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Technology and the Agricultural Output Mix

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Introduction

There is widespread agreement on the importance of technology as a source of growth for agriculture [Schultz, 1964]. 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 [Hayami and Ruttan, 1971]. But given general acceptance of these two propositions, policy makers and research administrators are still left with the problem of deciding on the allocation of research resources among commodities and 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

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resources [Dalrymple, 1971]. In recent years there has been a growing interest in the subject of diversification of agricultural production in the developing countries. Unfortunately, very little research on the economics of crop diversification has been done 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. . . ." [Dalrymple, 1968.]

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" [Welsch, 1972]. One 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.

The purpose of this paper is to show 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, and (c) the nature of the demand relations for the commodity outputs. 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 of the paper deals with the implications of technical change and demands for the outputs on the product mix. The policy implications of the analysis are discussed in the fourth part of the paper.

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

$$(1a) \qquad q_1 = \alpha_0\tau_1 L_1^{\alpha} K_1^{1-\alpha} = \alpha_0\tau_1 L_1 \left(\frac{K_1}{L_1}\right)^{1-\alpha}$$

$$(1b) \qquad q_2 = \beta_0\tau_2 L_2^{\beta} K_2^{1-\beta} = \beta_0\tau_2 L_2 \left(\frac{K_2}{L_2}\right)^{1-\beta}$$

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

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

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

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

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

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 Johnson [1966] and Abel, Welsch and Jolly [1973] for detailed derivations of the production possibility curve and methods for solving for the outputs q_1 and q_2, given the product prices.

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 [1973].

Further, we would like to be able to consider instances where a region is a net exporter of both q_1 and q_2. The income of our region is

(4) $$Y = p_1q_1 + p_2q_2.$$

Let q_i^d be the amount of total output of q_i consumed at home. Then our expenditure equation would be

$$(5) \qquad E = p_1 q_1^d + p_2^d + S$$

where S represents expenditures on things which are not produced in the region and do not enter into the production processes for the q_i's. In this formulation we assume $E = Y$. Thus, a region can be an exporter of both commodities and the underlying assumptions of our production model are maintained.

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. 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. Furthermore, 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 among 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.

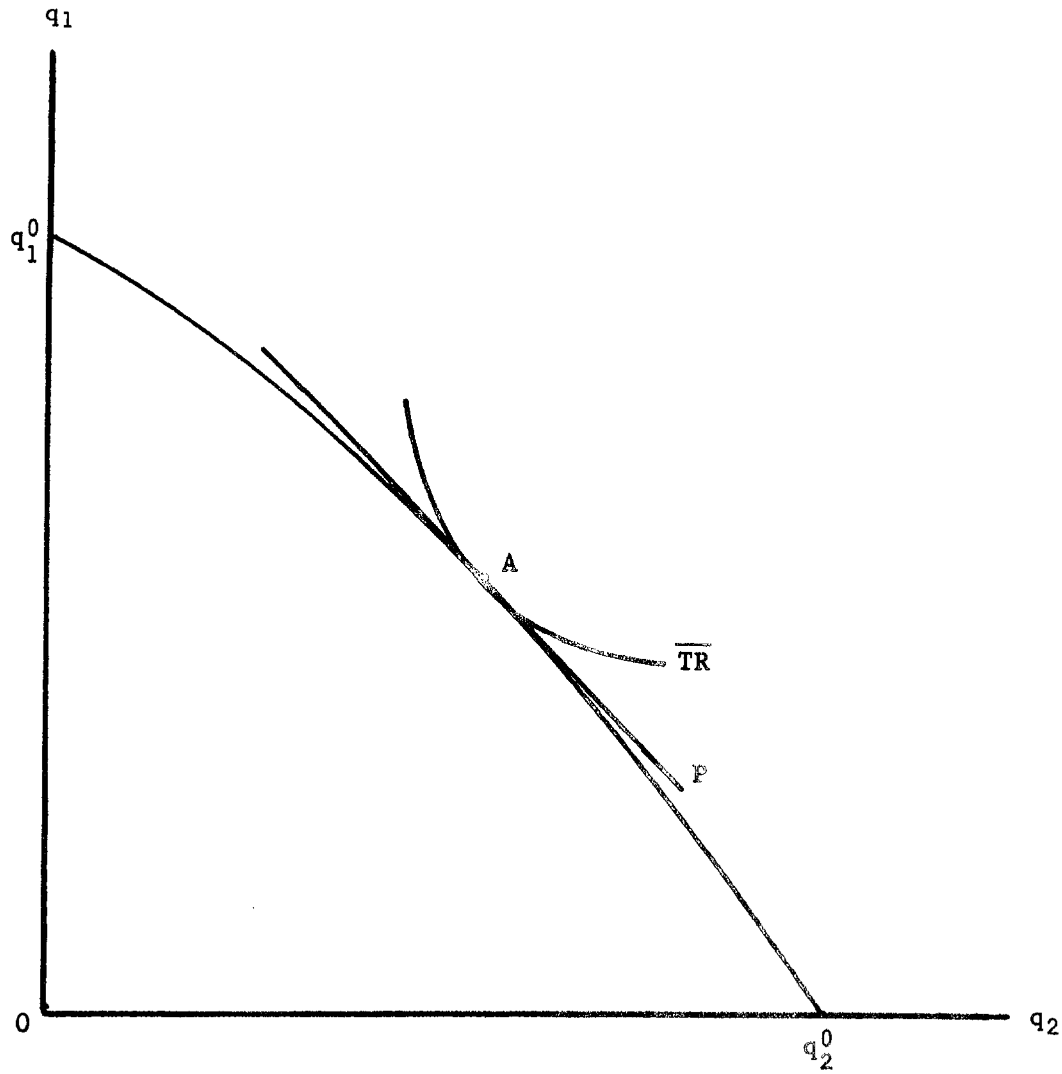
The model presented above has some interesting properties. Most important is that the production possibility curve will have little curvature for a wide range in values of the production elasticities α and β.[1/] This has been clearly demonstrated by Johnson [1966], and can be easily verified by evaluating 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 $q_1^0 q_2^0$.

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.

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 [1971] prescription of generating

Figure 1



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.

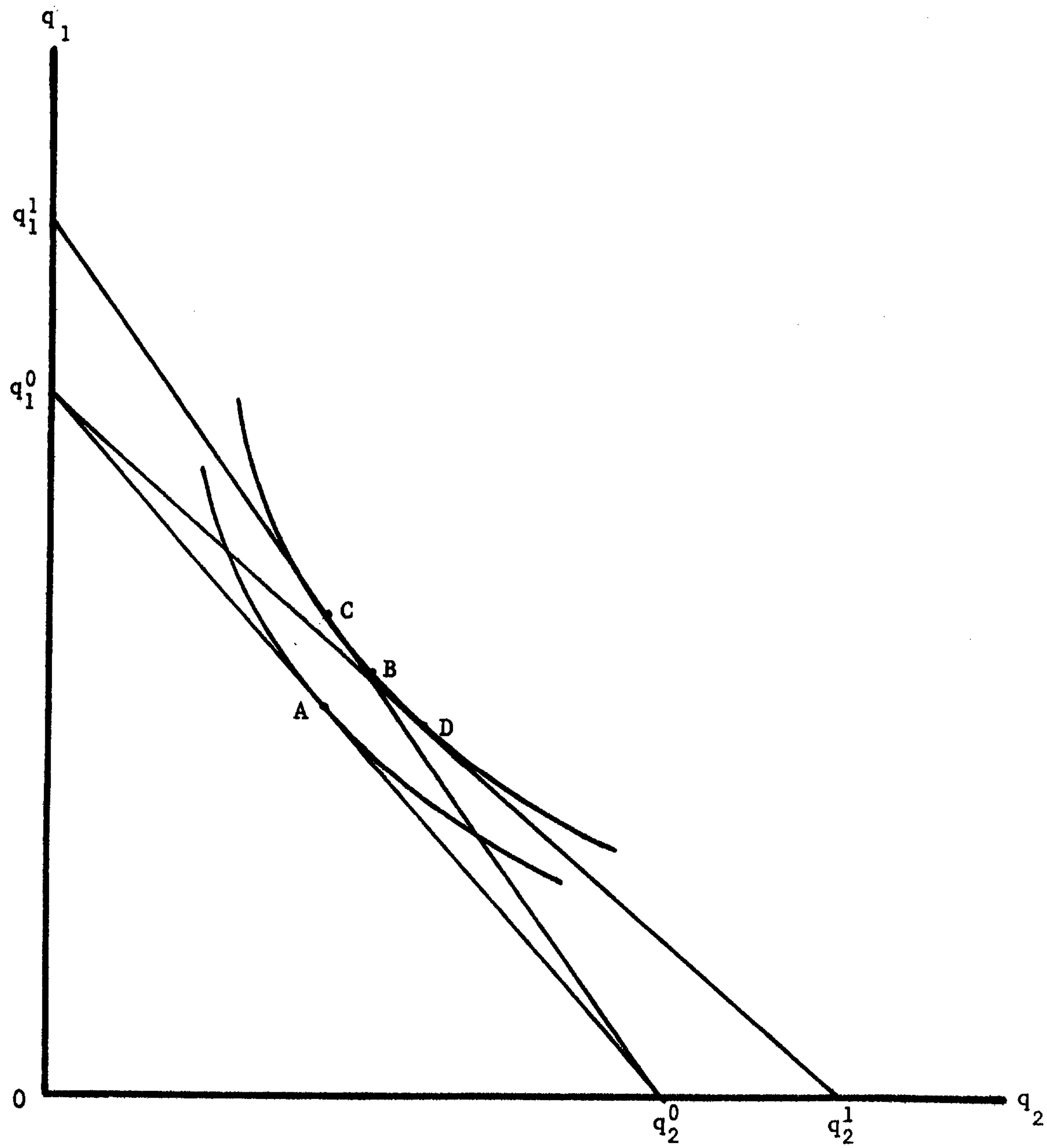
1. The initial production possibility curve, $q_1^0q_2^0$, is a straight line which implies $\alpha = \beta$.
2. If q_1 and q_2 are measured in terms of the same physical units, complete specialization in q_1 results in greater output than complete specialization in q_2.
3. Our producing region can face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

latter assumption implies that the two research production functions are identical. The analysis can be modified in appropriate ways for alternative assumptions about $q_1^0q_1^1$ and $q_2^0q_2^1$.

The implications of our assumptions are as follows:

1. Allocation of all research resources to increasing τ_1 results in a new production possibility curve $q_1^1q_2^0$. Similarly, allocation of all research resources to increasing τ_2 results in a new production possibility curve $q_1^0q_2^1$. Under the assumption of constant returns to scale in the research production function, linear combinations of research expenditures generate a family of new production possibility curves all passing through point B but with slopes somewhere between those of lines $q_1^1q_2^0$ and $q_1^0q_2^1$. Thus, the curve $q_1^1Bq_2^1$ traces out an <u>innovation possibility frontier</u> representing the highest output combinations from alternative allocations of the fixed research budget.
2. In this situation, complete specialization of research activities gives the highest attainable levels of production.
3. If the producing region faces fixed prices, it will completely specialize either in q_1 or q_2. If the region faces downward sloping demand curves, it will produce a mix of q_1 and q_2 such as at point A in figure 2.
4. If product prices are such as to initially result in complete

Figure 2



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 $q_1^1q_2^0$. The reader can verify that even with a range in relative prices which would result in production at either q_1^1 or q_2^1, total output would be greater at q_1^1 and, therefore, increasing τ_1 is superior to increasing τ_2. If prices are given but initially result in specialized production at q_2^0, then the converse of the above situation holds with respect to technical change. (This would not necessarily hold if $q_1^0q_1^1$ were sufficiently different from $q_2^0q_2^1$.)

5. If the region faces downward sloping demand curves, the output mix will depend on whether resources are invested in increasing τ_1 or τ_2. Investing all research resources in τ_1 would change the output mix from A to C. Investing all research resources in τ_1 would change the output mix from A to D. The extent to which technical change changes the output mix depends on the curvature of the iso-revenue curves. In general, 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.

6. Under the assumptions of situation I, it is advantageous to concentrate all research resources in changing either τ_1 or τ_2, regardless of the nature of the demand curves for the outputs.

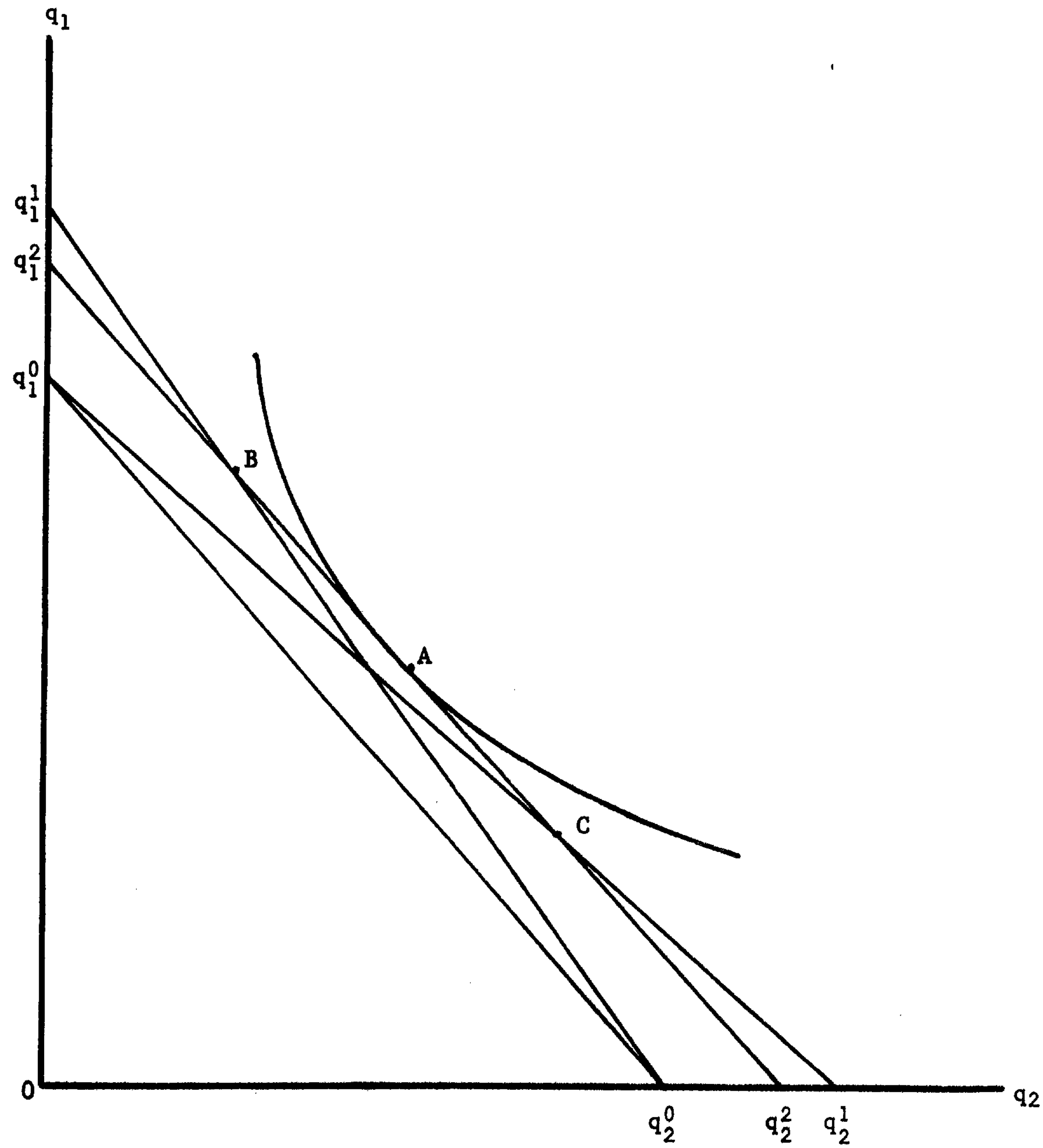
Situation II:

In this case we modify situation I by assuming that decreasing returns to scale prevail in the research production functions.[2/] 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 $q_1^1 q_2^0$. Similarly, allocating all research resources to increasing τ_2 gives us $q_1^0 q_2^1$. Linear combinations of research resources on τ_1 and τ_2 will trace out an innovation possibility frontier which is convex to the origin. We can illustrate this in the following way. Assume that research resources are equally divided between increasing τ_1 and τ_2. We then get a new production possibility curve such as $q_1^2 q_2^2$. 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 represents higher levels of output than is attainable from either $q_1^1 q_2^0$ or $q_1^0 q_2^1$. If one rotates line $q_1^2 q_2^2$ 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 successive absolute increases in research resources of a given size, one can see that this traces out an innovation possibility frontier which is convex.
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.

Figure 3



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 $q_1^2q_2^2$. Thus, unlike situation I, downward sloping demand curves dictate devoting research resources to increasing both τ_1 and τ_2 rather than complete specialization in research.

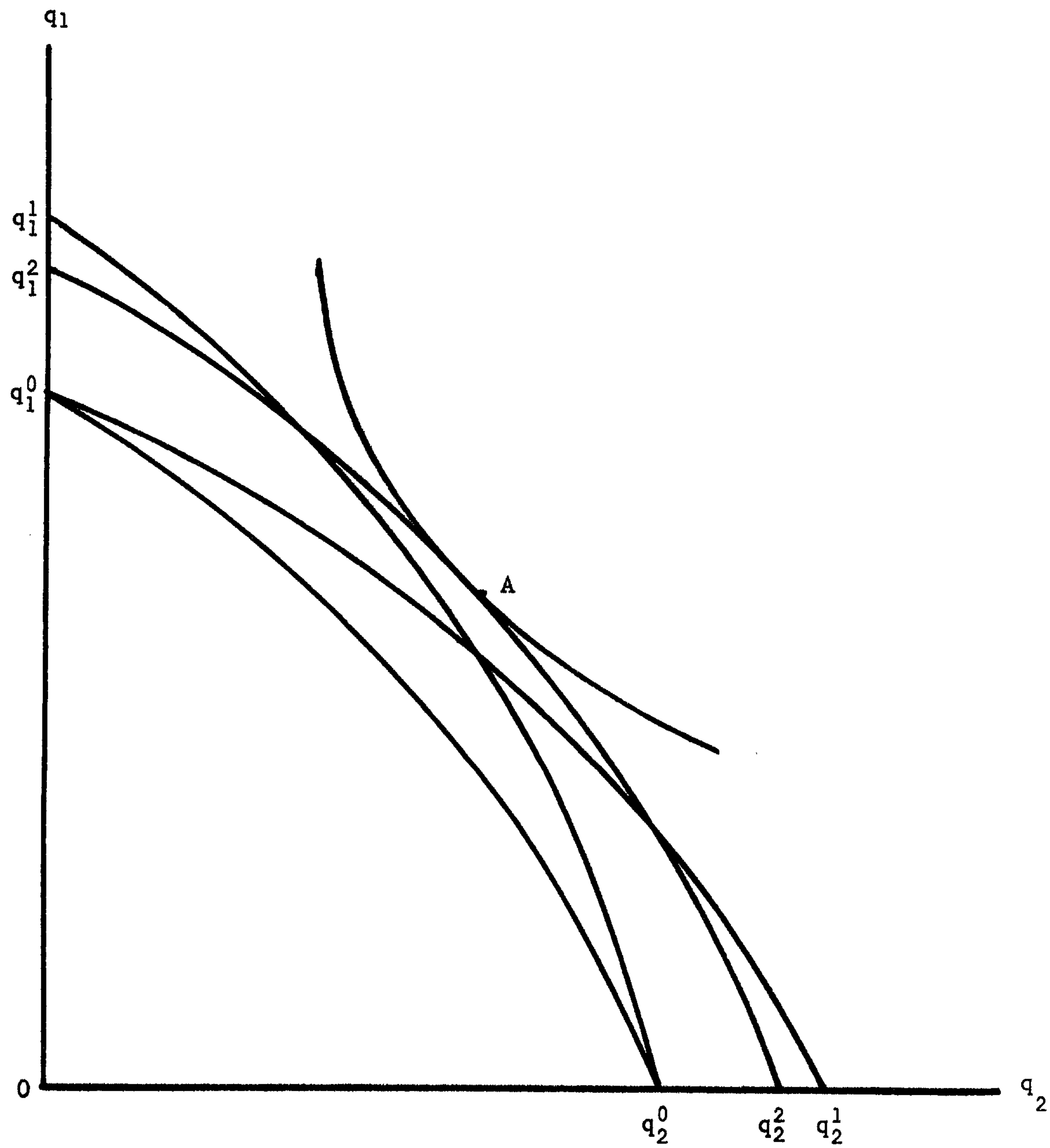
Situation III:

In this case we make the same assumptions as in situation II except that we now assume the initial production possibility curve, $q_1^0q_2^0$, 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 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

Figure 4



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 $q_1^2 q_2^2$ 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 $q_1^2 q_2^2$ at A. Also assume that the iso-revenue line resulting from downward sloping demand curves is also tangent to $q_1^2 q_2^2$ 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 $q_1^2 q_2^2$.

One might also wish to consider the case where the research production functions exhibit increasing returns to scale [Evenson, 1971]. 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 the region faces given prices or downward sloping demand curves for its products.

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 production of each), the extent to which there are either increasing or decreasing returns to scale in research, and whether the producing region faces given prices or downward sloping demand curves for its outputs. Information on all three aspects of the problem is required by research administrators to decide on the optimum allocation of research resources among commodities.

First, 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 τ_1 and τ_2. Research would re-enforce the tendency toward complete specialization in production. On the other hand, if there are decreasing returns to scale in research, technological change would increase the concavity of the innovation possibility frontier, reduce the degree of fluctuation in output mix as a result of given changes in relative product prices, and move a region away from complete specialization in production.

Second, 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. Lele [1967], 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 [1973], 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.

Yamaguchi [1973], 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 non-agricultural sectors (equivalent to our two commodities), he 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.

Third, 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.

Fourth, 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 the 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, and the nature of the demands for the outputs of the region. Research administrators require information on all three 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,[3/] but in also influencing the allocation of research resources. Falcon [1970] has cogently argued that agricultural price policies should be consistent with national development objectives. Unfortunately, this is not always the case.

FOOTNOTES

* University of Minnesota Agricultural Experiment Station Miscellaneous Journal Series, Paper No. The authors wish to thank Hans Binswanger for helpful comments on earlier drafts of this paper.

1/ This result will hold over the range in output variation for which the Cobb-Douglas production functions are good approximations of the real world.

2/ 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 could exhibit decreasing returns to scale because the stock of "basic" knowledge from which the research activities draw from 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 Evenson and Kislev [1971].

3/ The role of price in the allocation of resources among crops in developing countries was highlighted by Raj Krishna [1963] and subsequently, by many other analysts. See also Krishna [1967].

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