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DEVELOPMENT OF AN INNOVATION POSSIBILITY FRONTIER FOR PURPOSES OF RESEARCH PLANNING AND EVALUATION*

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Abstract

Agricultural research activities can be planned and evaluated on the basis of an Innovation Possibility Frontier. Procedures for estimating such a frontier (to be employed in a normative context) are developed. Its uses for screening projects and for sensitivity analyses are emphasized.

Technical change is usually defined as the production of a greater output with the same resources (Ruttan) or as the production of the same output with fewer resources (Hicks). Technical change can be neutral (where all inputs are reduced proportionately) or non-neutral (where a greater than proportionate saving in one or more inputs occurs). Hayami and Ruttan concluded, for example, that labor saving technology was developed for American agriculture whereas land saving technology was developed for Japanese agriculture.

The concept of an Innovation Possibility Frontier (IPF) has often been employed to help understand the direction of technical change. The IPF bounds the current state of knowledge which is relevant to the production of a given commodity. Ahmad has described the IPF as "an envelope of all the alternative isoquants (representing a given output on various production functions) which the businessman expects to develop with the use of the available amount of innovating skill and time ..." (p. 347). It is not necessary that all of the alternative isoquants be technically feasible at the time of the analysis. It is only necessary that they could be developed given the current state of knowledge and skills.

The possibility that shifting factor price ratios might influence the direction of technical change was first recognized by Hicks in 1932. A changed relative factor price ratio, he argued, would act as a "spur to invention". Research would be directed towards methods of production which could use the relatively more expensive factor less intensively.

Ahmad developed a model which demonstrated the Hicksian notion of induced technical change (see Figure 1). There are two factors of production in this model. During the current time period (t), one unit isoquant (UI_t) has been developed and is utilized by entrepreneurs. Other unit isoquants could have been developed along the IPF_t. However, UI_t represents the unit isoquant with the lowest total cost when the price ratio is P_tP_t'.

Substitution of factors along UI_t would occur if the factor price ratio changed during the current time period. However, a permanent shift in the factor price ratio would mean that the currently used isoquant (UI_t) was no longer the optimal one. Another unit isoquant could be developed within the IPF_t which would enable the production of the same output at a lower total cost.

The IPF moves inward with the accumulation of basic scientific knowledge. The unit isoquant which will be developed in a future period (e.g., period t + 1) will also be cost minimizing. Therefore, if the factor price ratio in period t + 1 is $P_{t+1}P'_{t+1}$, then UI'_{t+1} will be developed and utilized. The movement from UI_t to UI'_{t+1} would represent a technical change that is biased towards saving factor 2, since factor 2 has become relatively more expensive in period t+1.

It would seem that the IPF concept could be used in a normative as well as a descriptive sense. If so, it could be utilized in the planning and evaluation of applied research projects in agriculture. Research personnel are intimately involved in the movement of the IPF over time. Researchers and research administrators must decide which of the alternative unit isoquants to investigate and develop. If an IPF could be developed prior to or during the conduct of particular research projects, a more rational allocation of research resources could be undertaken. Research projects could be priorized, based upon economic criteria. Projects designed around the specification and development of clearly dominated unit isoquants could be eliminated. And, the sensitivity of particular isoquants (or portions of isoquants) to observed or assumed values of different variables could be tested.

Unfortunately, an IPF cannot be observed nor estimated in the conventional statistical sense. This follows from the definition of the IPF. The only source of present or historical data is that of the unit isoquants actually used in each time period.

An alternative approach is to synthesize the IPF. Alternative unit isoquants can be simulated on the basis of experimental data and notions or images of the future. An IPF so constructed could then be used in a normative context to assess future research priorities and strategies.

Several aspects of the conventional notion of an IPF merit some discussion, particularly regarding how they affect the useability of an IPF for normative analyses.

1) Any separation of technologies into alternative unit isoquants must be regarded as somewhat arbitrary. Consider the set of production alternatives a_i, $i = 1, 2, \ldots, I_A$ which are capable of producing output b at level $\bar{b}$. A subset of these production alternatives, e.g., a_i, $i = 1, 2, \ldots, m$, may be obsolete at current factor prices, another subset, e.g., a_i, $i = m+1, m+2, \ldots, n$, may be feasible at current factor

prices, and another subset, e.g., a_i, $i = n+1, n+2, \ldots, I_A$ may not have been developed as yet. The separation of so-called technologies is seldom distinct and need not be considered as such in the application of the IPF concept.

Furthermore, many research resources must usually be expended to develop production alternatives which are known but not yet technically feasible. By employing finer and finer differentials among the unit isoquants, analyses of the implied production adjustments may be undertaken.

2) The use of isoquants in an analysis of this kind presumes that some type of aggregation procedure has been employed. Eisgruber and Lee emphasized that different inputs or even different input levels do not necessarily produce the same output. For example, corn produced by one method or level of fertilization may not be the same corn as that produced by different methods or levels of fertilization. These small "quality" differences can usually be ignored (at least when the product market ignores them). However, they may be important in certain types of normative analyses of research priorities. Analysts using the concept of the IPF or just using unit isoquants for comparative purposes must be aware of the assumptions they are making.

3) Inputs into the production process include non-economic and/or non-controllable variables as well as controllable variables which have a market value. Eisgruber and Lee divided the inputs

into three categories: those over which the decision maker has complete control, those over which he has no control (states of nature), and those which describe the unique characteristics of the decision maker, including the organizational and institutional framework available for decision making. Inclusion of the two non-conventional categories of inputs may be important for normative analyses of research priorities. The states of nature and managerial proficiencies faced by the users of the research results may be sufficiently different from those of the producers of the research results. Their neglect could seriously decrease the value of any ensuing analyses.

A normative analysis of research priorities using the concept of the IPF would usually consist of two distinct steps. The first would involve synthesizing the IPF in purely physical terms. The second would involve an economic analysis of the IPF based upon forecasted or expected levels of input prices.

The synthesis of an IPF requires:

1) identification of alternative subsets of production alternatives to form unit isoquants (each subset ought to contain some unique characteristics which make it fundamentally different from the other subsets, e.g., plant varieties, animal breeds).
2) specification of relevant input categories (it may be important to disaggregate the same physical resource, e.g., labor, into different categories when its opportunity cost may not be

constant).

3) accounting of the input requirements for each production alternative (this usually involves budgetting or simulation; however, less sophisticated techniques may be employed).

Applied researchers must anticipate the changing factor and product prices when choosing among research projects. Their ability to investigate and develop production alternatives (or subsets of production alternatives) which substitute cheaper for more expensive resources largely determines the rate at which technical change in agriculture can proceed. The economic analysis of the synthesized IPF then, consists of determining optimal strategies on the basis of expected price ratios.

As mentioned previously, statistical estimation of the IPF is usually impossible. It is also unnecessary. For normative purposes, more useful information can often be obtained by concentrating more on the appropriate disaggregation of inputs and possible factor price scenarios than upon particular functional forms and levels of statistical significance.

It is possible to "trace the relevant portions" of unit isoquants (subsets of production alternatives) and/or the IPF by iteratively solving the following problem for different values of each element of Θ.

$$\begin{aligned} \text{Max} \quad & -(C + \Theta)' X \\ \text{subject to:} \quad & DL = Y^0 \\ & AL - IX = 0 \\ & L \geqq 0,\ X \geqq 0 \end{aligned}$$

where: C is a $(1 \times k)$ vector of factor cost coefficients,

Θ is a $(1 \times k)$ vector where all but one of the elements is (usually) zero,

D is a $(1 \times n)$ vector of observations on the output variable,

Y^0 is the output level of the unit isoquant,

A is a $(k \times n)$ matrix of production transformation coefficients,

L is a $(1 \times n)$ vector of activity levels,

I is a $(k \times k)$ identity matrix, and

X is a $(k \times 1)$ vector of inputs.

With this formulation, it is possible to investigate the surface of the unit isoquants and of the IPF in as much detail as is desired. The range of values selected for each element of Θ and any combinations used of two or more non-zero elements of Θ determine the direction and the precision of the search.

The search of the IPF is illustrated in Figure 2. Two unit isoquants, I_0 and I_1, are portrayed in two factor space. The isoquant I_0 is associated with production alternatives A and B; the isoquant I_1 is similarly associated with production alternatives C and D. With a factor price ratio of PP, production alternative A on isoquant I_0 represents the least cost method of production. An increased price of the first factor (or a decreased price of the second factor) to yield price ratio P'P' causes production alternative C on isoquant I_1 to become least cost. Parametric variation of the factor price ratio, in effect, traces the envelope of the individual unit isoquants.

The linear programming method of tracing the IPF provides a kind of laboratory facility for analyzing alternative research strategies. In particular, it can be used as a screening device for eliminating those projects where the expected research results will be clearly infeasible from any reasonable economic perspective. In addition, if the system into which the proposed research will fit is correctly simulated, various types of sensitivity analyses can be undertaken.

The sensitivity of the optimal solution to each of the data elements (including the factor prices) can be assessed easily and quickly. Strictly hypothetical data could be utilized in a preliminary analysis to determine the variables for which it would be most important (economically) to obtain precise estimates. Thus, a prior evaluation would provide directions for the most valuable research given the prior knowledge (or expectations) of the researchers.

The linear programming algorithm not only selects the least cost production alternative but it calculates the cost disadvantages of production of each of the other methods in the optimal and the non-optimal unit isoquants. These extra costs can be utilized in further economic analyses of:

1) the portions of particular unit isoquants which may warrant further scientific investigation, and
2) the costs of adjustment among the alternative unit isoquants (mixed integer programming could be used to advantage here).

The framework sketched above can be applied to normative analyses of many types of applied research projects. It facilitates analyses designed to:

1) establish research priorities,
2) select experimental procedures,

3) evaluate the progress of research projects, and

4) substantiate final research results.

In addition, a suitably developed analytical framework could assist in the preparation and presentation of research results to extension personnel and to farmer decision makers.

In an earlier study (see Klein) certain hypothetical and preliminary data were used to evaluate a large beef breeding project in Canada. A firm level systems model (Sonntag and Klein) was used to simulate various production alternatives for different breeds of livestock (here identified as alternative unit isoquants). Resource requirements were divided into seven categories of labor and seven categories of capital. Alternative factor price scenarios were utilized to synthesize an IPF. The expected competitiveness of the various breeds was examined. The sensitivity of the evaluation to various data was analyzed. The results from this evaluation could be helpful for periodic reviews of the current project and for planning further stages of research.

In conclusion, it might be noted that two groups of people have often expressed dissatisfaction with the type and quantity of agricultural research. Farm management advisors have found certain difficulties in using experimental results. Lloyd suggested that agricultural research projects be designed so that they could yield "more useful information about the profitability of particular practices at different levels, and/or in combination with other practices, under varying sets of farm conditions". And, funding agencies are always concerned with research resources being used in areas where the payoff per dollar of research input is the greatest.

Many applied research projects in agriculture contain economic objectives. It appears obvious that if they are to contain such objectives they ought to be subjected to economic evaluations. The IPF concept can be used before, during, and after particular projects are undertaken. Experiments can be designed in a manner which focuses greater attention upon the identified "important variables". Project reviews can be performed to determine the utility or the futility of proceeding with the outlined project. Upon completion of the project, the results can be economically evaluated to determine the degree to which the project's objectives were met, to identify areas where new research projects would provide valuable information, and to obtain insights into the incentives for adoption of the research results. The latter objective has obvious policy implications.

The framework of analysis outlined in this paper makes clear the dependence of the value of research results on present and anticipated price ratios. This method of analysis forces the analysts, the research administrators, and the researchers themselves to consider price signals in the planning and the conduct of their research activities.

In the absence of free resources with which to conduct research, there would appear to be significant benefits from economic evaluations of applied research projects. Economic evaluations conducted within this framework would diminish the above noted felt difficulties. Researchers and research administrators would be more cognizant of the value of particular research results to the farmer decision maker. And, by planning and conducting research projects within this framework, the valuable research resources could be used to determine the (economically) most important data.

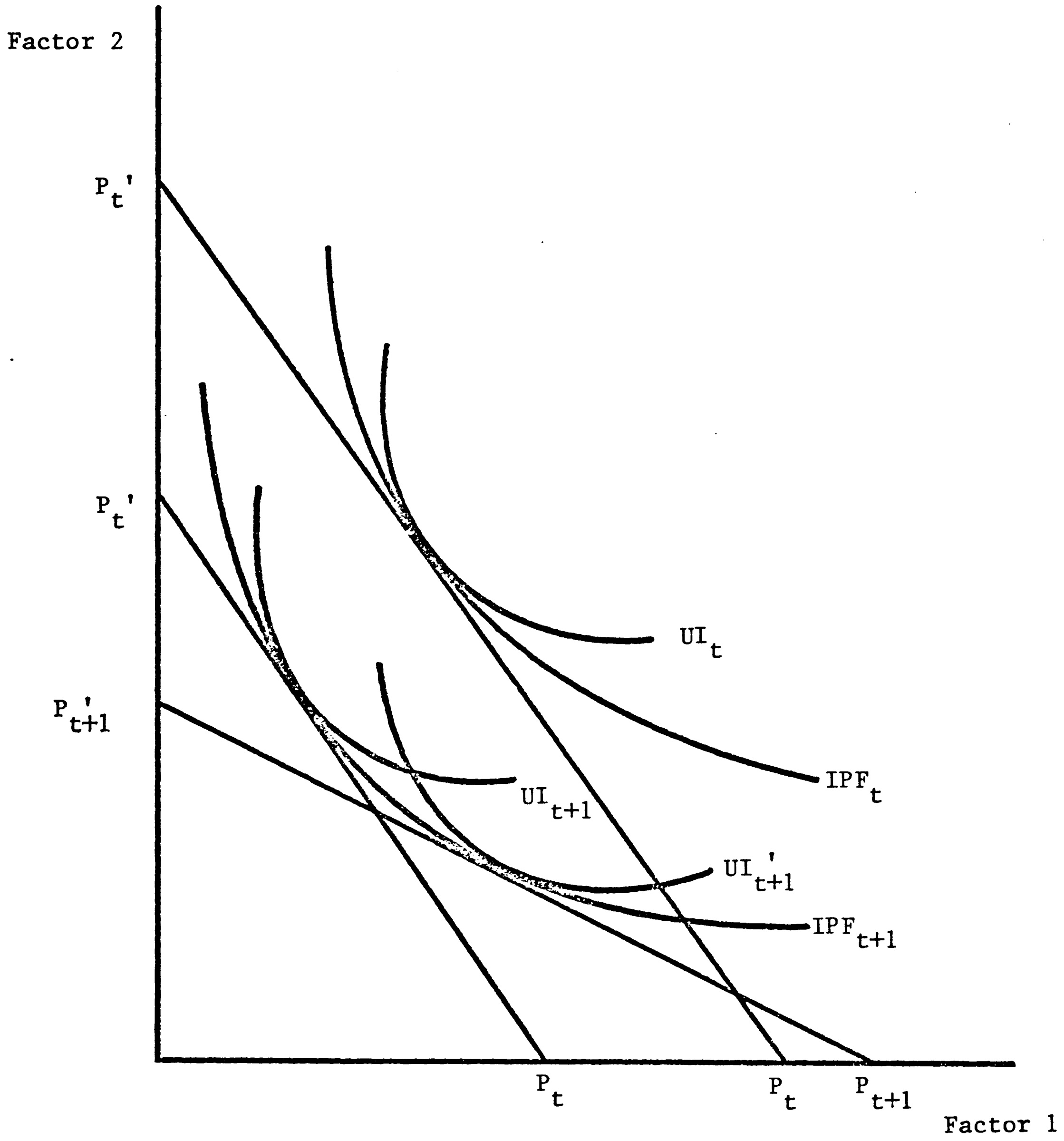

FIGURE 1. AHMAD'S INDUCED INNOVATION MODEL

Source: Ahmad (p. 349)

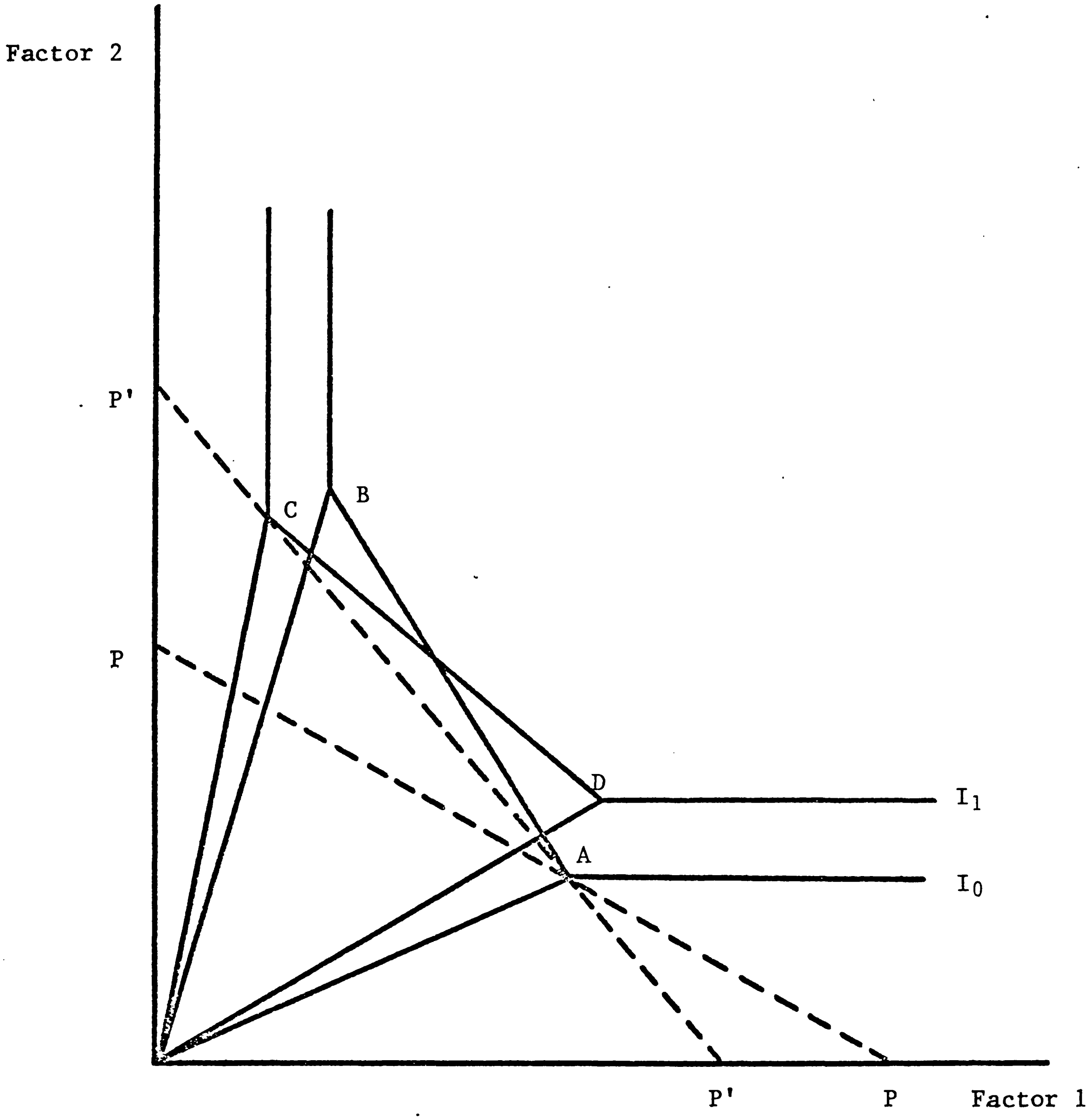

FIGURE 2. TRACING THE INNOVATION POSSIBILITY FRONTIER BY VARIATIONS IN THE FACTOR PRICE RATIO

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