Staff Paper P74-16 August 1974

MICROECONOMICS OF TECHNOLOGY AND THE AGRICULTURAL OUTPUT MIX

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Staff Papers are published without formal review
within the Department of Agricultural and Applied Economics

This paper will appear as a chapter in Hans P. Binswanger, Vernon W. Ruttan and Collaborators, Induced Innovation and Agricultural Development, to be published by the Johns Hopkins Press.

CHAPTER FIVE

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Martin E. Abel and Delane E. Welsch*

INTRODUCTION

There is widespread agreement on the importance of technology as a source of growth for agriculture.[1] Furthermore, there is increasing evidence that factor endowments and relative factor prices play an important role in inducing technical change in directions which augment the supply of scarce factors.[2] But given general acceptance of these two propositions, policy makers and research administrators are still left with the problems of deciding on the allocation of research resources among commodities and of determining how various allocations affect the output mix of a farm, a region within a country, or the total agricultural sector of a nation.

The allocation of research resources among commodities is closely akin to the topic of diversification, defined as changing either the number or the relative importance of commodities which can profitably be produced from a given set of resources in a given time period. We are

concerned with commodities which simultaneously compete for the same set of resources.[3] In recent years there has been a growing interest in the subject of diversification of agricultural production in the developing countries. Unfortunately, there has been very little research on the economics of crop diversification for these countries. " . . . Diversification is more a subject of vague references than actual knowledge. . . . Much more research is needed on diversification at the conceptual and applied levels. Development of a theoretical economic framework could be of significant value in organizing future analysis. One possibly useful starting point is the theory of comparative advantage. The theory should be applied to both production and marketing. . . ."[4]

Interest in agricultural diversification in the developing countries has been heightened by the production increases of the green revolution which, although limited in area covered and number of farmer participants, are real and have caused further "revolutions."[5] One of these is a higher degree of confidence among researchers in the developing countries that, with well funded and organized research programs, they can create new technologies. Another is the relatively new and generally accepted position of policy makers that peasant farmers, under the right conditions, are capable of rapid adoption of new technology and rapid increases in output. A third is in world grain markets and the price relationships between food grains and feed grains. An increasing number of persons are calling for diversification as a means for both capitalizing on the green revolution and avoiding some of its adverse consequences. All of the above combine to put pressure on those who allocate funds and administer research in the developing countries to concern themselves with a

broader range of agricultural commodities. Yet economics as a discipline has contributed little in the way of decision aids to help these people decide on the allocation of research resources among various commodities.

In this chapter we demonstrate how the allocation of research resources among commodities and the effects of such allocations on the output mix depend upon (a) the initial production conditions, (b) the nature of the research production functions, (c) the nature of the demand relations for the commodity outputs, and (d) relative factor endowments. The basic model used is a two-factor, two-product model in which certain types of technical change are introduced. This model is presented and discussed in the next section. The third section deals with the implications of technical change and demands for the outputs on the product mix. The fourth section deals with the role of factor endowments. The policy implications of the analysis are discussed in the fifth part of the chapter.

The role of commodity prices in the allocation of research resources discussed in this chapter relates to the discussion of commodity prices and induced innovation in chapter three. But while the focus in that chapter is on the relationship between product prices and bias in induced innovation, the focus of this chapter is on the allocation of research resources among commodities assuming unbiased technological change.

THE BASIC MODEL

To analyze certain questions concerning the benefits to be derived from diversification of agricultural production, we need a theoretical model which will enable us to trace through changes in production functions, factor endowments, and relative product prices on output, income, and factor rewards. A simple, but useful model for looking at the influence of technical change on the output mix is the standard two-factor, two-product model of production.

Let us start by assuming a region (thought of as an area within a country or a country which trades in a larger world market) produces two goods, q_1 and q_2, with two homogeneous factors of production, L and K, where L is the labor input and K is the land (capital) input. Total factor supplies are assumed to be fixed.

Production of our two goods is given by the Cobb-Douglas production functions

$$\text{(1a)} \qquad q_1 = \tau_1 L_1^{\alpha} K_1^{1-\alpha} = \tau_1 L_1 \left(\frac{K_1}{L_1}\right)^{1-\alpha}$$

$$\text{(1b)} \qquad q_2 = \tau_2 L_2^{\beta} K_2^{1-\beta} = \tau_2 L_2 \left(\frac{K_2}{L_2}\right)^{1-\beta}$$

which reflect constant returns to scale. τ_1 and τ_2 are indices of technology. In addition, the fixed supplies of labor and land (capital) are represented by

(2a) $$L_1 + L_2 = \bar{L}$$

(2b) $$L_1\left(\frac{K_1}{L_1}\right) + L_2\left(\frac{K_2}{L_2}\right) = \bar{K}$$

Furthermore, we assume that the factors of production are fully employed.

We can derive the expression for the slope of the production possibility curve, which is

(3) $$-\frac{d\left(\frac{q_1}{\bar{L}}\right)}{d\left(\frac{q_2}{\bar{L}}\right)} = \frac{\tau_1}{\tau_2}(bR)^{1-\alpha}(aR)^{\beta-1}[a + (b-a)\ell]^{\alpha-\beta}\left(\frac{a + \alpha\ell(b-a)}{a + (b-a)(1-\beta + \beta\ell)}\right),$$

where,

$$R = \left[\ell\left(\frac{K_1}{L_1}\right) + (1-\ell)\left(\frac{K_2}{L_2}\right)\right] = \frac{\bar{K}}{\bar{L}}$$

$$\ell = \frac{L_1}{\bar{L}}$$

$$a = \frac{\alpha}{1-\alpha}$$

$$b = \frac{\beta}{1-\beta}$$

The reader is referred to Harry G. Johnson, and Martin E. Abel, Delane E. Welsch and Robert W. Jolly, for detailed derivations of the production possibility curve and methods for solving for the outputs q_1 and q_2, given the product prices.[6]

We can consider two possibilities with respect to the influence on product prices of changes in the output levels of our producing region (country). One is a competitive environment in which both product prices, p_1 and p_2, are given to the region and do not vary with changes in q_1 and q_2. The other is where changes in either q_1 or q_2 influence the levels of market prices. In the first case, the region will face straight line iso-revenue curves. In the second case the iso-revenue curves will be convex to the origin over the relevant range of output. A fuller discussion of the price (revenue) side of the model is contained in Abel, Welsch and Jolly.[7]

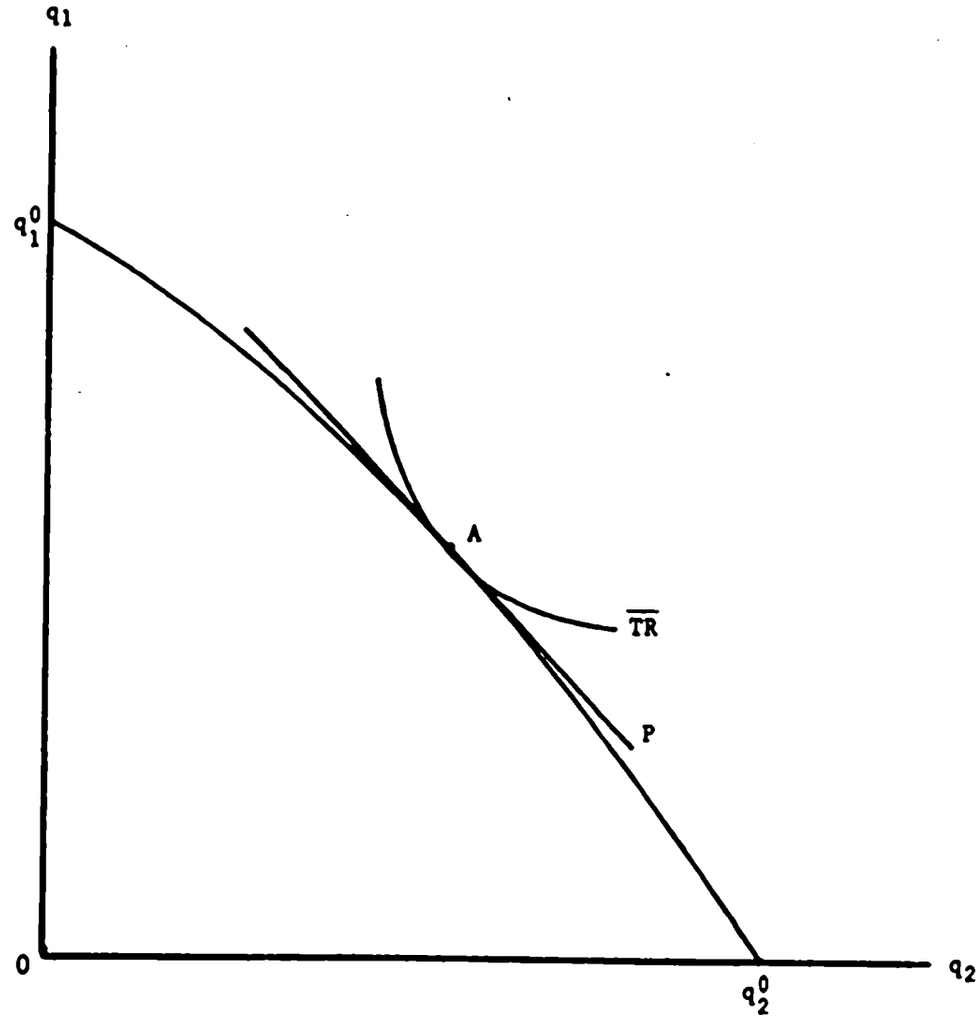
Our model assumes Cobb-Douglas production functions to be relevant throughout the full range of production--from complete specialization in q_1, to complete specialization in q_2. We would like to make two points about this assumption. First, there is no need to assume that the agricultural production world is Cobb-Douglas. Other forms of production functions, such as quadratic or CES production functions, may be more appropriate in some circumstances. Second, there is no reason to expect a particular form of the production functions to hold over the full range of possible factor substitution. At best, any given form may be a good approximation over a given (and sometimes small) range of resource substitution between the two production functions. At the extreme ranges of substitution between q_1 and q_2 the production possibility curve might

exhibit either a complementary or a supplementary relationship in the production of q_1 and q_2.

The model presented above has some interesting properties. Most important is that the production possibility curve will have little curvature for a wide range in values of the production elasticities α and β.[8] This has been clearly demonstrated by Johnson,[9] and can be easily verified by evaluating equation (3) for alternative values of α, β, and ℓ. From this result, it follows that the sensitivity of the output mix of q_1 and q_2 depends very much on whether the producing region operates as a price-taker or whether changes in the outputs of the region influence product prices. This is illustrated in figure 1. One can easily see how slight variations in the product price ratio, P, would cause large changes in the output mix along the production possibility curve $f(q_1^0, q_2^0) = 0$.

On the other hand, when our region faces downward sloping demand curves for one or both products, a high degree of stability in output mix is assured. Exogenous shifts in the demand curves for the two products of our region will result in a rotation of the conic section represented by the iso-revenue line $\overline{TR}$ in figure 1. The less the curvature of the iso-revenue lines, the greater will be the effect of exogenous shifts in the demand curves on changes in the output mix. In other words, as the price elasticities of demand approach infinity, the situation we assume to prevail under a competitive framework, the curvature of our iso-revenue line approaches a straight line and the effect of a given rotation of the iso-revenue line on changes in the output mix increases.

Figure 1



TECHNOLOGICAL CHANGE

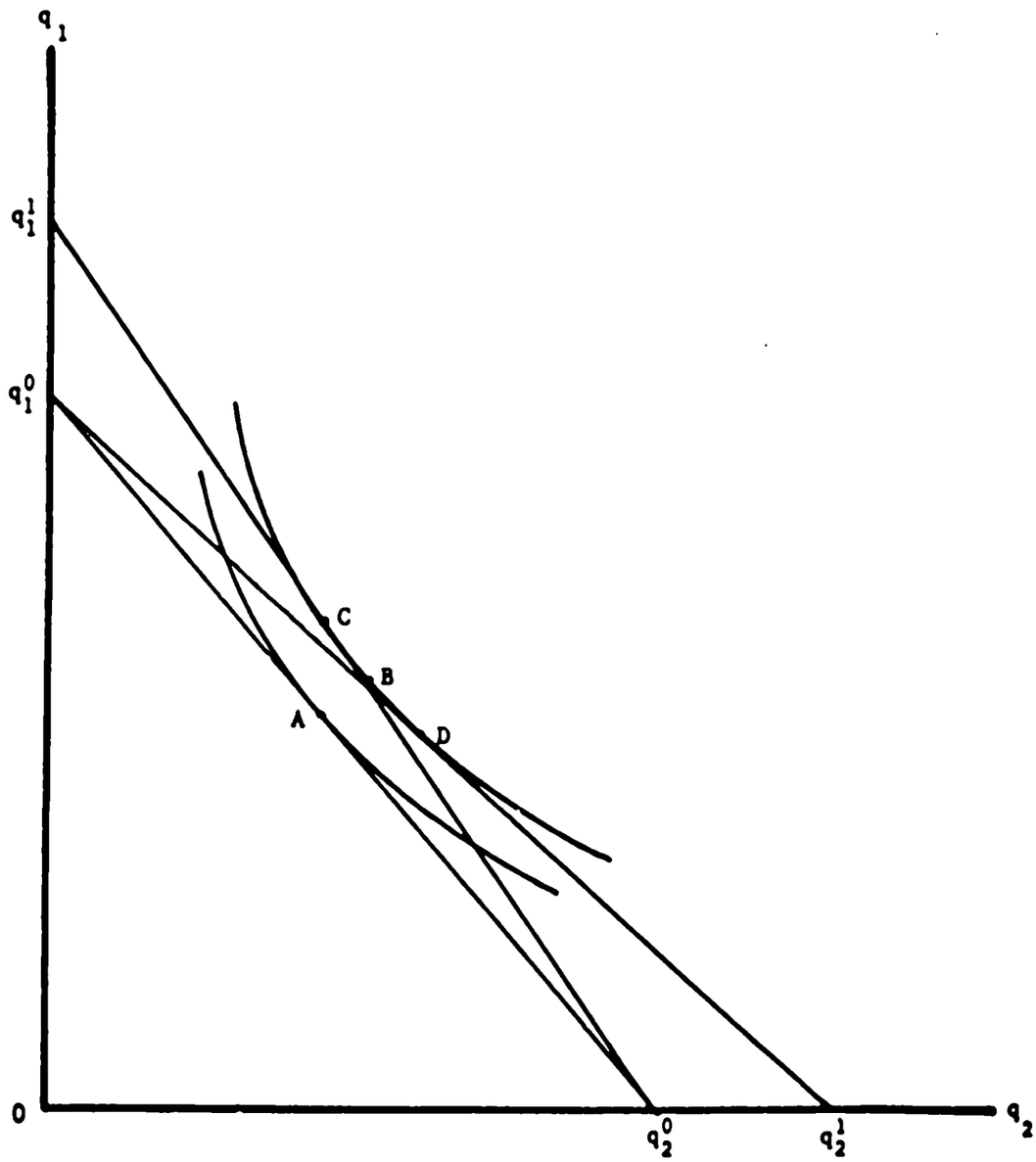
We now wish to examine the consequences of certain types of technological change in the context of our two-commodity, two-factor world. National (regional) research leaders are faced with the question of the allocation of research resources among commodities. Even if research administrators follow the Hayami-Ruttan[10] prescription of generating technological change of a type which is consistent with relative factor endowments and (undistorted) relative factor prices, they are still faced with the question of how best to allocate research resources among commodities. As we shall see, the decision as to how research resources are allocated depends not only on characteristics of the research production functions, but also on the nature of the demands for the final products. Three alternative situations are analyzed.

Situation I:

This situation is presented graphically in figure 2. The following assumptions are employed.

1. The initial production possibility curve, $f(q_1^0, q_2^0) = 0$, is a straight line which implies $\alpha = \beta$.
2. If q_1 and q_2 are measured in terms of the same physical units, complete specialization in q_1 results in greater output than complete specialization in q_2.
3. Our producing region can face either fixed prices or downward sloping demand curves for its outputs.

Figure 2



4. There is a fixed research budget which can be allocated between generating changes in τ_1 or τ_2. Thus, we are concerned with determining the optimum allocation of research resources subject to a research budget constraint.

5. The research production functions for τ_1 and τ_2 exhibit constant returns to scale. For simplicity, we assume the research production functions are of such a nature as to make $q_1^0 q_1^1 = q_2^0 q_2^1$. The latter assumption implies that the two research production functions yield identical absolute increases in production for equal research expenditures on τ_1 and τ_2. The analysis can be modified in appropriate ways for alternative assumptions about $q_1^0 q_1^1$ and $q_2^0 q_2^1$; e.g., a given budget increases efficiency in equal proportions for q_1 and q_2.

The implications of our assumptions are:

1. Allocation of all research resources to increasing τ_1 results in a new production possibility curve $f(q_1^1, q_2^0) = 0$. Similarly, allocation of all research resources to increasing τ_2 results in a new production possibility curve $f(q_1^0, q_2^1) = 0$. Under the assumption of constant returns to scale in the research production function, linear combinations of research expenditures trace out an innovation possibility frontier which is convex to the origin. The innovation possibility frontier represents the highest output combinations attainable from alternative allocations of a fixed research budget. We can illustrate this result in the following way. Assume that research resources are equally divided between increasing τ_1 and τ_2. We get a new

production possibility curve such as $f(q_1^2, q_2^2) = 0$. The line segment CD represents higher levels of output than are attainable from either $f(q_1^1, q_2^0) = 0$ or $f(q_1^0, q_2^1) = 0$. If one rotates line $f(q_1^2, q_2^2) = 0$ to reflect alternative combinations of research resources one can see that this traces out an innovation possibility frontier which is slightly convex to the origin.

2. If the producing region faces fixed prices, it pays to completely specialize in research, and there will be complete specialization in production of either q_1 or q_2. If product prices are such as to initially result in complete specialization in q_1 at level $0q_1^0$, our producing region would benefit most from investing all research resources in increasing output of q_1; i.e., generating the new production possibility curve $f(q_1^1, q_2^0) = 0$. The reader can verify that even with a range in relative prices which would result in production of either $0q_1^1$ or $0q_2^1$, total output would be greater at $0q_1^1$ and, therefore, increasing τ_1 is superior to increasing τ_2. If prices are given but initially result in specialized production of $0q_2^0$, then the converse of the above situation holds with respect to technical change. (This would not necessarily hold if $f(q_1^0, q_1^1) = 0$ were sufficiently different from $f(q_2^0, q_2^1) = 0$.

3. If the region faces downward sloping demand curves, not only will the region produce a combination of q_1 and q_2, but also the highest level of production is obtainable from allocating research resources to increasing both τ_1 and τ_2. In figure 2 we show that, given the iso-revenue line, the highest level of

output is achieved at B, which is on the new production possibility curve $f(q_1^2, q_2^2) = 0$. Furthermore, the more price inelastic the demand curves, the more convex to the origin will be the iso-revenue curves, and the smaller will be the effect of technical change on the changes in the output mix.

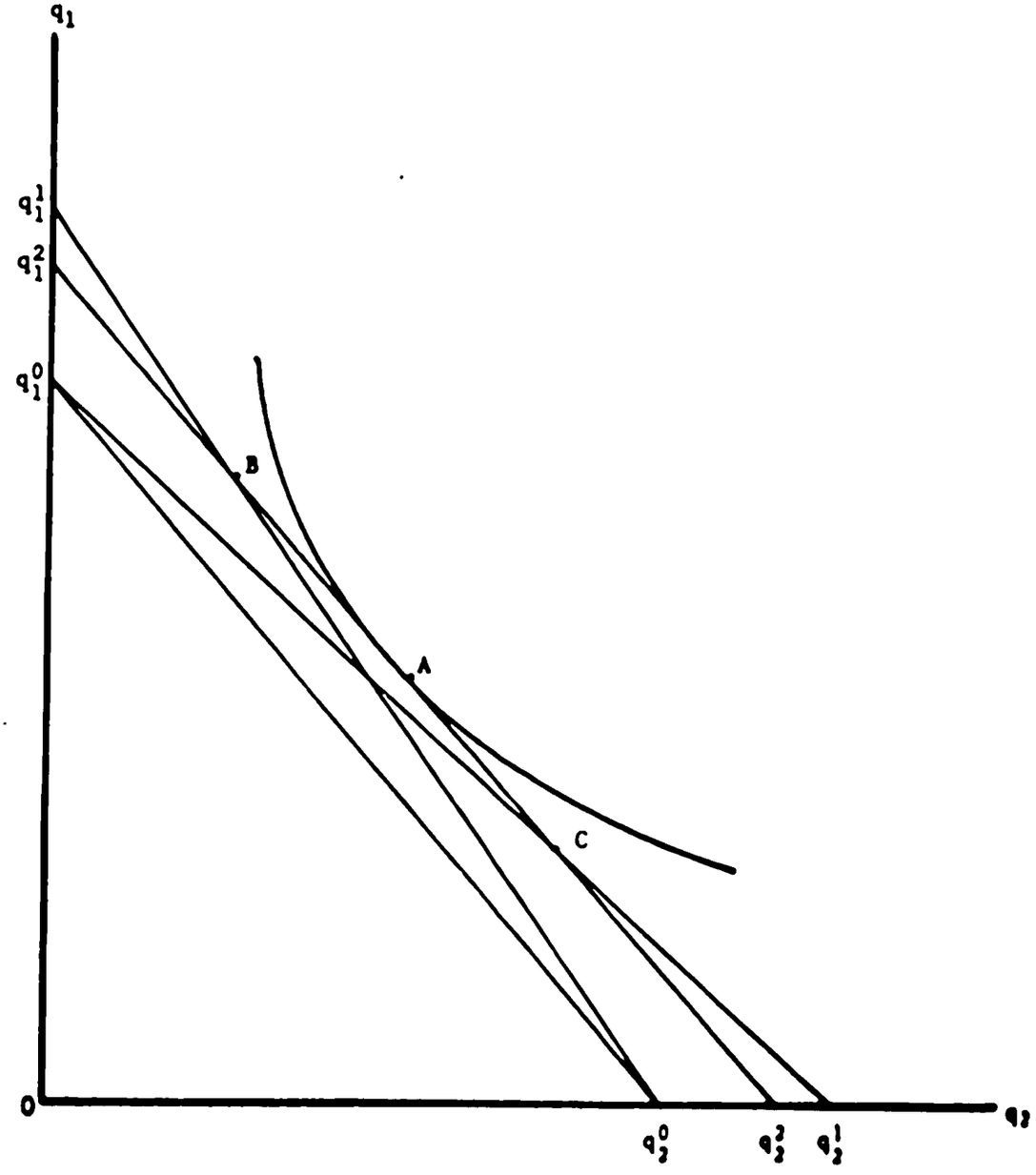
Situation II:

In this case we modify situation I by assuming that decreasing returns to scale prevail in the research production functions.[11] All the other assumptions in situation I hold in situation II. The results are illustrated in figure 3.

The implications of our assumptions are:

1. Allocating all research resources to increasing τ_1 results in the new production possibility curve $f(q_1^1, q_2^0) = 0$. Similarly, allocating all research resources to increasing τ_2 gives us $f(q_1^0, q_2^1) = 0$. Linear combinations of research resources on τ_1 and τ_2 will trace out an innovation possibility frontier which is convex to the origin, but less convex than in the case of situation I. We can illustrate this in the following way. Because of decreasing returns in both our research production functions, $q_1^0 q_1^2 > 1/2\ q_1^0 q_1^1$ and $q_2^0 q_2^2 > 1/2\ q_2^0 q_2^1$. The line segment BC in figure 3 is relatively longer than CD in figure 2. If one rotates line $f(q_1^2, q_2^2) = 0$ to reflect alternative combinations of research resources, and keeping in mind that decreasing returns to scale in the research production functions result in successively smaller increments in τ_1 or τ_2 for

Figure 3



successive absolute increases in research resources of a given size, one can see that this traces out an innovation possibility frontier which is convex, but less so than in figure 2.

2. If the producing region faces fixed prices, it pays to completely specialize in research, and there will be complete specialization in production of either q_1 or q_2. This result is the same as that obtained in situation I.

3. If the region faces downward sloping demand curves for its products, not only will the region produce a combination of q_1 and q_2, but also the highest level of production is obtainable from allocating research resources to increasing both τ_1 and τ_2. In figure 3 we show that, given the iso-revenue line, the highest level of output is achieved at A, which is on the new production possibility curve $f(q_1^2, q_2^2) = 0$.

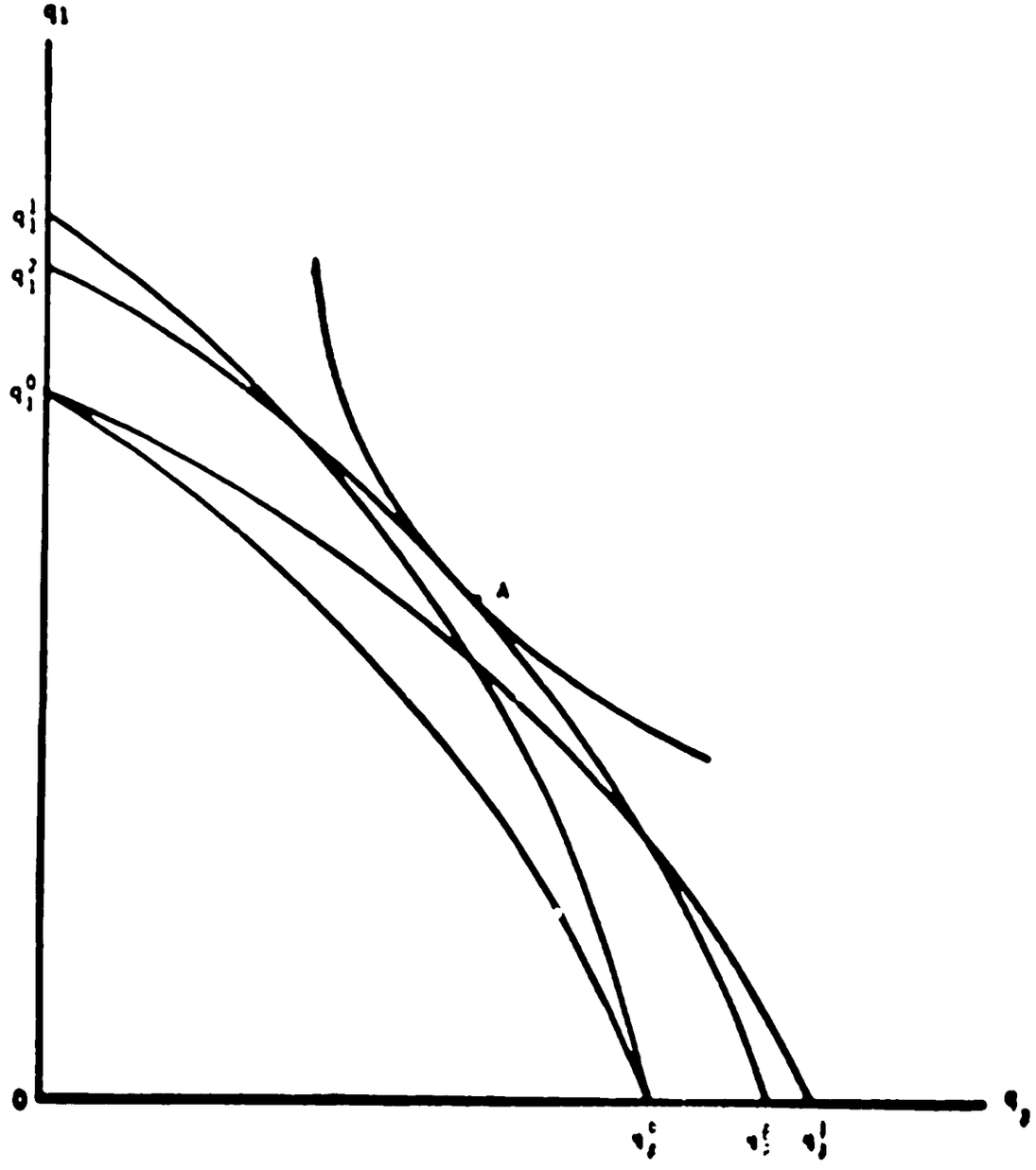
Situation III:

In this case we make the same assumptions as in situation II except that we now assume the initial production possibility curve, $f(q_1^0, q_2^0) = 0$, is concave to the origin. The results of these assumptions are shown in figure 4.

The implications of our assumptions in this situation are:

1. With given prices, the region would completely specialize in the production of q_1 or q_2 only if the terms of trade were sufficiently in favor of one output or the other. Otherwise the region would produce some combination of q_1 and q_2. The

Figure 4



more concave the production possibility curve, the more likely it is that there would not be complete specialization in production.

2. Alternative combinations of research resources for increasing τ_1 and τ_2 will trace out an innovation possibility frontier which is concave to the origin. This can be shown by the same procedure suggested in situation II. As in the previous case, the production possibility curve $f(q_1^2, q_2^2) = 0$ is the one which results from allocating one-half of available research resources to each commodity.

3. In this situation, it might pay to allocate research resources to increasing both τ_1 and τ_2, regardless of whether the region faced fixed product prices or downward sloping demand curves. This can be seen in figure 4. Assume that relative prices are such that the price line for fixed prices would be tangent to $f(q_1^2, q_2^2) = 0$ at A. Also assume that the iso-revenue line resulting from downward sloping demand curves is also tangent to $f(q_1^2, q_2^2) = 0$ at A. In either case, the highest attainable level of production results from an allocation of research resources to both τ_1 and τ_2 which generates the new production possibility curve $f(q_1^2, q_2^2) = 0$.

Situation IV:

One might also wish to consider the case where the research production functions exhibit increasing returns to scale.[12] Increasing returns might prevail if the research production functions are S-shaped and the

fixed research budget is sufficiently small so as to restrict research activities to the increasing returns portion of the research production function. If the initial production possibility curve is a straight line, as in figures 2 and 3, the new innovation possibility frontier representing alternative combinations of research expenditures on q_1 and q_2 will be convex to the origin. If, on the other hand, the initial production possibility curve is concave, the new innovation possibility frontier could be less concave, a straight line, or convex, depending on the degree of increasing returns in the research production function. Increasing returns to research will result in complete specialization in research activity so long as the new innovation possibility frontier is convex. This will be so whether or not the region faces given prices or downward sloping demand curves for its products.

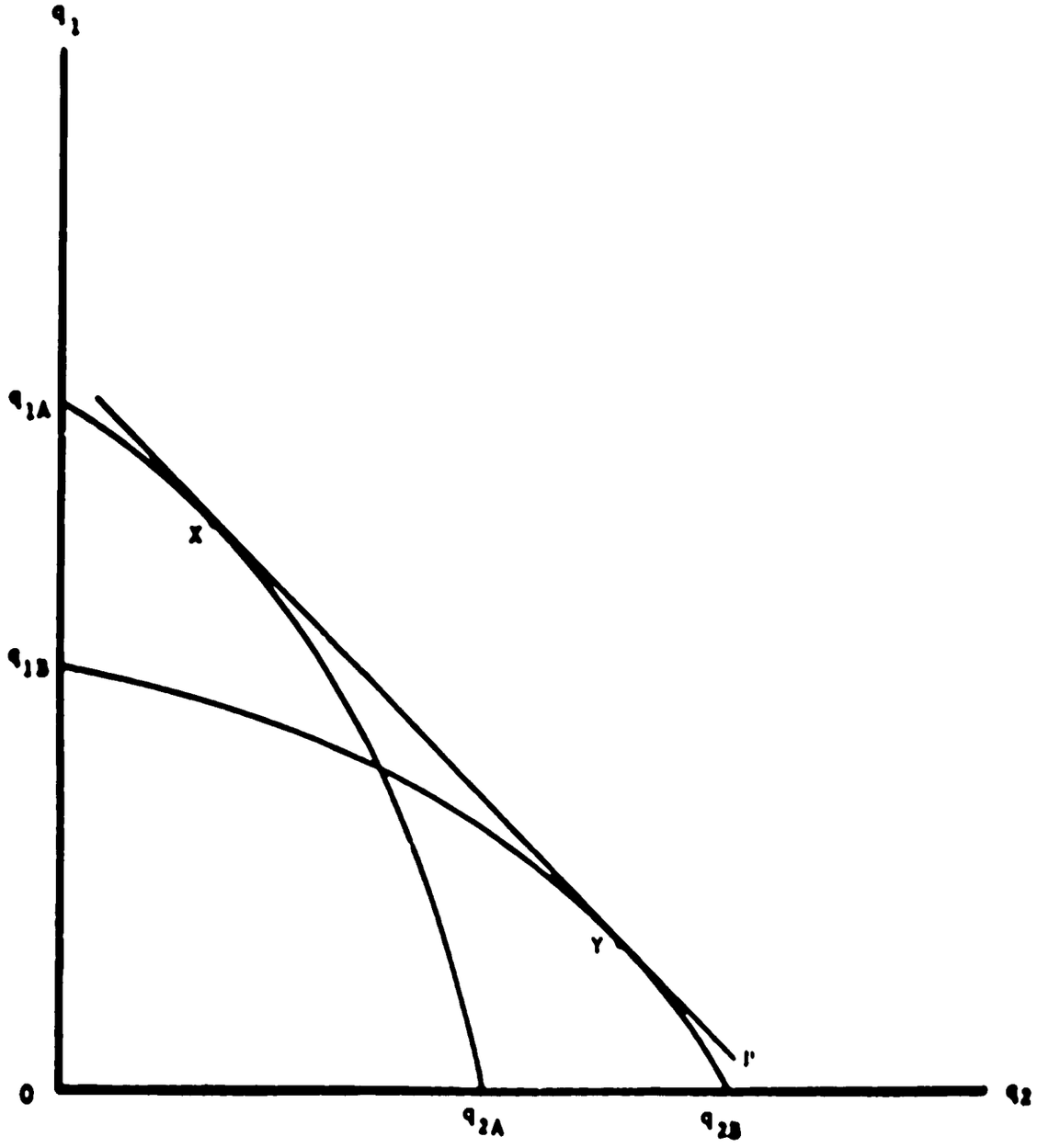
RESOURCE ENDOWMENTS

We can also use our model to illustrate how different resource endowments affect both the output mix and the allocation of research resources. We shall assume (a) two regions, A and B, producing the same two outputs q_1 and q_2, (b) the production function for each output is the same in both regions, (c) the production of q_1 is more intensive in the use of land (capital) relative to labor than the production of q_2, and (d) one region, A, has relatively more land than labor compared with the other region, B.

The initial situation is illustrated in figure 5. The production possibility curve for region A is $f(q_{1A}, q_{2A}) = 0$ and that for region B is $f(q_{1B}, q_{2B}) = 0$. Since the production of q_1 is relatively more land (capital) intensive than the production of q_2 we would expect region A to favor the production of q_1. With both regions facing the same fixed relative prices, P, the output mix of region A would be at point X and the output mix of region B at point Y in figure 5. The results are as one would expect. Region A, which has an abundance of land (capital) relative to labor, produces more of q_1 than q_2 , and region B, which has an abundance of labor relative to land (capital), produces more of q_2 than q_1.

Employing the same type of analysis concerning technological change as was used in the previous section and assuming the same fixed relative prices, P, in both regions as shown in figure 5, one can verify that (a) in region A it would pay to invest a higher proportion of the research

Figure 5



budget in increasing τ_1 than in increasing τ_2, and (b) in region B it would pay to invest a higher proportion of the research budget in increasing τ_2 than in increasing τ_1. However, the results may change as relative product prices change. If the price of q_2 is significantly higher relative to the price of q_1 than is the situation illustrated in figure 5, region A would allocate more resources to increasing τ_2 than τ_1. With sufficiently strong product price incentives in favor of q_2 both regions A and B would allocate proportionately more of their fixed research budgets to τ_2 than to τ_1. The reverse would be true with sufficiently strong price incentives in favor of q_1.

In addition to the role of demand conditions for the final products and the nature of the research production functions, variations in relative factor endowments and in relative factor intensities with respect to the outputs also play important roles in determining the allocation of research resources. For example, under the product price assumptions illustrated in figure 5 the labor "rich" region will allocate relatively more research resources to the labor intensive commodity and the labor "poor" region will allocate relatively more research resources to the land (capital) intensive commodity.

SOME IMPLICATIONS

Our analysis shows that the optimum allocation of research resources among commodities and its effect on the output mix of a region depend upon the initial production conditions (concavity of the production possibility curve and the relative size of q_1 and q_2 with complete specialization in the production of each), the extent to which there are either increasing or decreasing returns to scale in research, whether the producing region faces given prices or downward sloping demand curves for its outputs, and changes in relative factor endowments. Information on all four aspects of the problem is required by research administrators to decide on the optimum allocation of research resources among commodities.

If the production possibility curve is relatively flat and the region is a price-taker, we would expect significant shifts in the output mix as a result of changes in relative output prices. Furthermore, the allocation of research resources depends heavily on relative product prices and return to scale in research. Research resources would be devoted entirely to increasing the production of q_1 if (a) prices initially favor complete specialization in the production of q_1, (b) there are constant or increasing returns to scale in research, and (c) there are identical production functions for q_1 and q_2. Research would strengthen the tendency toward complete specialization in production. On the other hand, if the production possibility curve is concave, both

q_1 and q_2 would tend to be produced, except in the case where the region faced fixed prices and these were of such an extreme nature as to dictate complete specialization in production. Except for the extreme case, research resources would be allocated to increasing both τ_1 and τ_2.

Even if the production possibility curve is relatively flat over a wide range of variation in q_1 and q_2, we may still observe a high degree of stability in the output mix even with technological change because the region faces downward sloping demand curves for its outputs. The more price inelastic the demand curves, the more convex the iso-revenue lines, and the less sensitive is the output mix to technological change. Furthermore, even with downward sloping demand curves, it would still pay to devote all research resources to one commodity if the combination of (a) the slope of the initial production possibility curve and (b) returns to scale in research resulted in an innovation possibility frontier which was either a straight line or convex.

A region might face downward sloping demand curves for its products either because of short-run rigidities in parts of the marketing system or because changes in output levels of a region were sufficient to change prices throughout the marketing system. There is evidence that significant changes in the production of one crop can cause temporary distortions in the relative price structure of a region compared with prices in a larger marketing area. Uma J. Lele,[13] in her study of sorghum grain marketing in western India, found that distortions in intermarket price differentials arose when the volume of grain production and marketings pressed against the supply of transport services. Jolly,[14] in a study

of corn and soybean price behavior in southwestern Minnesota, found that the margin between central market prices and local prices was a function of the level of output and the output mix in the local region.

Mitoshi Yamaguchi, and Yamaguchi and Hans P. Binswanger,[15] in a study of the effect of technical change and population growth on the economic development of Japan, observed patterns of production and price behavior consistent with our model. In looking at the agricultural and nonagricultural sectors (equivalent to our two commodities), they found (a) a very flat production possibility curve and (b) a high degree of stability in the output and consumption mixes, because the demand curves for the outputs of both sectors were downward sloping and especially price inelastic in the case of demand for agricultural products.

In a situation with downward sloping market demand curves, intervention in the markets for q_1 and q_2 by government (or other groups) in the form of price support measures or trade restrictions can yield results similar to the competitive model, i.e., intervention can result in a higher degree of specialization than would result from a market solution. (This does not automatically follow because governments can also set the relative support prices in ways which will shift the terms of trade against the commodity experiencing the technological change.) Furthermore, price support programs or trade restrictions can also affect the allocation of research resources to the extent that product price behavior is important in determining such allocations.

The question of which commodity should receive research resources depends very much on society's developmental objectives and policies.

For example, suppose it is the primary concern of policy makers to increase the incomes of producers, and relative prices are unimportant. Then one rule which could be followed is to increase the production of the commodity with the highest price and income elasticities. In this way one would tend to minimize the extent to which a shift in the terms of trade tends to counteract the effect of technological change. On other hand, suppose one of the commodities is a wage good, it has lower price and income elasticities than the non-wage good, and it is the policy makers' desire to keep the price of the wage good as low as possible. In this case, it would make sense to invest research resources in bringing about technological change in the wage good, i.e., we want to maximize the shift in terms of trade against the wage good. These are but two of many possible situations.

Finally, we should be cognizant of the fact that the price elasticity of demand which a region or country faces depends on both domestic and export demand parameters. It is possible for the domestic demand curve to be quite price inelastic, but the export demand curve facing our country or region to be quite price elastic, e.g., the case of corn in Thailand. In such a situation it would be important for the country or region to follow price policies which did not exclude domestic production from entering export markets, if the policy objective is to minimize the adverse effect on terms of trade for corn of a change in output. On the other hand, if the name of the game is to keep domestic prices as low as possible, then export barriers might be erected, e.g., the case of the rice premium in Thailand.

CONCLUSIONS

We have constructed a relatively simple theoretical model which shows that the allocation of a fixed research budget between research on two commodities and the effects of such allocations on the output mix of a region depend on the initial production conditions, the presence of economies or diseconomies of scale in research, the nature of the demands for the outputs of the region, and changes in relative factor endowments. Research administrators require information on all these aspects of the problem in order to determine the optimum allocation of research resources.

Our analysis indicates that there is nothing inherently good or bad about diversification of production. Changes in output mix must be evaluated in terms of a country's developmental objectives.

Price policies can play an important role not only in the allocation of traditional resources among commodities in a region,[16] but also in influencing the allocation of research resources. Walter P. Falcon[17] has cogently argued that agricultural price policies should be consistent with national development objectives. Unfortunately, this is not always the case.

FOOTNOTES

*The authors are Professors, Department of Agricultural and Applied Economics, University of Minnesota. Dr. Welsch is also concurrently Agricultural Economist, The Rockefeller Foundation, and Visiting Professor, Kasetsart University and Thammasat University, Bangkok, Thailand. The authors wish to thank Hans P. Binswanger for helpful comments on earlier drafts of this paper.

[1]Theodore W. Schultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964).

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[6]Harry G. Johnson, "Factor Market Distortions and the Shape of the Transformation Curve," Econometrica 34 (July 1966): 686-98; Martin E. Abel, Delane E. Welsch, and Robert W. Jolly, "Technological Change and Agricultural Diversification," Staff Paper P73-10, Department of Agricultural and Applied Economics (University of Minnesota, Revised April 1974).

[7]Abel, Welsch, and Jolly, "Technological Change . . ."

[8]This result will hold over the range in output variation for which the Cobb-Douglas production functions are good approximati ns of the real world.

[9]Johnson, "Factor Market Distortions . . . "

[10]Hayami and Ruttan, Agricultural Development . . .

[11]This is probably the most realistic assumption about returns to scale in research. Decreasing returns could arise in two possible ways. First, the static research production functions could exhibit decreasing returns to scale because the stock of "basic" knowledge from which the research activities draw is fixed at any point in time. We assume that our research activities are not directed toward expanding the supply of "basic" knowledge. Second, if one views research as a probabilistic search process, decreasing returns in the research production functions are likely to prevail, as demonstrated by Robert E. Evenson and Yoav Kislev, "A Model of Technological Research," processed, August 1971.

[12]Robert E. Evenson, "Economic Aspects of the Organization of Agricultural Research" in Walter L. Fishel, ed., Resource Allocation in Agricultural Research (Minneapolis: The University of Minnesota Press, 1971).

[13]Uma J. Lele, "Market Integration: A Study of Sorghum Prices in Western India," Journal of Farm Economics 49 (February 1967): 147-59.

[14]Robert W. Jolly, "The Derived Demand for Specialized Inputs by a Multi-Product Firm: An Examination of Corn and Soybean Buying by Minnesota Country Elevators," processed, 1973.

[15]Mitoshi Yamaguchi, "Technical Change and Population Growth in the Economic Development of Japan," Ph.D. dissertation (University of Minnesota, July 1973); Mitoshi Yamaguchi and Hans P. Binswanger, "The Role of Sectoral Technical Change in Development: Japan 1880-1965," Staff Paper P74-7, Department of Agricultural and Applied Economics (University of Minnesota, April 1974).

[16]The role of price in the allocation of resources among crops in developing countries was highlighted by Raj Krishna, "Farm Supply Response in India-Pakistan: A Case Study of the Punjab Region," Economic Journal 73 (September 1963): 477-87, and subsequently, by

many other analysts. See also Raj Krishna, "Agricultural Price Policy and Economic Development," in Herman M. Southworth and Bruce F. Johnston, eds., Agricultural Development and Economic Growth (Ithaca: Cornell University Press, 1967).

[17] Walter P. Falcon, "The Green Revolution: Generations of Problems," American Journal of Agricultural Economics 52 (December 1970): 698-710.