ACROSS-COMMODITY SPILLOVER EFFECTS OF RESEARCH AND OPPORTUNITY COSTS IN A MULTI-PRODUCT PRODUCTION ENVIRONMENT+

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1. INTRODUCTION

Research evaluation has been the subject of extensive inquiry. In most of the studies, the basic model of research benefits based on the principle of economic surplus has been used to measure the size and distributional consequences of research-induced technological change. The literature on the subject so far has covered various factors such as the probability of research success, adoption rates and levels, regional and international spillovers and the effects of government economic policies on research benefits (e.g., Davis, Oram and Ryan 1987, Anderson 1986, Bantilan and Davis 1991, Alston, Edwards and Freebairn 1988). By and large, the analysis in previous works has been confined within the context of a single product market. The investigation of the problem within a multi-product context is yet in the initial stages. For example, a recent work by Alston (1990) has extended the basic model to allow an analysis of welfare changes with the consideration of general equilibrium type adjustments taking place in a multi-product setting. The purpose of this paper is to examine two aspects that may have significant bearing in the measurement of potential research benefits, i.e., opportunity cost and across-commodity spillover effects. Possible product substitution is highlighted in the process of explaining the underlying relationship of the agricultural response and cost structures in a multi-product production environment. It extends the scope of inquiry of Davis and Bantilan (1991) that explores the output cost linkages in various single-output production scenarios.

Section 2 gives a background on spillover effects of agricultural research. Section 3 is a discussion of the theoretical economic framework demonstrating the relationship between the output response and the cost structure in a multi-output multi-input production environment. It shows how product substitution in this setting comes into play in influencing the output-cost linkages. This section also discusses the role of technological change and spillover effects and their consequences on the cost structure. Section 4 develops the mathematical relationships implied in section 3. The paper concludes with a summary of the results obtained.

2. SPILLOVER EFFECTS OF AGRICULTURAL RESEARCH

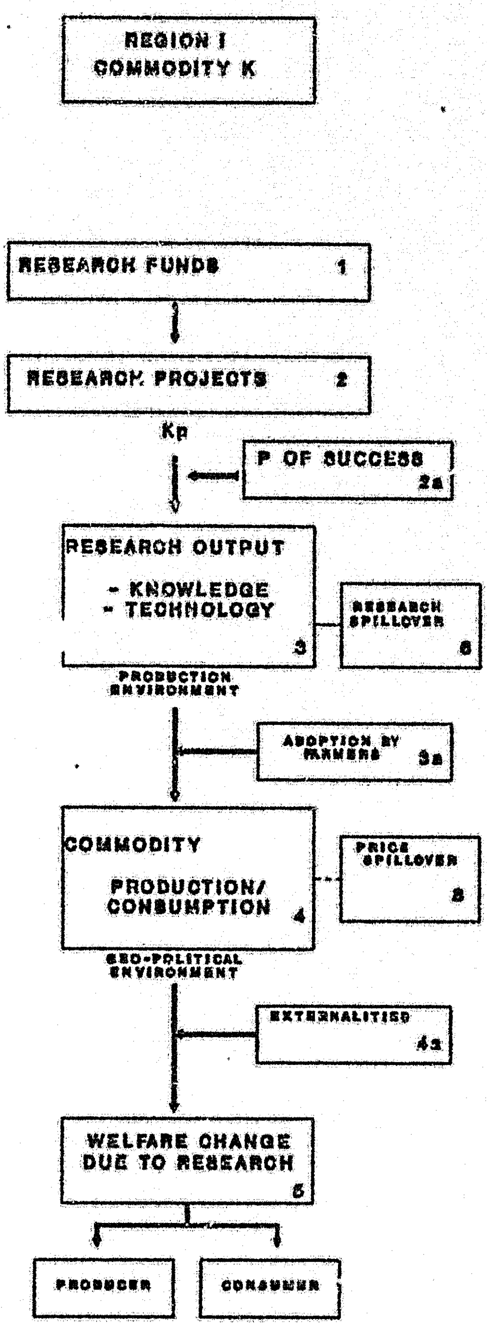
New knowledge or a technological breakthrough generated via agricultural research leads to increased yields, or improves the quality of output, or enhances the efficiency of input use via a reduction in unit cost. The new techniques or processes developed may have applicability beyond the confines of the location for which the technology was generated, or beyond the commodity for which the technology was developed. These effects have been referred to as spillover effects; and different types are distinguished in the agriculture research literature.

The different types of spillover effects may be systematically discussed by using the framework outlined in Figure 1. This general framework traces the development of the different components of the research process, its output and logical consequences. The conceptualization of the framework starts with the consideration of research investments (box 1) that funds the implementation of research projects (box 2). The new knowledge and technology generated (box 3) are expected to bring forth changes in the production and the consumption environment (box 4) as the commodity becomes more and more available in the market as a result of the utilization of the new technology. To be more specific, the application of science-based technologies in agriculture is expected to bring about increases in crop yields, average daily weight gain of poultry, the average litter size of livestock or increased fish production. Research is also expected to improve the efficiency of various inputs including management. Ultimately, the above changes in the production and consumption environment are translated into the upgrading of the welfare of society (box 5).

But, before the final benefits of research accrue to the members of society (i.e., producers and consumers),, three important conditions must be met. First of all, the research undertaken must be successful in achieving its targeted objectives. This introduces the notion of the probability of success or relative research capability (box 2a). Secondly, the potential increase in production promised by a new technology is ultimately achieved only when the technology is adopted and utilized by farmers. This condition necessitates the consideration of the rates of technology adoption and the factors constraining it (box 3a). Thirdly, the measurement of the welfare gain to society is incomplete if it does not take into account the externalities (both positive and negative) which the technology involves.

Classic examples of a negative externality (box 4a) are the human-induced soil erosion in agriculture and the detrimental effects of chemical-based technology. The long list of the effects of the latter example includes the deleterious effect of

FIGURE 1. RESEARCH EVALUATION PROCESS



pesticides on the health of farmers and his family, the transmittal of chemical residues through the food chain to consumers, the toxic effect of chemicals on animals like fish, shrimps, frogs and helpful insects in the paddy environment, the contamination of ground and surface waters, and the reduction of microorganism population in the paddy soil that help sustain soil fertility.

The positive externalities are incorporated within the above framework via consideration of the concept of spillover effects. Figures 2 and 3 illustrate how they are integrated in the analysis. Three types of spillover effects are considered. The first type (box 6) involves the across-location spillovers wherein a technology developed through research for one product in a specific location can be adapted to improve the production efficiency of the same product in other locations (geo-political or agro-ecological). The consideration of this type of spillover effects is relevant because the applicability of the new technology may not be the same for all locations as these locations refer to production environments differentiated by agronomic, climatological and ecological factors.

The second type of spillover effects refers to across-commodity applicability of the technology developed (box 7). For example, a cultural management technique developed specifically for rice production may also potentially improve the efficiency of production for corn and other cereal grains.

The nature of the first two types of spillover effects reflects the direct applicability of a technology across different locations/production environments and across different commodities. Thus, they are referred to as direct spillover effects.

A third type of spillover effect is referred to as the indirect or price spillover effects (box 8). Because technological change for a particular commodity in a specific location brings forth increased supply which may cause price changes, then the price effect on other locations (if the commodities are traded) or its price effect on related commodities may have significance. This is particularly relevant when the elasticities of the product demand are relatively small and/or the rate of product transformation among commodities is significant.

The theoretical considerations in this paper focus on the second type of spillover effects, that is, the across-commodity applicability of new technologies.

FIGURE 2. RESEARCH EVALUATION PROCESS

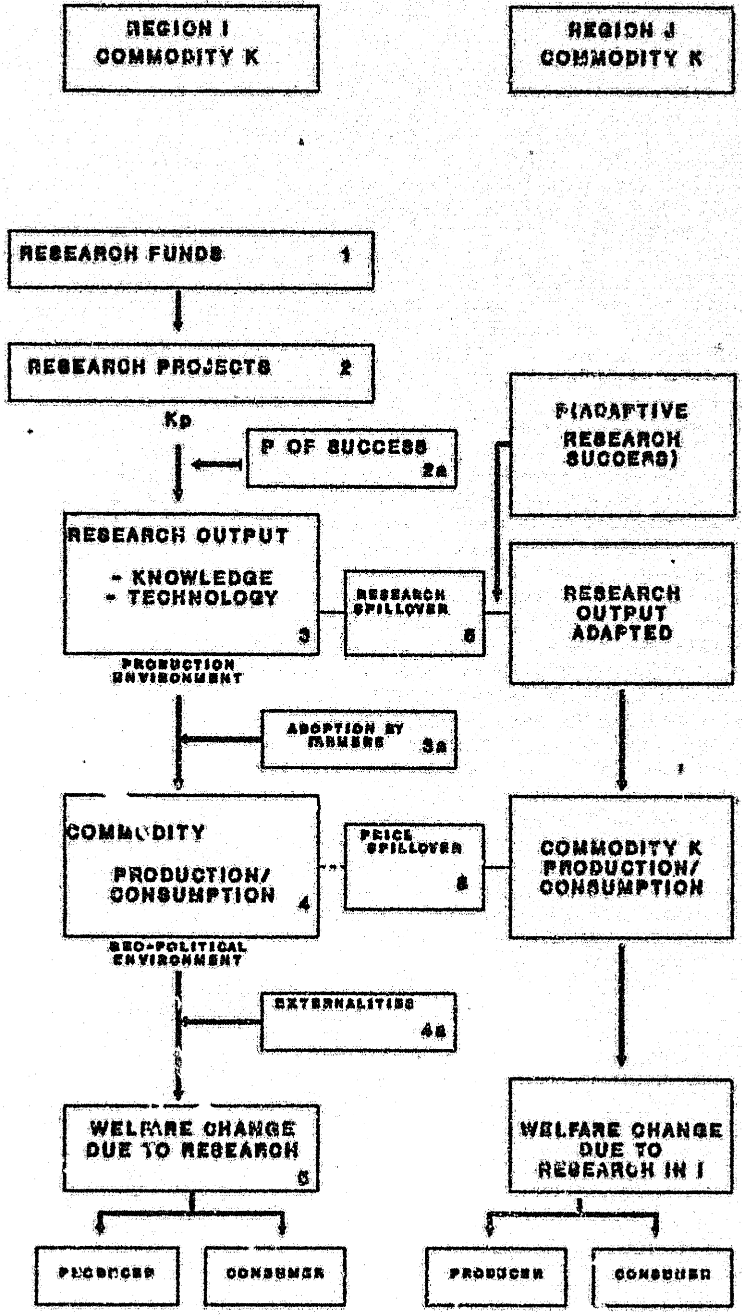
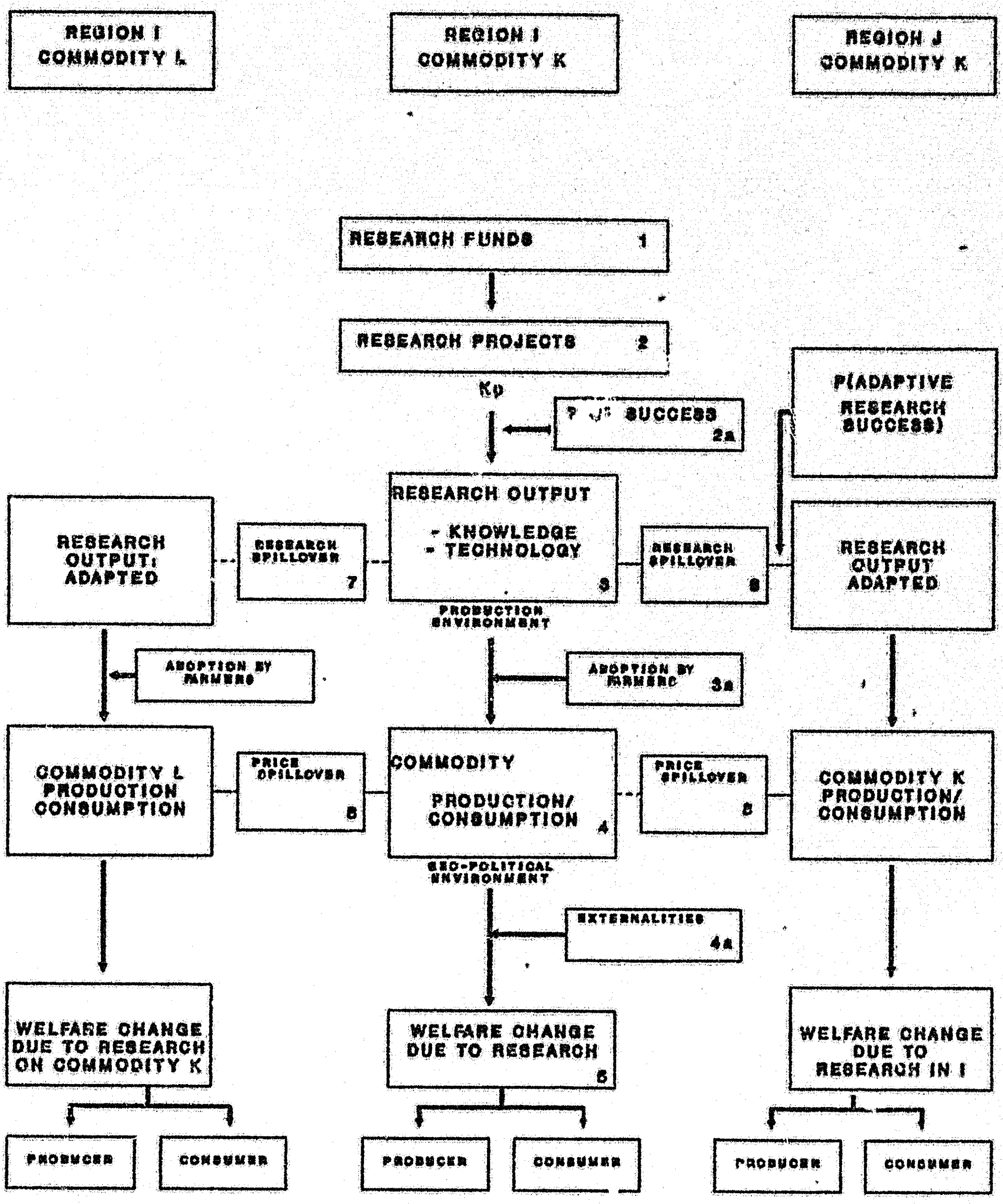


FIGURE 3. RESEARCH EVALUATION PROCESS



3. PRODUCTION AND COST LINKAGES, AND OPPORTUNITY COST IN A MULTI-PRODUCT PRODUCTION ENVIRONMENT

The limits of the technical production possibilities in a multi-output-multi-input framework can be represented by a transformation function given by, say,

$$Q(y_1, y_2, \ldots y_m) = I(x_1, x_2, \ldots x_n) \quad (1)$$

where $y_1, y_2, \ldots y_m$ represent the amounts produced for each of the m outputs and $x_1, x_2, \ldots x_n$ are the amounts used of each of the n inputs. The boundary relationship given by equation (1) expresses the constraints which limit the firm's transformations of a set of inputs into a set of final products. It indicates the substitutability of one input for another (while total output is held constant) as well as the substitutability of one output for another (while holding the total usage of inputs fixed).

Without loss of generality, the efficient allocation of inputs among alternative products can be most easily demonstrated for a two-input-two-output case. A graphic devise known as the Edgeworth-Bowley Box (Figure 4) comes handy for this purpose.

The Edgeworth-Bowley Box diagram permits all possible allocations of the two inputs between two products (y_1 and y_2) to be visualized. A firm (or farmer) with fixed quantities of productive resources (say, labor and capital) is assumed in the analysis. The dimensions of the box are given by the fixed quantities of inputs available. Isoquant maps are drawn to represent the production technologies used.

In the context of the conditions given above, efficient allocation of resources is achieved by the firm when resources are allocated among alternative output uses in such a way that the rate of technical substitution of the inputs is the same in the production of every output which he produces. In other words, the locus of efficient points is given by the points of tangency of the two isoquants. This traces out the optimal combination of the products, y_1 and y_2, which might be produced. These possibilities are shown by the production possibilities frontier, $y_{1*}y_{2*}$, shown in Figure 5. Moving along this efficiency locus, from P_1 to P_4, inputs are being transferred from the production of y_1 to the production of y_2. The slope of the production possibility frontier, called the rate of product transformation (RPT), measures the rate of product substitution in production.

Let us now examine the implications of a new technology that has been developed for one product, say y_1, on the firm's production decision and cost structure. Assume first that the

Figure 4. Edgeworth-Bowley Box Diagram showing the efficient ways in which a firm can allocate a fixed amount of K and L between the production of Y1 and Y2

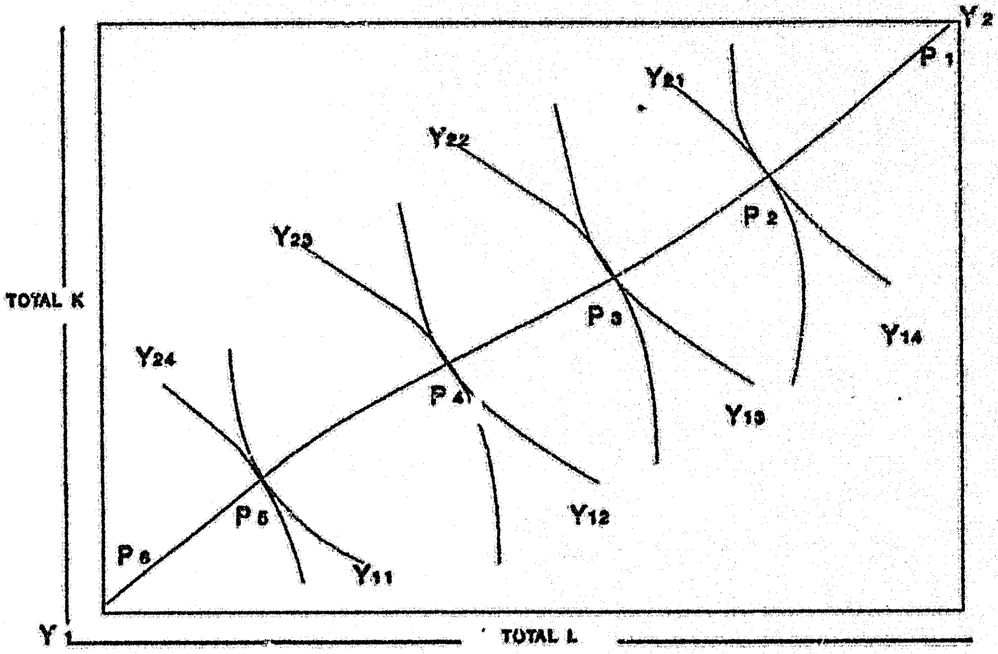
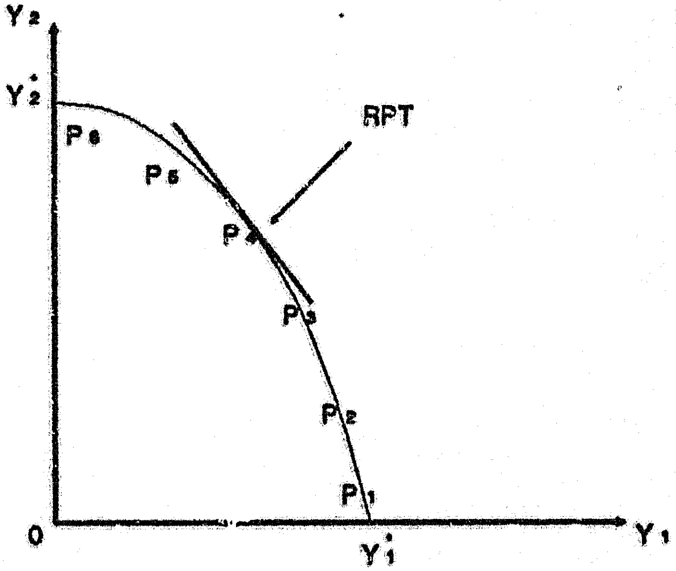


Figure 5. Production Possibility Frontier Derived from Figure 4.



technology does not affect the production of the other product, y_2.

In terms of figure 5, the technical change pushes the production possibility frontier outwards as depicted in Figure 6. Conceptually, the production frontier shifts as higher levels of output of y_1 can now be produced with the improved efficiency in producing that product. Note that the figure illustrates a case where the technology does not affect the productive efficiency of the other product, i.e., the maximum output expected, if all inputs were allocated for the production of y_2, remains at level P_A.

The improved efficiency in the production of y_1 induces a decline in the substitutability of the two products in the production process. This is illustrated in Figure 6 where the slope of the frontier labeled CA is steeper than the slope of the frontier CB which means that the rate at which y_2 can be traded for y_1 in the productive process becomes smaller than before the technical change.

If the new technology were also applicable to y_2, (i.e., positive spillover effects are present) so that its productive efficiency also increases, then the production possibility frontier for y_1 and y_2 is pushed further outwards from CB to DB. (Refer to Figure 7.) It is noted that the maximum production of y_1, if all resources were allocated to it, remains at point B; while the maximum production for y_2 increases to D. Moreover, it is noted that the frontier labeled DB (representing the case of a positive spillover effect of technology) has a higher slope than that of CB (which assumes a no spillover effect). This observation indicates that the spillover effects of some technology developed for certain commodities may in fact alter the extent of substitutability among products, and hence, affect the decision processes of the firm.

This observation motivates an investigation of the opportunity costs that may be reflected by the possible substitution among products in the production process which may underlie the cost structure of a multi-product firm. The implicit cost involved may be inadvertently ignored in the usual analysis of a firm's cost structure as this is usually done within a single-product framework. Let us use Figure 8 as a reference frame.

In terms of a one-output-multiple-input framework depicted in Figure 8, a production function may be defined by

$$Q(y_1) = I(x_1, x_2.$$

The figure illustrates the effect of a technological breakthrough

Figure 6. Production Possibility Frontier with an upward shift due to technological change for product Y1.

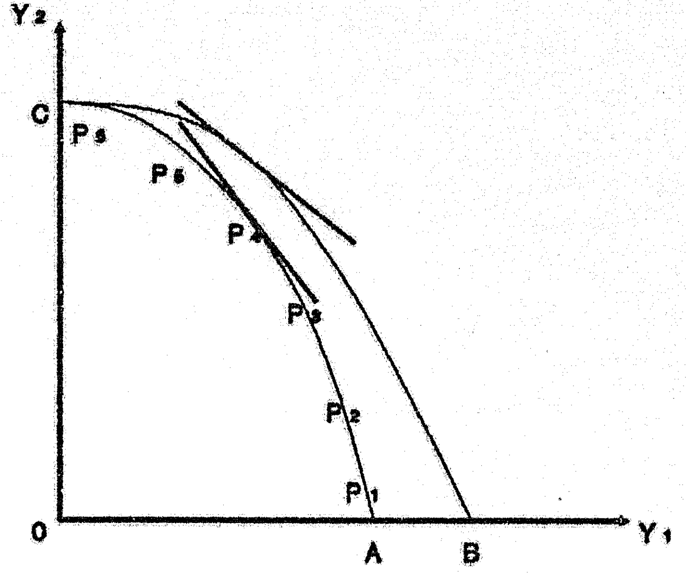
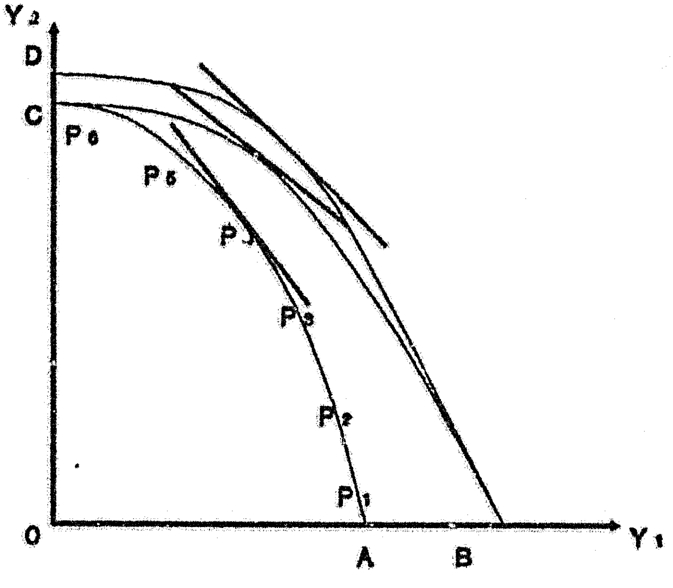


Figure 7. Effect of Technological Change for Product Y1 on the Production Possibility Frontier: No Spillover and with Spillover Effects



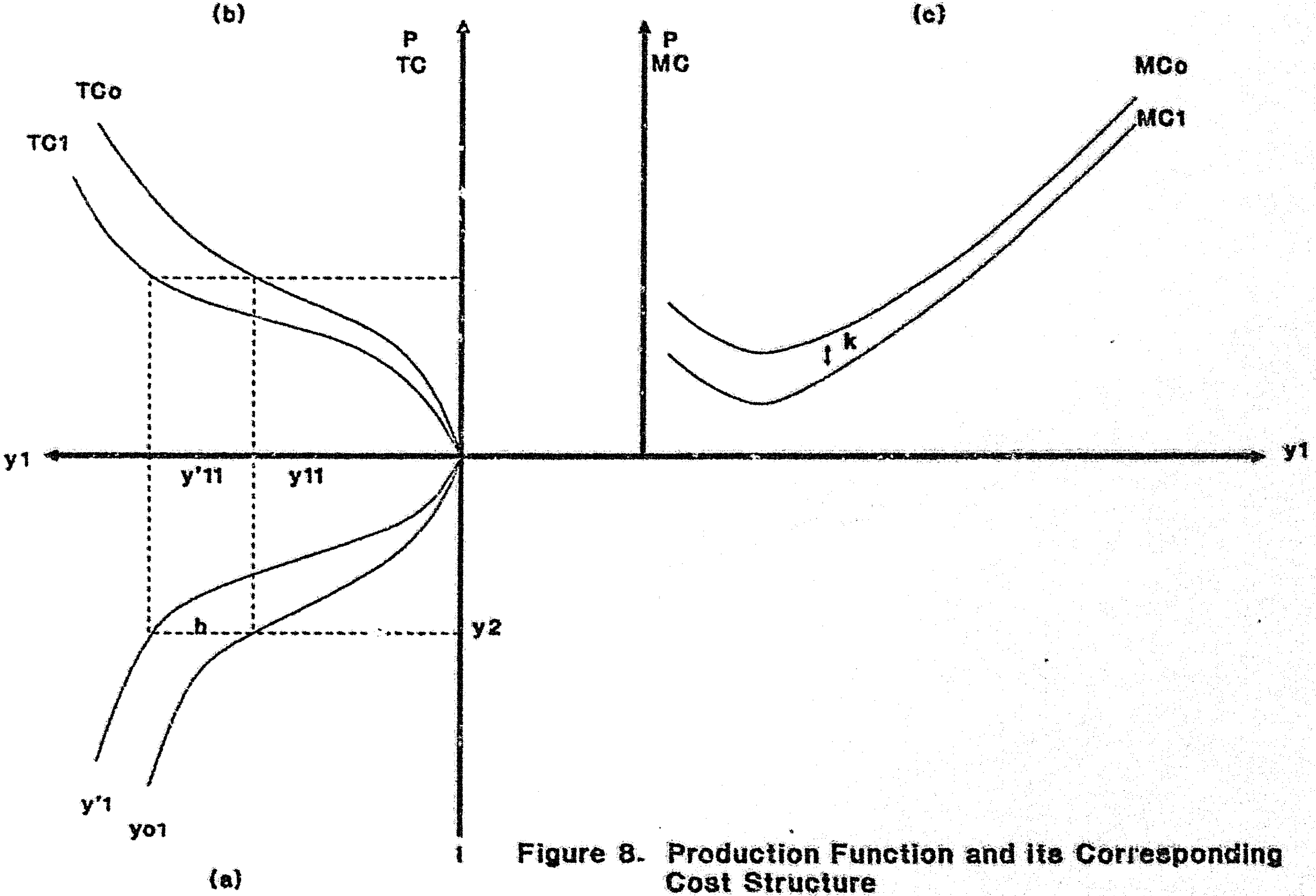


Figure 8. Production Function and its Corresponding Cost Structure

so that the production response shifts as higher levels of output are produced with the improved production efficiency. As shown graphically, the same level of input (composite) use, say I_0, brings forth an increase in production from y_{11} to y_{11}'. The enhancement of the production efficiency (shown in Figure 8, panel a) is translated into changes in the firm's cost structure, that is, in terms of a lower total cost and a downward shift in the firm's marginal cost or supply function. This change in the cost structure is depicted in Figure 8 (panels b and c).

When the framework is extended to a multi-product firm, consideration must be given to the effects of the new technology on the commodity for which it was developed as well as the possible substitution among products and the spillover effects the new technology may have on the other commodities the firm is producing. The possible substitution among products involve an implicit cost or opportunity cost for the producer as he chooses to produce a unit of one product versus another. The spillover effects result in the alteration of the rate of product transformation (RPT) and hence change the firm's cost structure.

It was shown in Figure 6 that technical change enhancing the production of product y_1 (with no spillover effect on y_2) reduces the RPT between y_1 and y_2, i.e. dy_2/dy_1 falls with the technical change. This means that the marginal cost of producing y_1 (measured in terms of the alternative product y_2) declines with the application of the new technology as the firm now loses less of y_2 when it produces y_1 instead.. The implication of this change on the firm's cost structure is reflected in panel c of Figure 8. In this case, the downward shift in the marginal cost is expressed in terms of how much of the other product (y_2) is sacrificed when one product (y_1) is produced instead. This opportunity cost may also be measured in terms of the value of the inputs used.

The implications of technical change on the production and cost structure of product y_2 are discerned in a similar manner. In this case, technical change (which enhanced only y_1) increases the opportunity cost of producing an additional unit of y_2 as it may be measured in terms of the alternative product, i.e. y_1. This may also be measured in terms of the inputs used in production. This means that even if the production response surface of y_2 does not change (no spillover effect), the marginal cost of producing a unit of y_2 increases as the marginal productivity of the input improves via technical change.

Now, let us take the case where positive across-commodity spillover effects are realized. Recall Figure 7 which depicts the outward shift of the production possibility frontier from CB to DB due to the spillover effect on product y_2. Note that RPT_{DB} >

RPT_{12}, i.e. greater product substitution is effected. The spillover effect is also reflected by an upward shift in the production surface of y_2 which causes the marginal cost to decline. This means that the marginal cost of producing y_2 (measured in terms of how much of y_1 is sacrificed or how much input is used if the firm produces y_1 instead) is less when positive spillover effects are realized compared to the no-spillover case.

The analysis reveals that across-commodity spillover effects of technical change finds its way into the firm's cost structure via changes in the product substitution among the firm's outputs. While technical change specific to the production of one commodity, say y1, reduces the marginal cost of producing that commodity, further welfare gains are actually achieved by the firm if such technology has some applicability such that the efficiency in production is also improved in other products.

4. OPPORTUNITY COSTS IN A MULTI-PRODUCT PRODUCTION ENVIRONMENT- A MATHEMATICAL FORMALIZATION

4.1 Costs in a Multiple Output-Multiple Input Production Environment

Given a transformation function, i.e., equation (1), that constrains the firm's ability to choose combinations of inputs and outputs, the optimal production decisions of a producer may be determined with the assumption that he maximizes profits. Thus, the derivation of optimal input demand and output supply levels may logically start from a consideration of a short run profit function given by

$$\prod = \sum_{i=1}^{m} p_i y_i - \sum_{j=1}^{n} w_j x_j - FC \qquad (2)$$

where p_i = price of output i;
w_j = price of input j;
FC = fixed cost

In other words, in the context of production studies, optimal input and output levels implied by the technical transformation function and the necessary conditions are equivalently obtained by the optimization of its dual profit function.

A constrained maximization is solved by specifying a Lagrangian function, say,

$$L = \sum_{i=1}^{m} p_i y_i - \sum_{j=1}^{n} w_j x_j - FC - \lambda\left[Q(y_1,\ldots,y_m) - I(x_1,\ldots,x_n)\right]$$

The necessary conditions are:

$$\frac{\partial L}{\partial y_i} = p_i - \lambda\frac{\partial Q}{\partial y_i} = 0, \qquad i = 1,\ldots m;$$

$$\frac{\partial L}{\partial x_j} = - w_j + \lambda \frac{\partial I}{\partial x_j} = 0, \qquad j = 1,\ldots n;$$

$$\frac{\partial L}{\partial \lambda} = Q(y_1,\ldots,y_m) - I(x_1,\ldots,x_n) = 0.$$

From these necessary conditions, the following equilibrium solution is obtained, i.e.,

$$\frac{\frac{\partial Q}{\partial y_1}}{p_1} = \ldots = \frac{\frac{\partial Q}{\partial y_m}}{p_m} = \frac{\frac{\partial I}{\partial x_1}}{w_1} = \ldots = \frac{\frac{\partial I}{\partial x_n}}{w_n} = \frac{1}{\lambda} \qquad (3)$$

In principle, the m+n equations implied by equation (3) plus the constraints represented by equation (1) are the basis for the optimal values of the m outputs, n inputs and the shadow price which maximize the firms profits.

The cost structure of the firm can be translated in terms of the transformation function defined in equation (1). To do this, take the total differential of the transformation function to obtain

$$\sum_{i=1}^{m} \frac{\partial Q}{\partial y_i} dy_i = \sum_{j=1}^{n} \frac{\partial I}{\partial x_j} dx_j \qquad (4)$$

From equation (4), $\partial Q/\partial y_i dy_i$ is obtained, i.e.,

$$\frac{\partial Q}{\partial y_i} dy_i = \sum_{j=1}^{n} \frac{\partial I}{\partial x_j} dx_j - \sum_{\substack{k=1 \\ k \neq i}}^{m} \frac{\partial Q}{\partial y_k} dy_k$$

so that

$$dy_i = \frac{1}{\frac{\partial Q}{\partial y_i}} \left[\sum^{n} \frac{\partial I}{\partial x_j} dx_j - \sum_{\substack{k=1 \\ k \neq i}}^{m} \frac{\partial Q}{\partial y_k} dy_k \right]. \qquad (5)$$

Substitution of equation (3) into equation (5), gives

$$dy_i = \frac{1}{\partial Q/\partial y_i} \left[\sum \frac{w_i}{\lambda} dx_j - \sum_{k \neq i} \frac{\partial Q}{\partial y_k} dy_k \right]. \qquad (6)$$

Taking the total cost function expressed by

$$TC = \sum_{j=1}^{n} w_j x_j + FC$$

the total differential of TC is obtained, i.e.,

$$dTC = \sum_{j=1}^{n} w_j dx_j . \qquad (7)$$

By dividing equation (7) by equation (6),

$$\frac{dTC}{dy_i} = \frac{\sum_{j=1}^{n} w_j \, dx_j}{\sum_{j=1}^{n} \frac{w_j}{\lambda} dx_j - \sum_{k \neq i}^{m} \frac{\partial Q}{\partial y_k} dy_k} \frac{\partial Q}{\partial y_i}$$

$$= \lambda \frac{\partial Q}{\partial y_i} \left[\frac{1}{1 - \sum_{\substack{k=1 \\ k \neq i}}^{m} \frac{\partial Q}{\partial y_k} dy_k + \sum \frac{w_j}{\lambda} dx_j} \right] \quad (8)$$

$$= \left(\lambda \frac{\partial Q}{\partial y_i} \right) \delta \, . \quad (9)$$

where

λ = shadow price of the resources implied by the Lagrangian function;

$\partial Q/\partial y_i$ = marginal input required for an incremental change in output i; and

δ > 1, opportunity cost multiplier.

The interpretation of $\partial Q/\partial y_i$ comes from solving the transformation function, i.e.,

$$\frac{\partial Q}{\partial y_i} = \frac{\partial I(x_1, x_2, \ldots, x_n)}{\partial y_i}$$

$$= \sum_{i=1}^{n} \frac{\partial I}{\partial x_j} \frac{\partial x_j}{\partial y_i}$$

In other words $\partial Q/\partial y_i$ is the sum of the marginal changes in the inputs required to produce an increment of output y_i. In short, $\partial Q/\partial y_i$ is a composite measure of the marginal input required for output i.

From equation (3) and (8),

$$\delta = \frac{1}{1 - \sum\limits_{\substack{k=1 \\ k \neq i}}^{m} \frac{\partial Q}{\partial y_k} dy_k + \sum\limits_{j=1}^{n} \frac{\partial I}{\partial x_j} dx_j},$$

and using equation (4), we have

$$\beta = \frac{\sum\limits_{\substack{k=1 \\ k \neq i}}^{m} \frac{\partial Q}{\partial y_k} dy_k}{\sum\limits_{j=1}^{n} \frac{\partial I}{\partial x_j} dx_j} < 1.$$

Based on the derivation above, dTC/dy_i or the marginal cost resulting from an increase in one output y_i is equal to the marginal input required for output i, i.e. $(\partial Q/\partial y_i)$, valuated by the shadow price λ, and adjusted by an index of opportunity cost, δ, whose value is nonnegative and has a magnitude which depends on

$$\beta = \frac{\sum\limits_{\substack{i=1 \\ i \neq k}}^{m} \frac{\partial Q}{\partial y_k} dy_k}{\sum\limits_{j=1}^{n} \frac{\partial I}{\partial x_j} dx_j}.$$

Note that in a one output production environment, dTC/dy_i is equivalent to $\lambda\ \partial Q/\partial y$, i.e., $\delta = 1$. However, when a firm's production decision involves two or more products, then the opportunity costs incurred due to the possibility of producing other products out of the available set of inputs x_j, $j = 1, \ldots n$, are relevant. In other words, the marginal input requirements of the other products in proportion to the total change in total cost cannot be ignored.

The above formulation of the marginal cost function allows a more general analysis of the output supply decisions in a multiple product-multiple input production environment. An additional perspective provided by this framework is that it makes explicit consideration of the opportunity cost incurred when decisions are made in favor of the production of one product versus another.

4.2 Technical Change, Spillover Effects and Consequences on the Cost Structure

In the context of the framework presented in the previous section, this section examines the implications of technological change on the firm's production decision and cost structure. Theoretical consideration is focused on the second type of spillover effect, that is, the across-commodity applicability of a new process or technique developed for one commodity, which may be applicable to other related commodities.

In terms of equation (8), the marginal cost of the firm is measured by the value of the marginal input required for every incremental change in y_1. In a monoculture (one-product) environment, the opportunity cost multiplier, s, is equal to 1.

The corresponding analysis for a multiple-output-multiple-input environment is illustrated by using a two-output, three input production scenario, where the transformation function is represented by

$$Q(y_1,\ y_k) = I(x_1,\ x_2,\ x_3). \qquad (10)$$

The one-to-one correspondence between the output vector Q and the input vector I reflecting the transformation expressed by equation (10) is shown in Figure 8.

By equation (9), the production constraints given by equation (10) is incorporated in the following marginal cost function given by

$$\frac{dTC_1}{dy_1} = \lambda \frac{\partial Q}{\partial y_1} \left[\frac{1}{1 - \frac{\partial Q}{\partial y_k} dy_k + \sum_{j=1}^{3} \frac{\partial I}{\partial x_j} dx_j} \right]$$

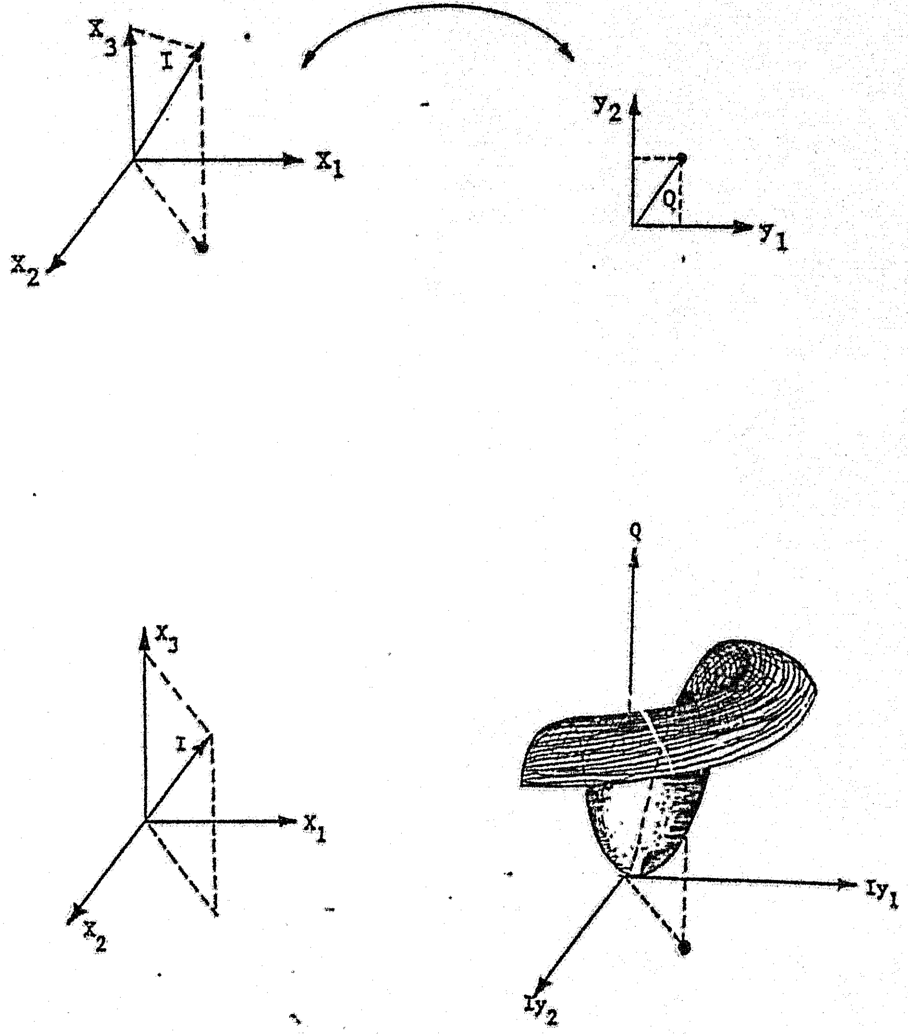


Figure 9. A two-output-three-input transformation function.

It is noted that the marginal cost in this multiple-product scenario is significantly higher if the opportunity cost of producing the alternative output is substantial, i.e., $dTC/dy_i > \lambda * \delta Q/\delta y_i$. This relationship about the firm's marginal cost reflects the change in the total cost incurred by the firm when it decides to increase production of output y_i by one unit. The change in total cost involves the marginal input (index) required to produce an incremental increase in output y_i valued at the shadow price, λ, with adjustments made to account for the opportunity cost involved when one product is produced in favor of another.

Important implications are given by the equation above. The first implication is that, with technological change, the marginal cost decreases with the improvement in the efficiency of input use as $\delta Q/\delta y_i$, which measures the marginal input required for an incremental increase in output i, goes down.

Second, if the new process designed for one product, say output y_i produces a spillover effect on other products, i.e., the technology is also applicable to another product, say output k, then $\delta Q/\delta y_k$ declines due to the enhancement in the efficiency of input use brought about by the new process. This circumstance allows a decline in the opportunity costs. Thus, the marginal cost incurred by a multi-output producer is effectively less in a positive "across-commodity spillover" regime compared to the case where the technology is exclusively applicable only to one product.

Third, in a neutral technological change environment, the relative marginal productivities of the inputs do not change, i.e., the marginal rate of technical substitution of one input for another along a fixed input proportion remain unchanged so that the relative shares are not affected.

However, in the case of biased technical change, the marginal product of one or more inputs are increased relative to the marginal product of others. This means that the producer will have the incentive to use more of some inputs relative to other inputs. This is tantamount to saying that the prices of some inputs will tend to increase relative to other input prices, and that the relative share of some inputs accordingly increases while others decline.

The change in the relative input prices effectively changes the firm's cost structure. If the relative share of the inputs for which prices increase is large then the marginal cost may shift upwards substantially. Effectively, the cost structure under a neutral technology change regime deviates from the cost structure under a biased technological change environment because of the possible "input price spillovers" that may occur.

5. SUMMARY

In resume, a re-examination of the linkage between the firm's production response function and the corresponding cost structure within the context of a multi-product production environment indicates that the usual marginal cost formulation is deficient -- it underestimates the marginal cost. It is clear that this deficiency arises from the fact that the usual analysis ignores the opportunity cost of producing alternative products using the same input. This is equivalent to setting the opportunity cost index s equal to one, when in fact, δ is necessarily greater than one in a multi-product environment.

The framework developed is a more general formulation that accommodates positive externalities like across-commodity spillover effects. In particular, spillover effects across commodities are translated into smaller values of δ relative to the case in which no spillover effects are involved.

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