industrial production functions has emerged as a byproduct of an interdisciplinary movement - variously known as "operations research", "management science", or as "industrial engineering".

During the past decade, the operations research movement has taken on the dimensions of a fad, and much nonense has been written in an attempt to define the relationship between the new and the old. At the risk of adding still further to this infamous mountain of literature, I shall be concerned here with the ties between interindustry economics and intrafirm production analyses.

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Areas of non-overlap

It seems easiest to begin by noting these types of operations research (hereafter abbreviated O. R.) that rightly occupy a good deal of space within the literature, but which do not always have a direct bearing upon the production functions of interindustry economics. To begin with, a good deal of O.R. is not concerned with production activities. Much of it is directed toward the effect of marketing effort upon the sales of the individual firm. See Herniter and Magee (1961). Other studies are devoted to the effects of research and development expenditures upon the profitability of the firm. And still others are concerned with the adaptation of the firm to an oligopolistic market environment. See Shubik (1960).

Even when an O.R. study is directed inward toward production management problems within the firm, this does not inevitably mean that much light is thrown upon economy-wide decisions. Within batch-type processes (e.g., special-order metalworking shops), the control problem is frequently centered around the optimal <u>sequencing</u> of individual lots. E.g., Baker and Dzielinski (1960). Poor sequencing choices mean that excessive amounts of working capital are tied up in in-process inventory, and that at the same time many high-priority orders are delayed due to the lack of one or more critical components. The efficiency of the individual shop is significantly affected by the management's ability to make good sequencing decisions. However, from the viewpoint of the economy as a whole, sequencing analyses imply an inordinate degree of disaggregation. In order to remain within manageable dimensions, it looks as though interindustry models will have to avoid sequencing details, and instead be concerned with the aggregate availability of equipment and the aggregate workload. The price of such aggregation consists of taking as a datum one of the chief variables within intrafirm analyses: the processing delay on individual jobs.

Sequencing is closely related to another favorite O.R. topic: the analysis of waiting lines. This is a theory built around the random nature of demands for service - plus the randomness of processing times. It is this probabilistic feature that accounts for the fact that it pays to plan work assignments at a good deal less than 100% of the theoretical capacity to handle a static, predictable load. The most elementary version of waiting line theory (single server, infinite calling universe, and negative exponential distribution of servicing times and of times between arrivals) predicts the following relationship between the workload assignment and the expected number of delayed jobs:

$$\text{expected number of jobs being serviced or waiting for service} = \frac{r}{1-r}$$

where r represents the workload assignment as a fraction of the static, theoretical servicing capacity. (See Sasieni, Yaspan, and Friedman (1959), p.133.)

Waiting line theory here leads to a typical neoclassical situation: smoothly increasing marginal costs of delay.* It is the job of the

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* Waiting line theory does not always lead to such neoclassical results. "Pooling" phenomena imply that there are significant economies-of-scale. See Feller (1957), pp. 418 - 420.

industrial engineer to recommend a workload assignment balancing off the costs of delay versus the costs of unutilized capacity. Similar models may be employed to analyze the possibilities of substitution between workmen and machines in the case of semi-automatic production processes. Within the context of an interindustry model, no one - to my knowledge - has yet attempted to allow for such trade-offs. Economy-wide models will probably continue to take as a datum several of the factors regarded as variables within intrafirm analyses: the effective amount of equipment capacity that may be utilized without "undue" delays to customers or "undue" idle time of workmen.

One more example will be noted, and this time a favorite type of linear programming application, the trim problem. See Eisemann (1957). Here the scheduler's job consists of prescribing a combination of alternative methods for slitting wide rolls (e.g., coils of paper or of strip metal) into narrow rolls so as to: (a) satisfy prescribed demands for the narrow rolls, and (b) minimize the trim loss. For an individual plant, it is not an excessive task to enumerate the alternative stock-splitting combinations and product size requirements, and then to perform the appropriate calculation of minimum trim losses. Within an economy-wide model, however, it is much more reasonable to believe that the trim loss percentage would be regarded as a datum, and that the various roll widths would be aggregated together so as to form a single class of products.

Interindustry applications

Even after making allowances for the fact that a substantial fraction of O.R. models are intended for use only within a single enterprise or plant, there still remain many cases where such models are directly applicable - or could be made applicable - to problems of interindustry economics. In each of the instances to be cited here, the single-sector model is of an activity analysis type, and - from a computational standpoint - would be directly compatible with similar models of other sectors. I shall attempt a thumbnail sketch of only three individual cases: (a) electric power, (b) petroleum refining and transportation, and (c) chemical production.

(a) Electric power. Massé and Gibrat (1957) have reported on the programming of investments within the nationalized power industry of France. They were particularly concerned with the evaluation of several competing methods of producing electric power: steam, tidal, and various types of hydroelectric plants. In comparing these alternatives, they found it unsatisfactory to measure capacity in terms of just a single dimension, e.g., the total number of kilowatt-hours available within a year. Instead, they found that a more realistic multi-dimensional measure of capacity was needed, and that it could be obtained through the use of an activity analysis model.

Massé and Gibrat observed that the output of each type of electricity plant could be described in terms of a bundle of joint products: the amount of power available for meeting certain daily peaks and seasonal averages of demand. Their model was phrased in terms of meeting these peaks and average demands for electricity by means of a minimum-cost combination of plant types: "The French economy which is possessed of neither rich hydraulic resources, nor rich mine deposits like those of the United States or the Soviet Union, must remedy this relative poverty by the intelligent combination of all its resources. One hope is variety." p. 163.

From the viewpoint of an interindustry model, what is interesting about the Massé-Gibrat study is the following: (1) An activity analysis model is distinctly more desirable here than a conventional input-output formulation. There are several alternative processes of production available in this sector, and there are also joint products. The particular choice of process will have significant interindustry effects upon the demand for fuel, for cement, for electrical equipment, and for capital investment. In turn, the choice between processes will depend upon interindustry demands for the various joint products. And (2) it is practical to describe the electric power sector along the lines of activity analysis. It is not an impossible matter to obtain engineering estimates of the inputs and outputs for the various process alternatives. Furthermore, activity analysis does not entail exorbitant computational costs. The original Massé-Gibrat model proved useful, even though it referred to a single region and a single time period, and it involved only four equations, four slack activities, and five process alternatives.

(b) Petroleum refining and Transportation. Within the United States, the oil and chemical companies probably represent the single largest group of users of linear programming.* A good summary of the petroleum

* The importance of the oil and chemical industry among the major users of linear programming can be gauged very roughly from the following list of sponsors of one of the codes written for the I.B.M. 704 calculator: Socony-Mobil, Standard Oil of California, and Richfield. For the I.B.M. 7090, the sponsors were: Socony-Mobil, Texaco, Union Carbide, Shell, Gulf, and Esso.

This list should not be taken to imply that the oil and chemical companies represent the sole U.S. users of linear programming. There have probably been more individual applications within agriculture and food processing than elsewhere. Typically, however, the agricultural models have been small-scale (under 20 restraints), and they lend themselves to a variety of shortcut methods. See Waugh and Burrows (1955); also Candler (1960).

industry's uses of linear programming is to be found in a paper by Garvin, Crandall, John, and Spellman (1957). The activity analysis structure seems particularly well-suited to a chemical process industry such as petroleum refining.** Here, there are closely interlocked sets of material balances

** Steel represents another major chemical process industry, where process alternatives and joint production are significant. Steel, however, has been slow to adopt linear programming - despite the demonstration by T. Fabian (1958) of an appropriate methodology for iron and steel mill applications. This is not the only recent instance in which the steel industry has been slow to adopt a technological innovation.

and product specifications, and there there are numerous process alternatives for shifting the product-mix. Furthermore, joint production is typical within oil refining processes.

There is no longer much question of the advantages of employing the activity analysis framework for intrafirm operating problems within the petroleum industry. But is this a practical approach for economy-wide purposes?

Here again - as in the case of the electric power sector - I believe that the answer is in the affirmative. An industry-wide U.S. model has already been worked out for petroleum refining at a level of engineering process detail fairly comparable to that practiced within individual firms. See Manne (1958). This model contained 105 restraint equations and 205 non-slack activities - probably an excessive amount of detail to be incorporated within an interindustry model. However, Thomas Marschak (1958) has simplified this larger model and reduced it to 39 equations. With further experience, there is little doubt that such a model could be made more compact, while still preserving the activity analysis features of process alternatives and of joint products.

Marschak has embedded the 39-equation model of refining technology into a four-region, 195-equation spatial model of the United States. He has concerned himself with the interdependence between crude oil production, refining, and transportation. It is only through such a regional model that it is possible to explore the determinants of the industry's demand for transportation services - and in turn, the petroleum transport industry's demand for petroleum products. Similar multi-location models are known to be in use within a number of the major U.S. oil companies.

(c) <u>Chemical production.</u> The chemical companies are characteristically more reticent than the oil companies about the disclosure of process information. There is, however, one extensive analysis of the petrochemical and synthetic fiber sector that is within the public domain and that seems typical of the remainder of the chemical industry. See Isard, Schooler, and Vietorisz (1959). Despite the fact that their monograph is addressed to a particular practical question - the optimal type of industrial complex to be located in Puerto Rico - the authors provide the reader with an activity analysis table covering a substantial fraction of the chemical industry. Altogether, they estimate the technical coefficients for 73 processes - some of them being alternatives to each other, and many of them involving joint products.

Isard, Schooler and Vietorisz report only two significant departures from the activity analysis framework - increasing returns to scale with respect to labor and capital. A good deal of evidence is cited in favor of the hypothesis that labor and capital inputs into chemical processes are related to output via a fractional exponent law. This, of course, violates the fundamental activity analysis axiom of divisibility. Economies-of-scale - i.e., indivisibility of processes - are of major significance for interindustry programming. Much of the rationale for multi-sector coordination - particularly for programming investments within underdeveloped countries - is based upon the argument that single-sector optimization will often result in misleading conclusions when economies-of-scale are present. Chenery (1959) and Haldi (1960) have already begun to explore this problem area; and Gomory (1958) has devised a computing algorithm which ought to prove useful for this purpose. Somehow or other - by integer programming or other means - it now ought to be possible for the interindustry model-builder to study problems that involve economies-of-scale. Perhaps the development of integer programming for intrafirm purposes will result in the availability of this computing tool for interindustry analysis - just as the intrafirm analyses have already provided substantial amounts of numerical data that can be utilized as input and output coefficients.

Conclusions

In this brief review, I have had space to sketch out only a few of the instances in which input-output stands to profit from continuing its interchange of ideas with the operations research disciplines. Numerical coefficients, computing algorithms, and - most important - human beings are not perfectly transferable between interindustry and intrafirm uses. There is, however, a wide margin of resource substitution, and both fields can profit by trade. Once a sufficient amount of interchange has taken place, it is not too optimistic to expect that the "technological coefficients" of input-output will really be based upon technology, and no longer upon money-flow transactions.

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