Staff Paper Series

STAFF PAPER P74-19 AUGUST 1974

ENVIRONMENTAL CONSTRAINTS, COMMODITY MIX, AND RESEARCH RESOURCE ALLOCATION

by
Martin E. Abel and Delane E. Welsch

Department of Agricultural and Applied Economics

University of Minnesota
Institute of Agriculture
St. Paul, Minnesota 55101

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

Paper to be presented at the ADC/IBRD conference on Resource Allocation and Productivity in International Agricultural Research, Airlie House, Virginia, January 26-29, 1975.

ENVIRONMENTAL CONSTRAINTS, COMMODITY MIX, AND RESEARCH RESOURCE ALLOCATION*

Martin E. Abel and Delane E. Welsch**

INTRODUCTION

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, (c) the nature of the demand relations for the commodity outputs, (d) relative factor endowments, and (e) the existence of different types of environmental constraints. 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 role of factor endowments is discussed in the fourth section. This is followed by a discussion of the effect of certain types of environmental constraints on the allocation of research resources and on the output mix. The policy implications of the analysis are discussed in the sixth part of the paper.

This paper draws heavily upon an earlier work of Martin E. Abel and Delane E. Welsch.[1]

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

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

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

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) $$L_1 + L_2 = \overline{L}$$

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

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

where,

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

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

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

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

The reader is referred to Harry G. Johnson, and Abel, 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.[2]

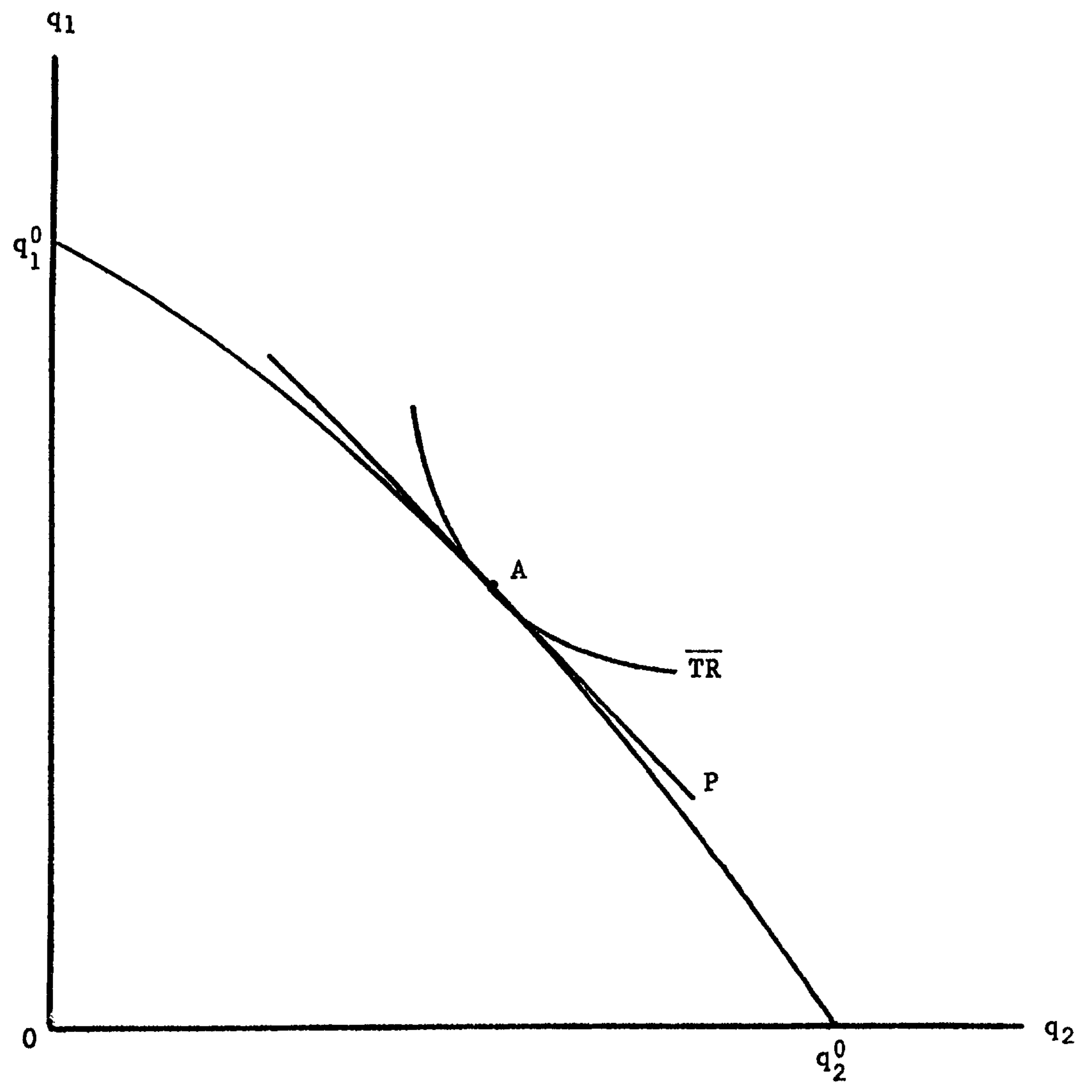
We can consider two possibilities with respect to the influence on product prices of changes in the output levels of our producing region (country). One is a competitive environment in which both product prices, p_1 and p_2, are given to the region and do not vary with changes in q_1 and q_2. The other 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.[3]

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.[4] This has been clearly demonstrated by Johnson,[5] 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 $f\left(q_1^0,\ q_2^0\right) = 0$.

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

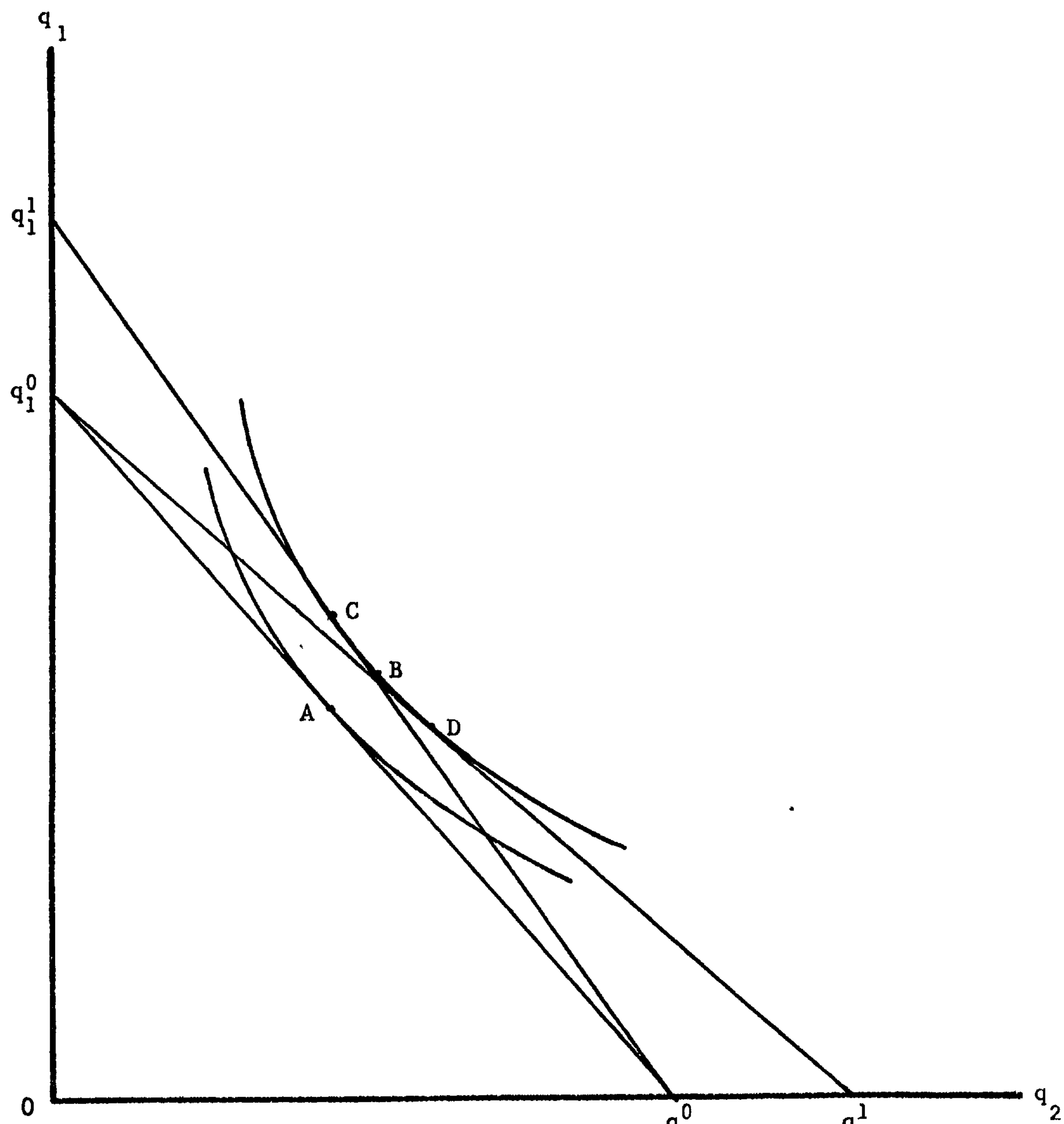
We now wish to examine the consequences of certain types of technological change in the context of our two-commodity, two-factor world. National (regional) research leaders are faced with the question of the allocation of research resources among commodities. Even if research administrators follow the Hayami-Ruttan[6] 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 $f\left(q_1^1, q_2^0\right) = 0$. Similarly, allocation of all research resources to increasing τ_2 results in a new production possibility curve $f\left(q_1^0, q_2^1\right) = 0$. 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.

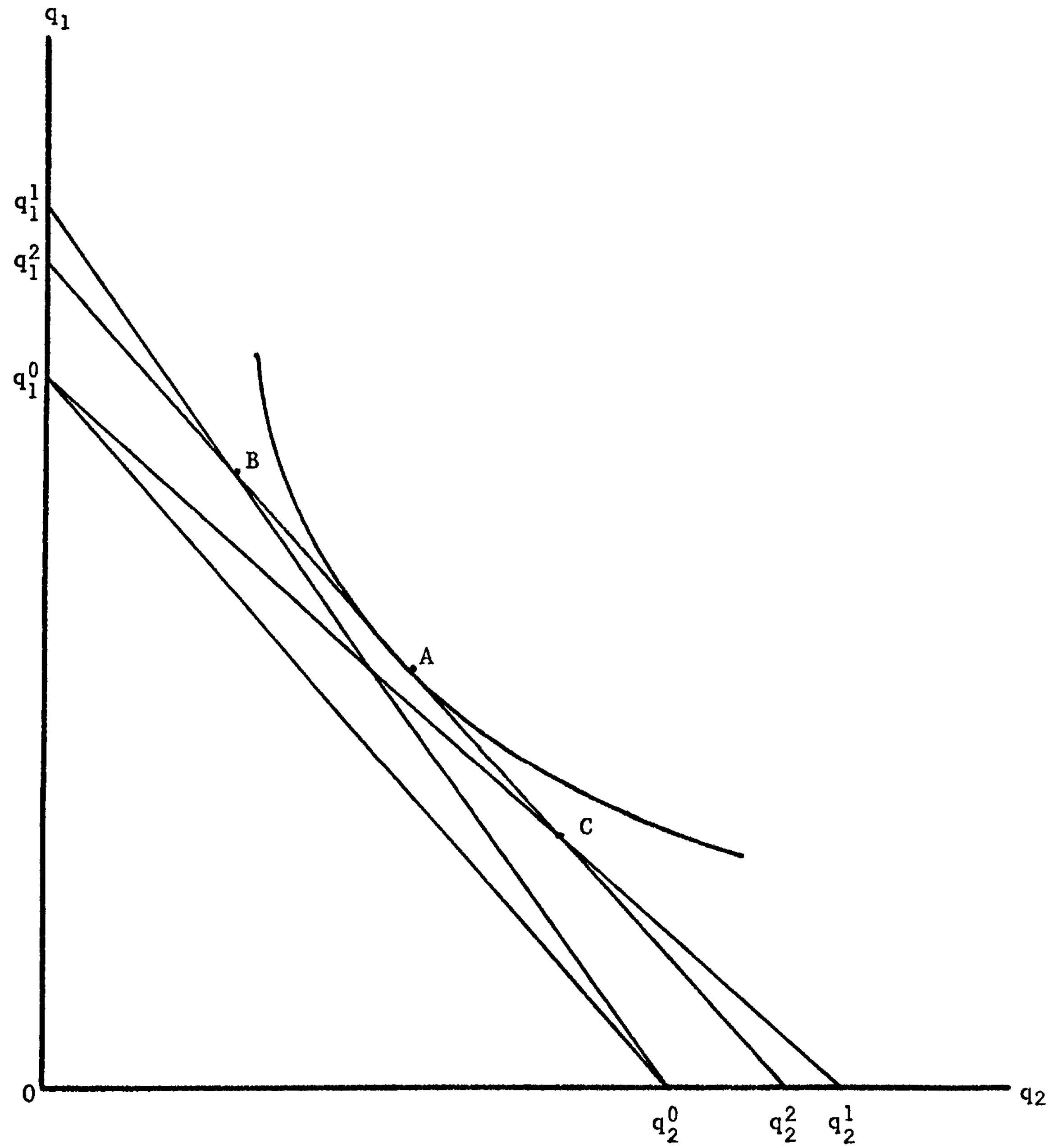
Situation II:

In this case we modify situation I by assuming that decreasing returns to scale prevail in the research production functions.[7] 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 $f\left(q_1^2, q_2^2\right) = 0$.

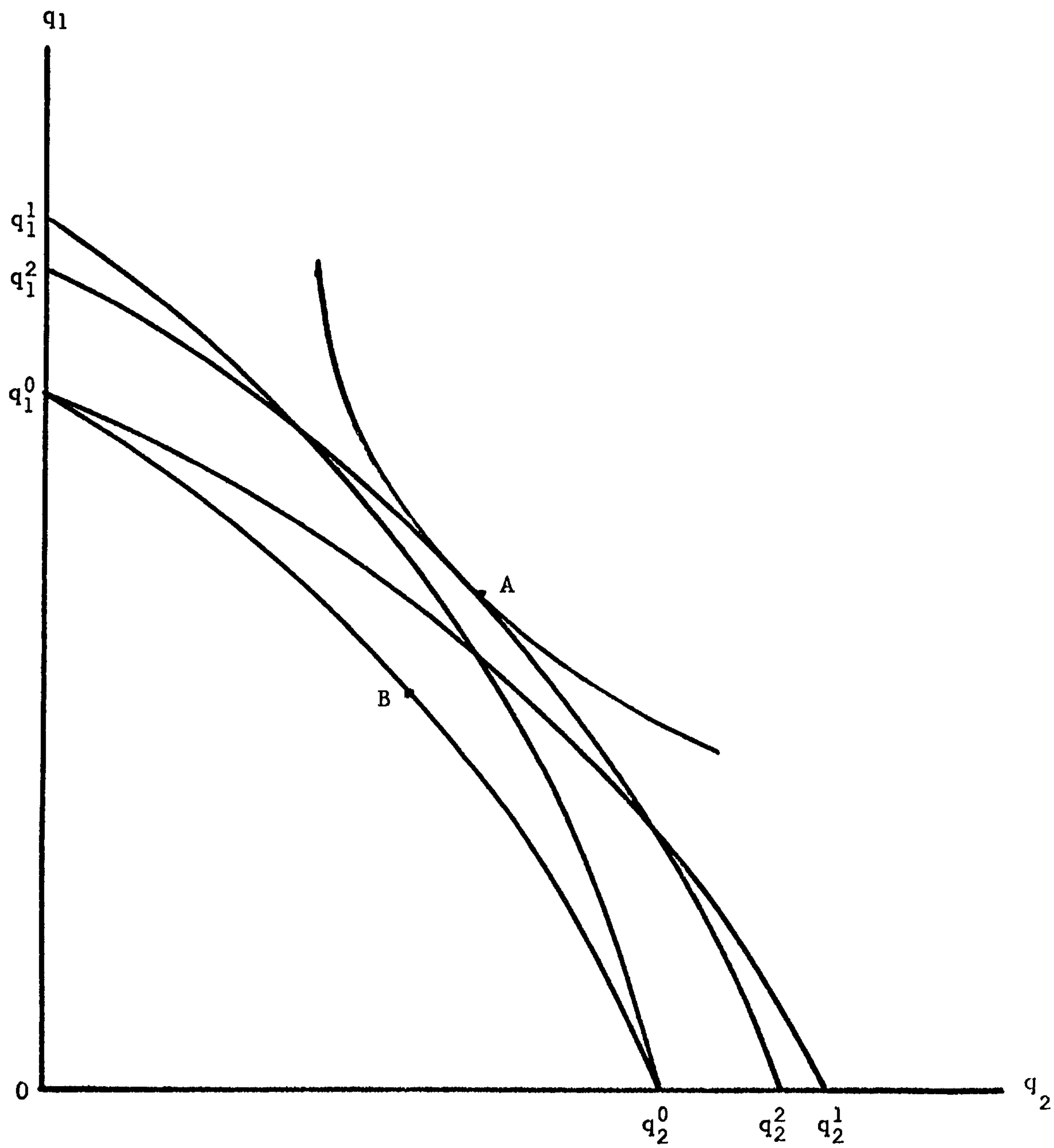
Situation III:

In this case we make the same assumptions as in situation II except that we now assume the initial production possibility curve, $f\left(q_1^0, q_2^0\right) = 0$, 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 $f\left(q_1^2, q_2^2\right) = 0$ 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 $f\left(q_1^2, q_2^2\right) = 0$ at A. Also assume that the iso-revenue line resulting from downward sloping demand curves is also tangent to $f\left(q_1^2, q_2^2\right) = 0$ 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 $f\left(q_1^2, q_2^2\right) = 0$.

Situation IV:

One might also wish to consider the case where the research production functions exhibit increasing returns to scale.[8] 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.

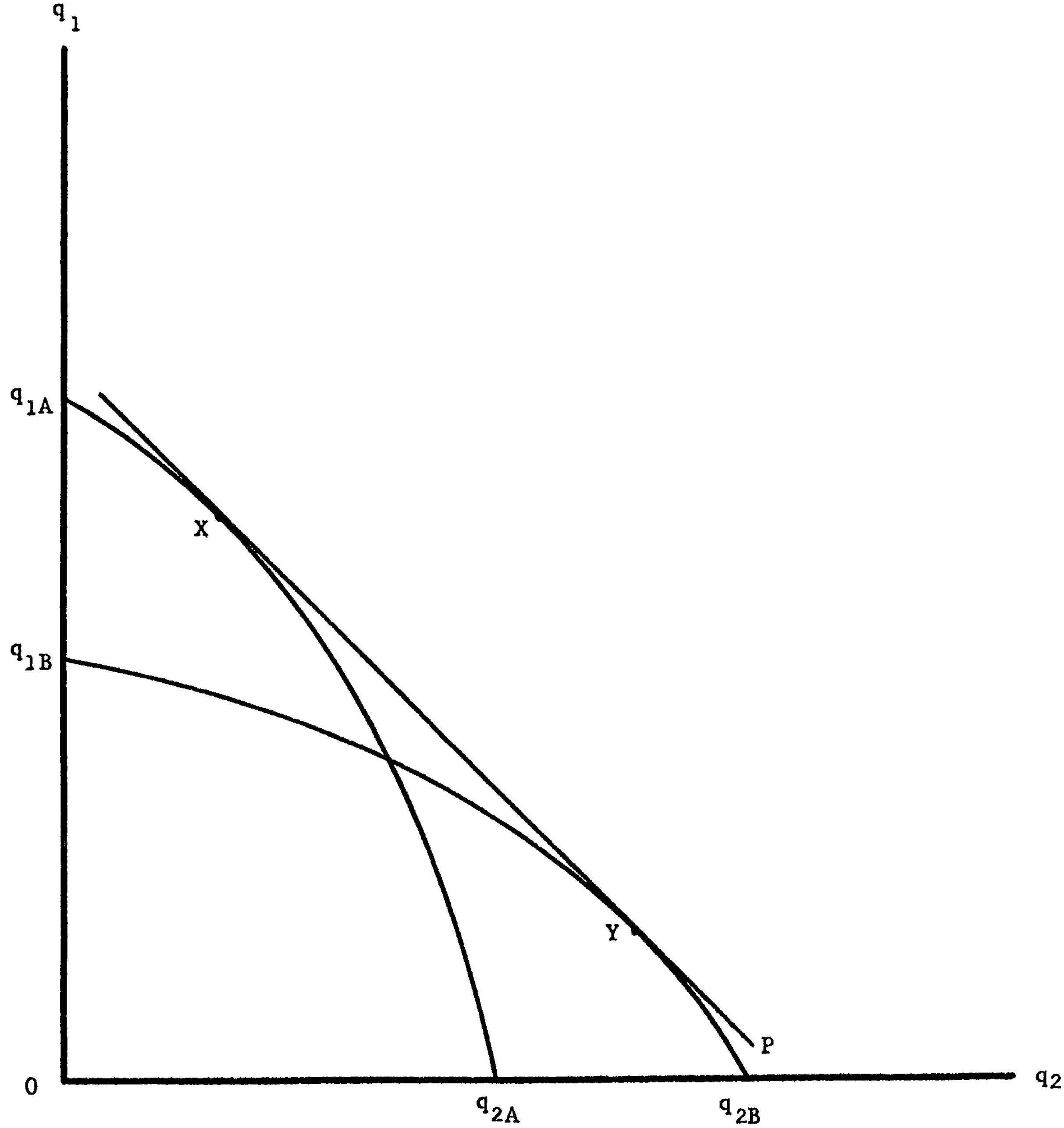
RESOURCE ENDOWMENTS

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.

ENVIRONMENTAL CONSTRAINTS

We will now use the model to examine how several environmental constraints affect the allocation of research resources and the output mix. We consider four types of physical or institutional (economic) situations: (1) heterogeneity in the quality of at least one factor of production; (2) restrictions on the use of certain technologies; (3) restrictions on the output of one commodity; and (4) improvement in the quality (productivity) of one or more inputs.

Heterogeneity in Factors of Production

Thus far we have assumed the factors of production to be of homogeneous quality. In fact, one finds considerable variability in the quality of factors, particularly land. The introduction into our analysis of variability in the quality of factors assures concavity of the production possibility curve, as illustrated in figure 4.

In general, the effects of technological change and different demand conditions and the implications for the allocation of research resources are the same as in Situation III.

An extreme case of heterogeneity in factor quality might be one where a certain proportion of land is suited for the production of only q_1, and the remaining land can be used for the production of only q_2. In this situation, the production possibility curve of the type postulated in Situation III would be a rectangle whose northeast corner is at B in figure 4 prior to technological change and at point A after technological change.

Thus, heterogeneity in the quality of factors increases the likelihood that it is profitable to allocate research resources to increasing factor productivity for both commodities.

Restrictions on Technology

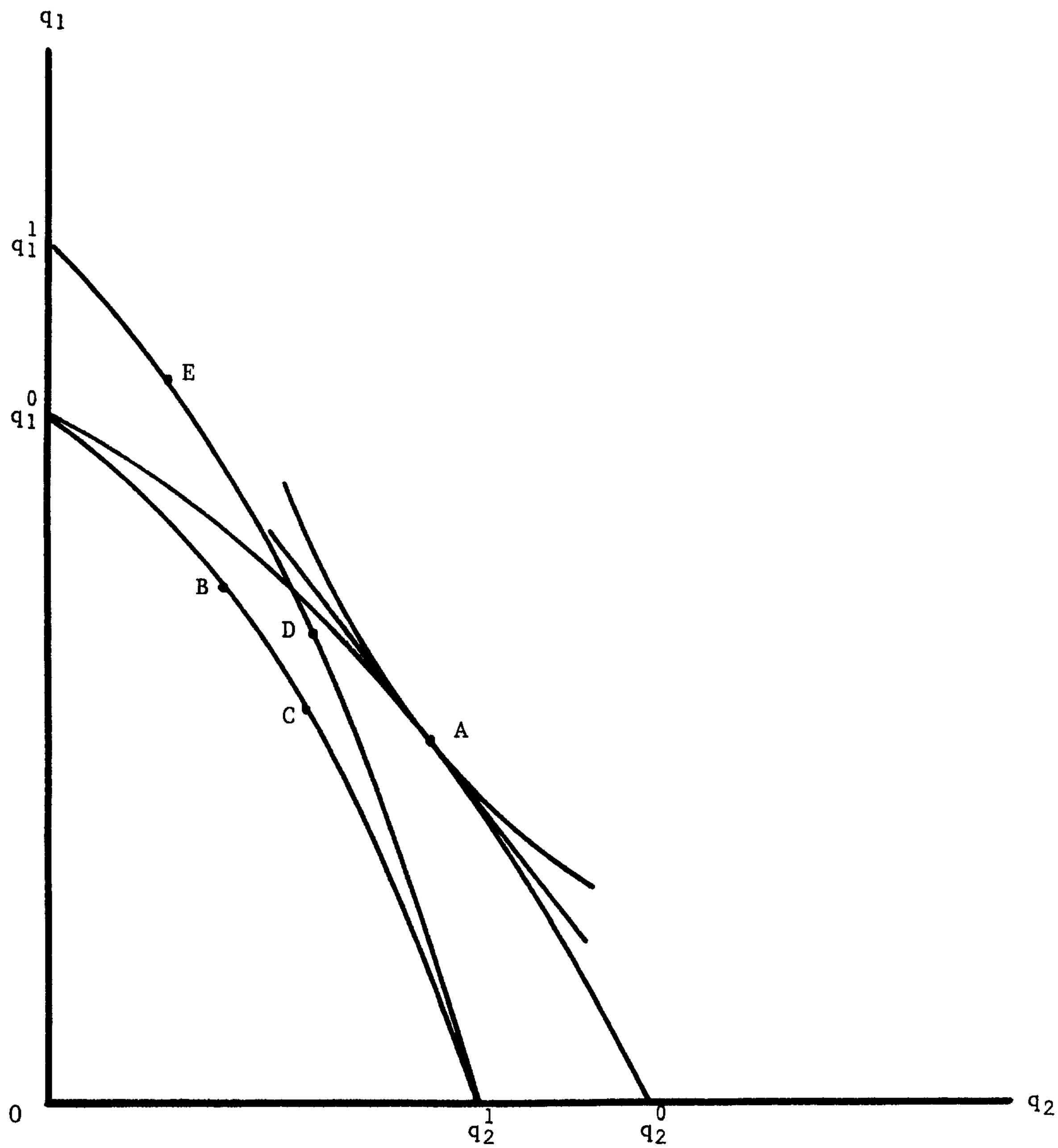
The case where restrictions are placed on the use of certain technologies is illustrated in figure 6. Assume our initial production possibility curve to be $f\left(q_1^0, q_2^0\right) = 0$. The output mix of the region is given at point A for either downward sloping product demand curves or given prices.

Now assume society bans the use of a particular technology, say DDT, which affects the production of q_2 but not q_1. The new production possibility curve would be $f\left(q_1^0, q_2^1\right) = 0$. The output mix would be at C if the region faced downward sloping demand curves, and at B if it faced given product prices.

All research resources could be used either to increase τ_1 which would generate $f\left(q_1^1, q_2^1\right) = 0$, or to increase τ_2 which would get the region back to the initial production possibility curve $f\left(q_1^0, q_2^0\right) = 0$. Complete specialization of research to increase τ_1 would result in output mixes of either D or E, depending on whether the region faced downward sloping demand curves or given prices. Complete specialization of research to increase τ_2 would put the output mix at A, the initial point. Linear combinations of research resources in τ_1 and τ_2 would trace out an innovation possibility frontier which is convex to the origin.

The optimum allocation of research resources depends heavily on final demand conditions. This can be seen most easily in the case of

Figure 6



given product prices. If in figure 6 relative prices strongly favored the production of q_2, then research resources should be allocated more to increasing τ_2 than τ_1. As relative prices moved more in favor of q_1, the relative mix of research resources would move in favor of increasing τ_1.

Restrictions on the Level of Commodity Output

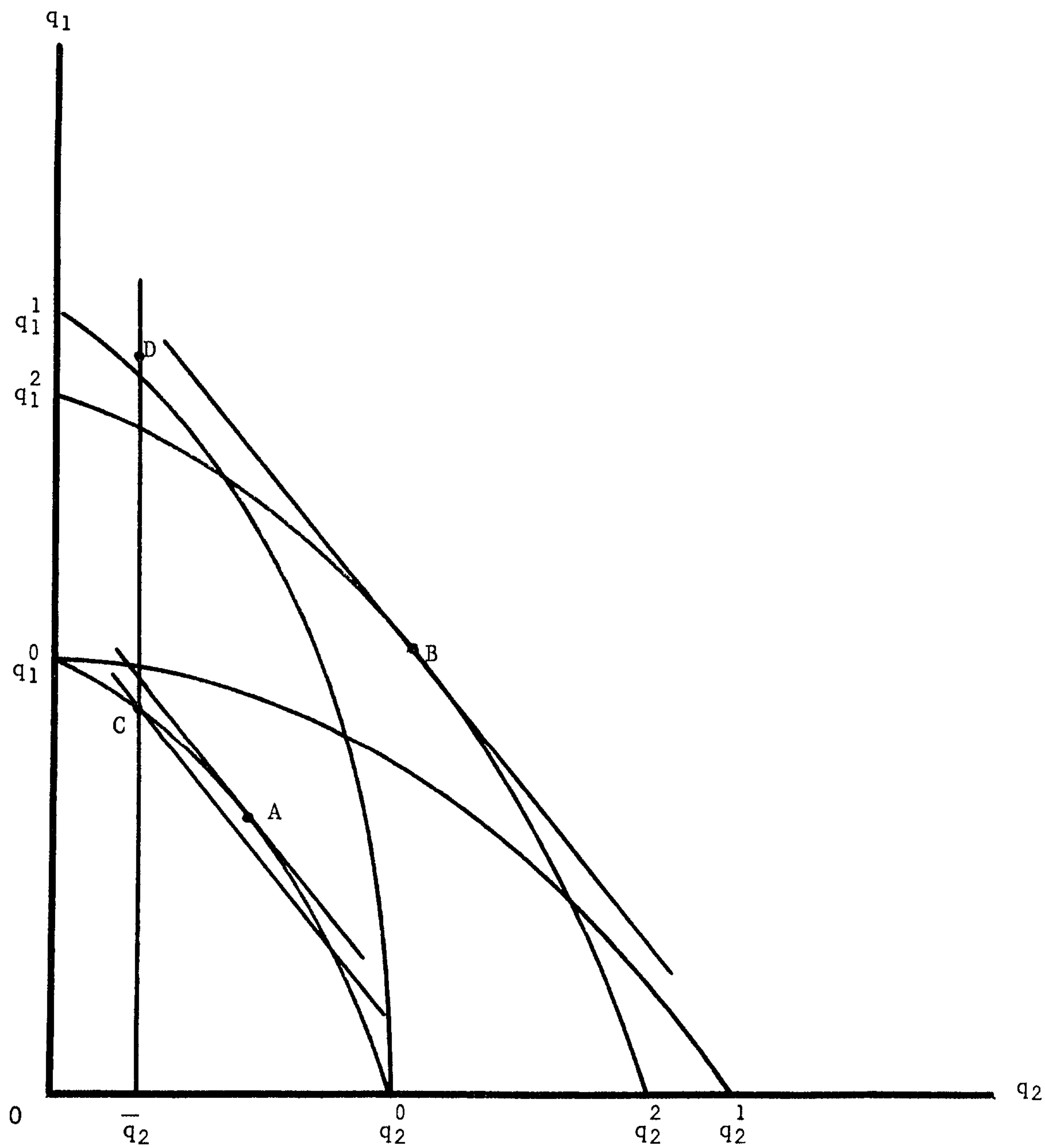
We now consider the case where governments place restrictions on the output of one commodity but not on the other; i.e., a maximum level of output for one output is specified and enforced. This situation is illustrated in figure 7 where the output of q_2 cannot exceed $\overline{q}_2$.

The initial production possibility curve is $f\left(q_1^0, q_2^0\right) = 0$, and the initial output mix prior to the imposition of output controls is A. We assume that prices are given to the region. In the absence of a restriction on the output of q_2 and assuming decreasing returns to scale in the research production functions, it pays to allocate equal amounts of research resources to increasing τ_1 and τ_2. Such an allocation of research resources yields the production possibility curve $f\left(q_1^2, q_2^2\right) = 0$ and the output mix is at point B. (The production possibility curves $f\left(q_1^1, q_2^0\right) = 0$ and $f\left(q_1^0, q_2^1\right) = 0$ represent complete specialization of research resources in increasing either τ_1 or τ_2, respectively.)

With the output restraint in effect, output would be at point C prior to any change in technology. For given prices, C represents the highest level of revenue which the region can attain.

Operating under the output restraint it would pay to devote substantially more research resources to increasing τ_1 relative to τ_2 than was true in the unrestrained case. The highest returns would be obtained from an allocation of research resources which generated a new

Figure 7



production possibility curve passing through point D. In order to simplify the figure, this curve is not drawn in figure 7. This curve would be steeper than $f\left(q_1^2, q_2^2\right) = 0$. The price line would also pass through point D but, as is the case at point C, it would not necessarily be tangent to the new production possibility curve at D.

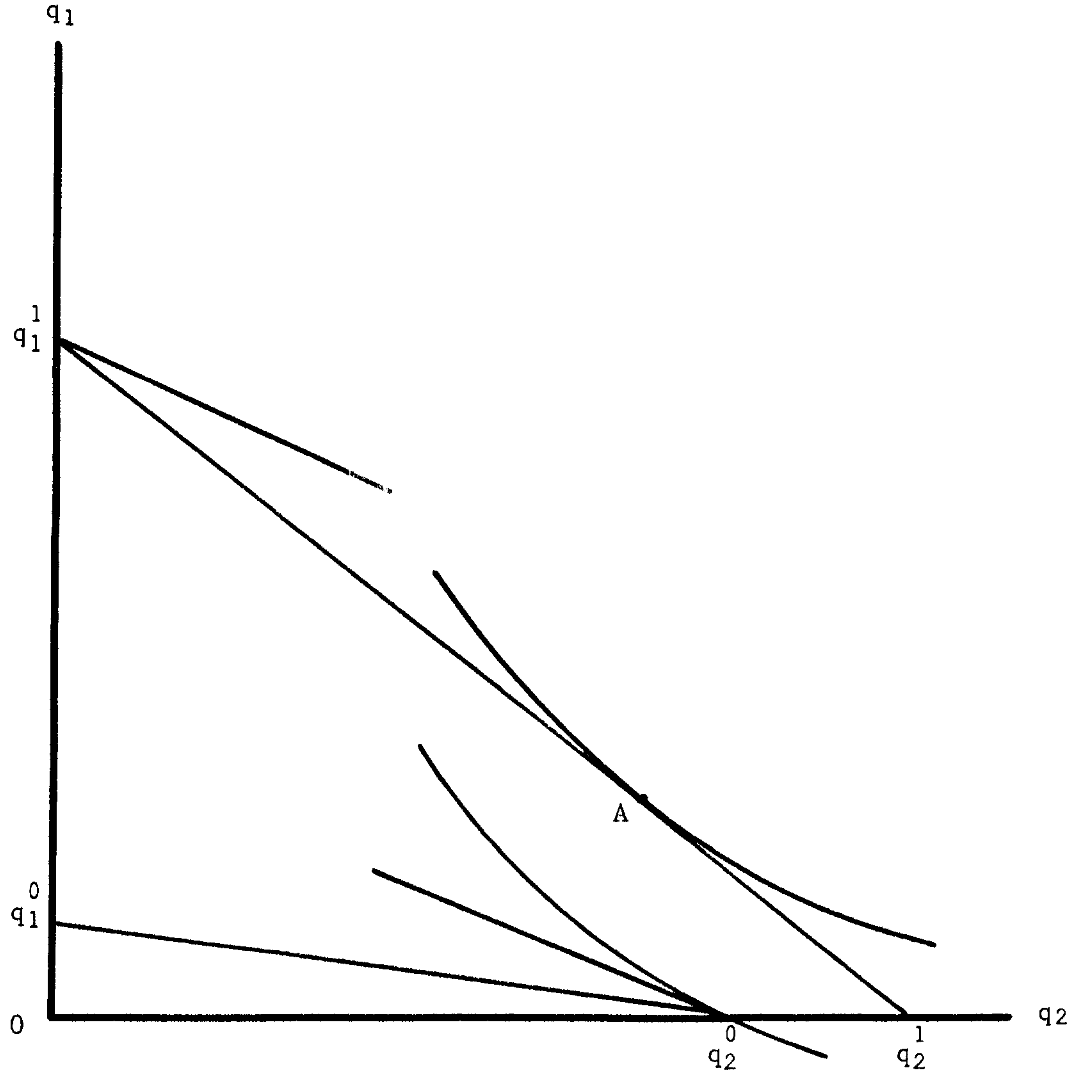
When an output restraint for one commodity is binding, it may still pay to devote some research resources to increasing factor productivity for that commodity. However, the general effect of the restraint is to cause a reallocation of research resources to increasing factor productivity for the unrestrained commodity.

Improvement in the Quality of Inputs

Finally, we wish to consider the case where investments are made to improve the productivity of one of the inputs, say land. As an example, consider the initial stock of land to be irrigated, but with no control over the application of water in individual fields. The initial production possibility curve might look like $f\left(q_1^0, q_2^0\right) = 0$ in figure 8. (For simplicity, we will use straight line production possibility curves.) In the initial situation, there will be complete specialization in the production of q_2 at point q_2^0 whether or not the region faces downward sloping demand curves or given prices as depicted in figure 8. As a practical illustration we can think of q_2 being rice and q_1 being vegetables. Without water control in individual fields vegetables might be grown by forming ridges of earth to keep the crop above water.

Now consider improvements in the irrigation system which result in full water control in individual fields. The new production

Figure 8



possibility curve is $f(q_1^1, q_2^1) = 0$. With the same given prices as in the initial situation the region would switch from complete specialization in q_2 to complete specialization in q_1 at an output level of $0q_1^1$. With downward sloping demand curves output would be at point A.

The construction of figure 8 departs from our previous assumptions in two ways. First, improving the productivity of one of the factors, such as land, through improving the quality of irrigation systems may or may not be considered technological change. Second, if it is considered technological change, the assumption that complete allocation of research resources to increasing either τ_1 or τ_2 results in equal absolute increases in q_1 and q_2, respectively, no longer holds. Nevertheless, we find the results depicted in figure 8 to be quite instructive.

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 τ_1 and τ_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,[9] 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,[10] 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,[11] 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.

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.

Finally, we explored the implications of four types of environmental situations for the allocation of research resources and for the resulting output mix. In each situation our model gives us useful insights. Demand conditions for the products play an important role in allocating research resources in each environmental situation considered.

Heterogeneity in the quality of factors of production imparts convexity to the production possibility curve. Regardless of demand conditions, heterogeneity in factors will tend to cause research resources to be allocated to both commodities. In the case of restrictions on the use of certain technologies in the production of one of the commodities, the optimum allocation of research resources depends heavily on final demand conditions. Restrictions on the level of output of one commodity should cause a reallocation of research resources to increasing factor productivity in the other commodity. However, it may still be profitable to allocate research resources to both commodities even when the output restraint is binding. Improving the quality of one factor can also have a significant effect on the output mix with the nature of final demand conditions again playing an important role.

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, changes in relative factor endowments, and the existence of certain types of environmental constraints. 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,[12] but in also influencing the allocation of research resources. Walter P. Falcon[13] has cogently argued that agricultural price policies should be consistent with national development objectives. Unfortunately, this is not always the case.

Environmental considerations can also play an important role in determining the optimum allocation of research resources.

FOOTNOTES

*Paper prepared for the Conference on Resource Allocation and Productivity in International Agricultural Research, Airlie House, Virginia, January 26-29, 1975.

**The authors are Professors, Department of Agricultural and Applied Economics, University of Minnesota. Dr. Welsch is also Agricultural Economist, the Rockefeller Foundation, and Visiting Professor, Kasetsart and Thammasat Universities, Bangkok, Thailand.

[1] Martin E. Abel and Delane E. Welsch, "Microeconomics of Technology and the Agricultural Output Mix," Staff Paper P74-16, Department of Agricultural and Applied Economics, University of Minnesota, August 1974.

[2] 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, January 1973).

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

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

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

[6] Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective (Baltimore and London: The Johns Hopkins Press, 1971).

[7] 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.

[8] 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).

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

[10] 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.

[11] 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).

[12] 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).

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