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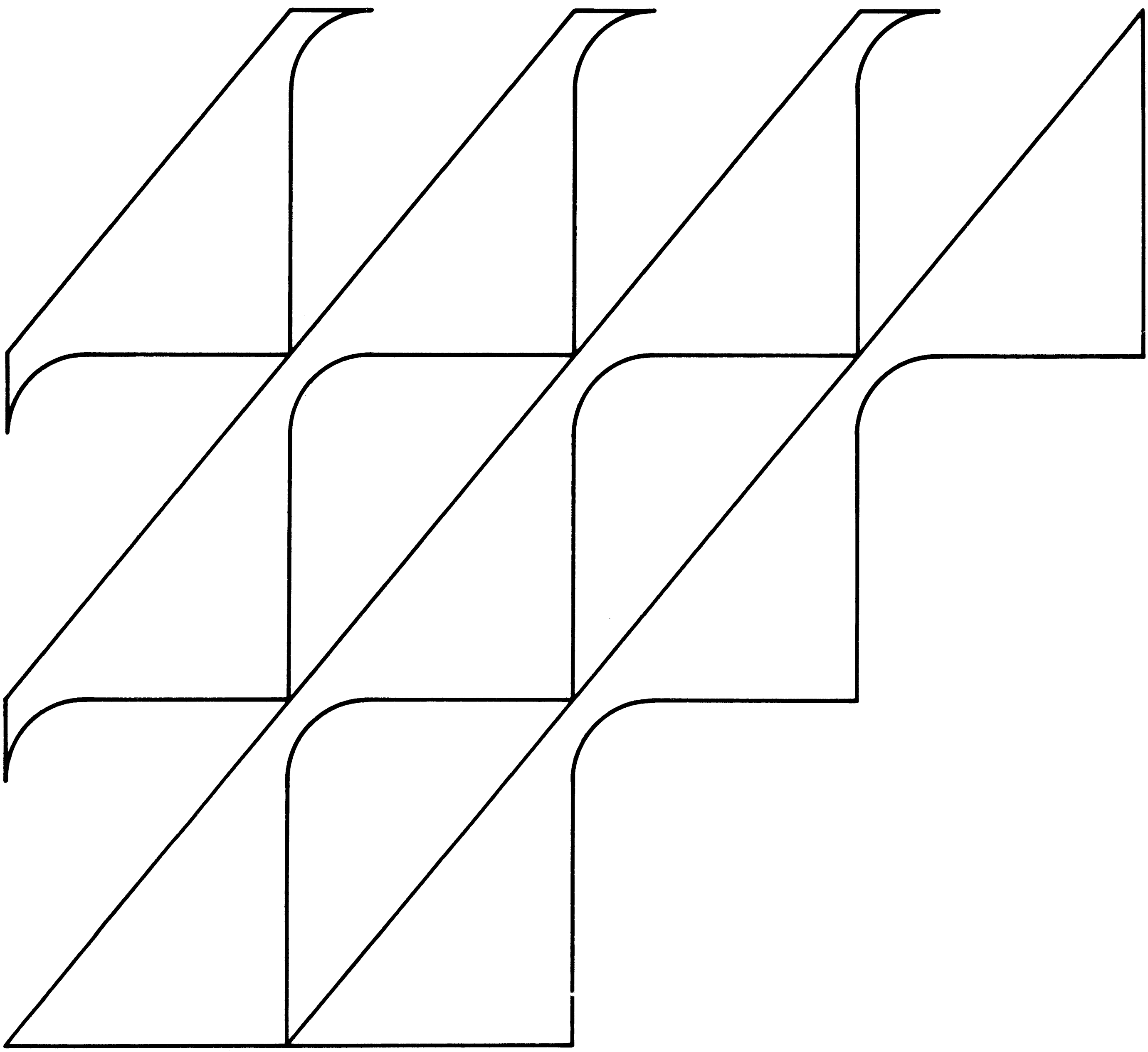
Cost-Reducing and Output-Enhancing Technologies

John M. Reilly



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ABSTRACT

Technical change in agriculture has two possible results: costs decline or yields increase. But, both results allow more production at less cost. Thus, decisions on how to spend research and development (R&D) funds should not hinge on whether a technology reduces per acre costs or increases crop yields, but rather on which projects promise the greatest gains compared with their R&D costs. The author used both an aggregate econometric analysis and a farm-level response evaluation to examine the differences between adopting cost-reducing or yield-enhancing technology.

Keywords: Agricultural technology, production economics, public research and development, technology adoption, technical changes.

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SUMMARY

Technical change in agriculture has two possible results: costs decline or yields increase. But, both results allow more production at less cost. Thus, decisions on how to spend research and development (R&D) funds should not hinge on whether a technology reduces per acre costs or increases crop yields, but rather on which projects promise the greatest gains compared with the R&D project cost. The author used both an aggregate econometric analysis and a farm-level response evaluation to examine the differences between adopting cost-reducing or yield-enhancing technology.

Both types of technology will lead to increased output, but output-enhancing technologies will generally lead to a greater increase. The author estimates that adopting a technology which increases yields by 10 percent per acre would lead to a 60- to 180-percent increase in output if prices do not change. A technology that reduces per acre costs by 10 percent would lead to a 50- to 170-percent increase in output if prices do not change.

The author used standard economic production theory to analyze the effects of adopting cost-reducing and output-enhancing technologies. He derived data from existing estimates of U.S. agricultural production. He developed a hypothetical example for a cost-reducing pest-resistant corn variety and an output-enhancing higher yielding corn variety.

Cost-Reducing and Output-Enhancing Technologies

John M. Reilly*

INTRODUCTION

As commodity surpluses have reached record levels, many observers of U.S. agricultural policy have suggested that Government-supported research and development (R&D) efforts should be aimed at reducing costs rather than increasing output. 1/ An economist might argue, however, that there is really no difference between the two types of technology and that there is no reason to distinguish between them.

This conclusion apparently evolves from the dual nature of production functions describing the relationship between inputs and output (the technology set) and cost functions describing the relationship between the cost of production and input prices. When a factor of production (such as land) is fixed or, more generally, when returns to scale decrease, a difference between an output-enhancing technology and a cost-reducing technology exists. However, output increases significantly in either case.

This report examines the implications of this relationship for agricultural R&D policy and applies standard economic production theory to a hypothetical situation to illustrate the relationship.

TECHNICAL CHANGE IN THE PRODUCTION FUNCTION

Output, Y, can be generally represented as dependent on the level of inputs (the vector **x**) and a vector **a** describing how output changes with technology:

$$Y = y(\mathbf{x},\mathbf{a}) \qquad (1)$$

In the traditional fixed-technology production function, $\mathbf{a}^*$ (* denotes a particular set of values for **a**) is implicit in the functional specification itself. Thus, the fixed-technology production function represents a subset of the substitution opportunities among inputs implied by the "metaproduction function" in equation (1). Several more restrictive representations of equation (1) exist. One apparently less general form is to assume **x** and **a** are both (1 x n) vectors and that each element of **a** is uniquely associated with an element of **x**:

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* The author is an agricultural economist in the Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture.

1/ For example, Fry (1986) identified the 1980's as a period when new technologies that reduce costs are needed, compared with the 1960's and 1970's when R&D focused on expanding output.

$$Y = y_1(h_1(x_1,a_1), \ldots h_n(x_n,a_n)) \qquad (2)$$

where

$$\partial Y/\partial a_i = h'(x_i) > 0.$$

Technical change is more frequently represented in the form

$$Y = y_2\,(\mathbf{aX}) \qquad (3)$$

where **X** is an n x n diagonal matrix with x forming the diagonal elements.

Hence,

$$\partial Y/\partial a_i = \partial Y/\partial\, x_i > 0.$$

With linear homogeneity, neutral technical change is a special case of the above function when it can be represented as

$$Y = a\ y_3(\mathbf{x}) \qquad (4)$$

where a is a scalar. Here

$$\partial Y/\partial a = \ y_3(\mathbf{x}) = \sum_i^n a\ y_3^i(\mathbf{x}) \qquad (5)$$

where y_3^i is the partial derivative of y_3 with respect to the ith input. As metaproduction functions, the characterizations of technology in equations (1) through (4) represent successively more restrictive representations.

The representation in equation (2) suggests that different values for each a_i are separate "technologies;" that is, technical change always can involve only one input. Thus, a technological improvement can be defined as an increase in a_i for at least some i. This assumption rules out a technical change that reshapes the entire mix of inputs, particularly technologies that increase the use of some inputs while decreasing the use of others.

A more realistic assumption is that technical change is a discrete change consisting of an entire, new **a** vector. An improved technology (**anew**) is one that requires less of at least one input (x_i) for a given level of output, Y*; that is,

$$x_i|Y^*,\mathbf{anew} < x_i|Y^*,\mathbf{aold} \text{ for at least one i.} \qquad (6)$$

If this condition does not hold, then the new technology is completely dominated by the old technology and would not be chosen under any set of factor prices. If the condition holds for all i, then the new technology dominates the existing technology.

The interpretation of separate technologies as changes in multiple elements of the **a** vector suggests, however, the discreteness normally associated with technology. Treating production decisions as the choice among discrete alternatives is at least as general as the representation in equation (1) and illustrates the limits of treatments based on equation (1). The discrete technology characterization would represent a choice among

$$Y = \mathbf{f}_1(\mathbf{x}) \qquad (7)$$

where $\mathbf{f}_1$ is a vector function representing the z =1,2,...,m technologies that exist at a point in time for transforming **x** into Y. A less general form of equation (7) is to assume that the changing functional relationship in f_1 can be fully incorporated in a set of technical change coefficients that display a one-to-one correspondence with inputs:

$$Y = f_2(AX) \tag{8}$$

where **X** is defined as before, **A** is an m x n matrix with elements a_{ij}, and f_2 is a function defined over the rows of **AX**. The coefficients may be zero for some inputs in some or all existing technologies. Equation (8) is less general than (7), providing a fixed definition of what separates one technology from another which is by no means obvious. If, for example, in (8), a technology is defined as a single point in n space, a collection of k such points could be used to approximate a technology as defined in (7). The redefined matrix A becomes km x n. 2/ Thus, with that flexibility to define a technology, equation (8) is equally as general as (7). Equation (8) or equation (1) can also be used to describe the same production possibility set. In this sense, they are equally general. The convex hull containing the production set described by equations (1) or (8) will describe the efficient technologies existing at a given time. If the production set is not convex, technologies in the nonconvex area will be dominated by nearby technologies and will never be used under any set of factor prices.

The difference between the metaproduction function approach and the discrete technology approach is whether the move between two "efficient" points of production is without cost. This difference manifests itself only over time. If relative prices change and the move is without cost, the production function concept is adequate for explaining dynamics; adjustment is instantaneous. If the change is costly, the production function approach is inadequate by itself. If the cost of change is, for example, due to long-lived, specialized physical capital equipment in which the technology is embodied, then the production function approach can describe the ultimate equilibrium position. But, the knowledge of the time path of adjustment requires additional description of the replacement of physical capital. Explicit treatment of quasi-fixed inputs in the production theoretic approach addresses this issue. If the cost is a nondepreciable barrier such as institutional rules, bureaucratic inertia, or cultural taboo, the production function approach will not necessarily define the new equilibrium position. A small change in relative input prices may be insufficient to overcome the threshold price change necessary to cause a shift to a new technology.

The differences between the metaproduction function and discrete technology analogies are due to perspective rather than ultimate limitations of either approach. However, the choice of analogy tends to create real differences in applied work. The discrete technology analogy forces consideration of what makes one technology discretely different from another technology. This analogy also requires the analyst to describe the forces encouraging or blocking a shift to a different technology. The production function approach begins by defining a single technology at a given point in time with smooth substitution among factors. Smoothness of the production function is not necessarily required, but it makes solutions single-valued and determinate.

To contrast cost-reducing and output-enhancing technical changes, one must compare two discrete technologies: an output-enhancing technology and a cost-reducing technology. Because exploration of this difference is the goal, adopting the formulation in equation (8) does not limit the findings in any way. Further, this exercise ultimately compares two equilibrium states. This exercise is not concerned with issues of transition between states and, therefore, does not deal with questions of technology adoption or penetration.

2/ Rosenberg (1976), for example, suggested that technology might best be described by individual points and descriptions of the process of moving between points rather than a production function per se. Nelson and Winter (1982) used such an approach in their treatment.

THE PRODUCTION FUNCTION AND COSTS

The relationship to costs can be seen by imposing profit maximization as a behavioral assumption and deriving factor demands by maximizing output given a technology (**a***) subject to a cost constraint. The relationship can also be seen by minimizing cost subject to the constraint that the combination of inputs is within the technology set defined by **a***. The minimization problem is

$$\min \quad \mathbf{w}'\mathbf{x} \tag{9}$$

$$\text{subject to} \quad f(\mathbf{x},\mathbf{a}^*) \leq Y^*$$

where **w** is the vector of input prices. Input demands will generally be described by

$$\mathbf{x}^* = \mathbf{x}(\mathbf{a}^*,\mathbf{w},Y^*). \tag{10}$$

With neutral technical change, this expression will reduce to

$$\mathbf{x}^* = g(Y^*/\mathbf{a}^*)\ \mathbf{x}(\mathbf{w}) \tag{11}$$

where a is a scalar and adding constant returns to scale (CRS)

$$\mathbf{x}^* = (Y^*/a)\ \mathbf{x}(\mathbf{w}). \tag{11a}$$

The cost of production is

$$C = \mathbf{w}'\mathbf{x}^*$$

Substituting for **x** in equation (12) from equation (11) or (11a) shows neutral technical change to be equivalently described by a proportional reduction in costs holding output constant. Thus, there is a one-to-one correspondence between cost and technology. With nonneutral change, there may be multiple **a** vectors, with a given w, that yield a given cost, C^*. Moreover, a nonneutral technical improvement as defined in equation (6) need not be cost reducing for a given w. For example, a new technology may change demand for factors by increasing the demand for a relatively expensive factor while reducing the demand for a relatively cheap factor. In such a case, costs would increase if the technology were adopted. Under some set of factor prices, the new technology is an improvement over the previously available technology, and, should those prices prevail, the end technology would be used. 3/

COST-REDUCING TECHNICAL CHANGE

Because a cost change and a technical change are related, one might be tempted to describe cost-reducing technology as merely an output-enhancing technology with output held constant. That is, we need not distinguish between cost-reducing and output-enhancing technologies. This discussion does not directly address the issue raised by farm programs, however. In particular, the representation of technology developed thus far offers only one type of technical change and interprets its effect on cost. Technical change as described above appears to be consistent with the output-enhancing category because it works directly on the production set. Cost-reducing technical change can be treated as operating directly

3/ Because there are costs involved in demonstrating commercial scale technologies, some argue that only technologies currently in use can be considered "known" technologies (see, for example, Rosenberg, 1976). From the more practical aspect of technology adoption, a firm chooses among technologies recognizing that the certainty associated with the choice varies considerably across technology options but that the outcome is not certain even for well-known technologies.

on the cost constraint. If a type of technical change effectively reduces the cost of inputs for the individual firm, then

$$C = c(\mathbf{b}, \mathbf{w}X) \tag{13}$$

where **b** is the vector of technical change coefficients. If one allows, as above, technical change to be represented by changes in multiple elements of **b**, then an equally general representation of costs is

$$C = \mathbf{bW}\mathbf{X} \tag{14}$$

where W is an n x n diagonal matrix with w forming the diagonal elements and with

$$\partial C/\partial\, bi < 0 \qquad \text{for all i where bi is an element of } \mathbf{b}.$$

To find factor demand functions, minimize equation (14) as before subject to the technology set. The general form of the factor demand equations will be

$$\mathbf{x} = \mathbf{x}(\mathbf{bW}, \mathbf{Y}^*). \tag{15}$$

In the special case where b is a scalar, the expression becomes

$$\mathbf{x} = \mathbf{x}(\mathbf{w}, \mathbf{Y}^*). \tag{16}$$

COST-REDUCING VERSUS OUTPUT-ENHANCING CHANGE

The cost function can be formed by substituting factor demands into cost equation (12) or (14) as appropriate. To assess the effect of a change on firm output, one can derive the supply function for the firm using the first-order conditions from profit maximization where the profit function is formed as revenue minus the costs as described by the cost function. The industry behavior is the sum of individual firm supply responses. 4/

Constant Returns to Scale

In the case of constant returns to scale, the cost functions of output-enhancing change (17a) and cost-reducing change (17b) are

$$C = w'/a\ Y^*\ x(w) \text{ and} \tag{17a}$$

$$C = w'b\ Y^*\ x(w). \tag{17b}$$

Here, b and a play identical roles with b = 1/a. With cost-reducing technical change, no change in factor demand is implied for a given output. However, with output-enhancing technical change, input demand is reduced by the technical change factor 1/a for a given output. For constant returns to scale technologies, the industry quantity supplied is completely determined by demand factors (firm size is indeterminate). This situation is seen from the condition that zero profits exist in the industry

$$P\ Y = w'/a\ Y\ x(w) \text{ and} \tag{18a}$$

$$P\ Y = w'b\ Y\ x(w). \tag{18b}$$

4/ Assuming the industry is composed of k identical firms allows the industry-level conclusions to be drawn directly from the firm-level response.

Because Y can be eliminated from the equation, price is completely determined by the technology; producers are indeterminate regarding quantity supplied.

Nonconstant Returns to Scale

With nonconstant returns to scale (NCRS) and neutral technical change, the cost functions are

$$C = w'g(Y^{*}/a)\ x(w) \text{ and} \tag{19a}$$

$$C = w'b\ g(Y^{*})\ x(w). \tag{19b}$$

Two observations can be made: output is not independent of the technology; and, for cost-reducing technology, cost is a linear function of the change. In output-enhancing technology, cost is related in a more complex fashion. Thus, the output response for a cost-reducing technology will differ from that of an output-enhancing technology.

The supply function can be derived through maximizing profits (revenues minus costs) using the cost functions implied in equation (19). First-order conditions are

$$P - w'(1/a)\ g'(Y/a)\ x(w) = 0 \text{ and} \tag{20a}$$

$$P - w'b\ g'(Y)\ x(w) = 0. \tag{20b}$$

Solving for output (Y), yields

$$Y = a\ h(P/(a^{-1}w'x(w))) \text{ and} \tag{21a}$$

$$Y = h(P/(bw'x(w))). \tag{21b}$$

Equations 21a and 21b can be partially differentiated with respect to the technical change factor to derive the effect of changing technology:

$$\partial Y/\partial a = h'(P/(a^{-1}w'x(w)))\ (P/w'x(w))\ a + h(P/a^{-1}w'x(w)) \text{ and} \tag{22a}$$

$$\partial Y/\partial b = -h'(P/(bw'x(w)))\ b^{-2}\ (P/w'x(w)). \tag{22b}$$

An improvement in technology is represented by $\Delta b < 0$ and $\Delta a > 0$. Initial values of a and b can be set to unity. Thus, for a cost-reducing technical change, the direction of change in Y will depend on the sign of h'. Cost is an increasing function of Y; therefore, $g' > 0$ and $h > 0$. With decreasing returns to scale (DRS), $g'' > 0$; unit cost increases as output increases. The sign of h' will be determinate only if its argument is positive. In that case, $h' > 0$. The argument of h' is greater than zero in this case because it is output price divided by unit cost, both greater than zero. Thus, with DRS and a cost-reducing technical change, the supply-side effect (assuming price is fixed) will be an increase in output. An output-enhancing technical change will have a similar effect on output, as can be seen from the first term of equation (22a). An additional effect on output will be described by the second term of (22a). Because $h > 0$, this effect on output will be positive. Thus, for equal percentage changes in a and b, an output-enhancing change will cause an additional increase in output beyond the output response for the cost-reducing technical change with DRS.

The arguments of both h and h' (price divided by unit cost) provides additional insight into the differential effects of cost-reducing technology versus output-enhancing technology under DRS. The usual interpretation of DRS is that there exists a fixed factor. The denominator in the expression can then be interpreted as the unit cost of the variable factors, and the difference between output price and variable costs is the return to the fixed factor. Thus, the supply effect on output is directly related to the importance of the fixed factor in the production process. If returns to the fixed factor are very small, the argument will tend toward unity (fig. 1). DRS implies that the supply curve slopes upward. The cost-reducing technical change is represented by a shift from S to S,' and an output-enhancing technical change represents a further shift in the supply curve to S". The output-enhancing effect implies that, as production tends toward zero, the additional reduction in cost at the level of output tends toward zero. Thus, the effect is equivalent to increasing the amount of the fixed factor, because the difference between the two types of change is the effect on the fixed factor.

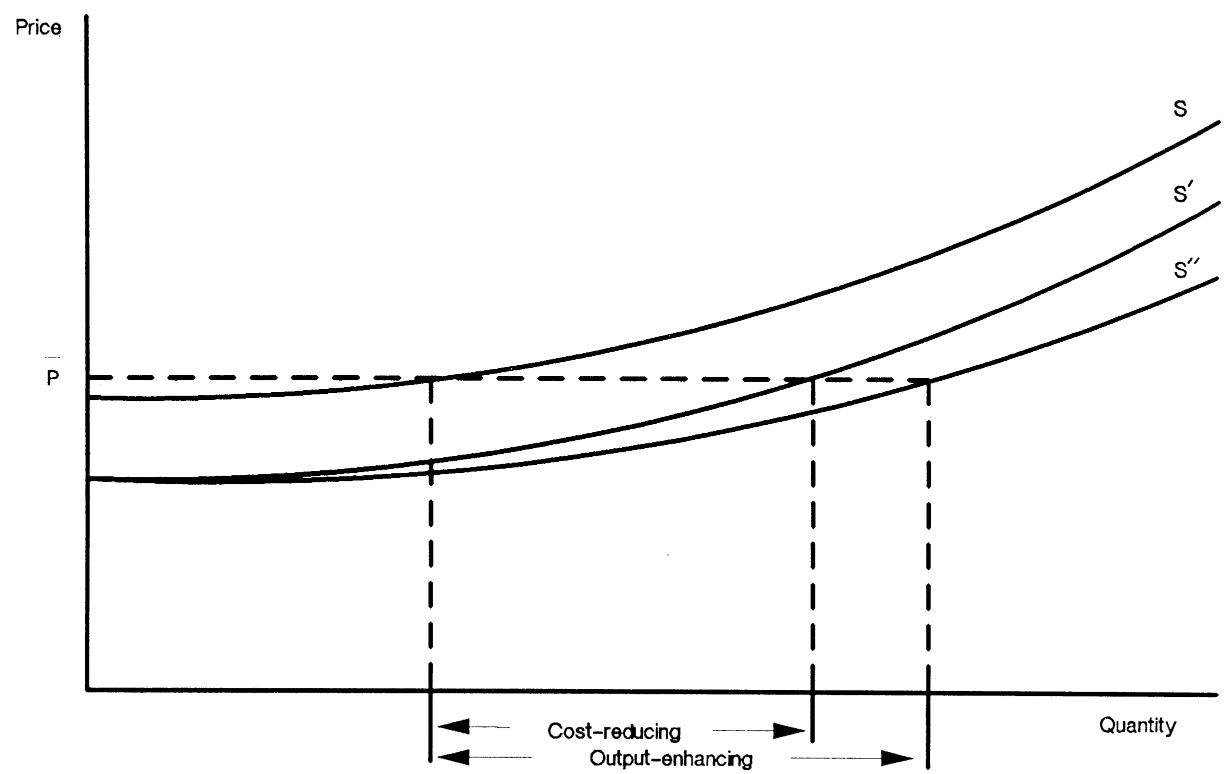
With CRS, the argument of h' will be unity, but g' is zero in equations (20a and 20b), as is the case of a horizontal supply curve. The horizontal distance between horizontal supply curves is undefined. The increasing returns case is also somewhat perverse; the signs on equation (22b) and the first term of equation (22a) are negative, reflecting the so-called natural monopoly case where profits are negative in the long term, with price equal to marginal cost.

Biased Technical Change

With biased technical change and constant returns to scale, output will be completely determined by demand. Thus, biased change alone is not sufficient to introduce a difference between cost-reducing and yield-enhancing technologies. Equal bias can be introduced through cost-reducing technology as through output-enhancing technology. However, the

Figure 1

Cost-reducing technology versus output-enhancing technology



structure of the problem essentially prevents equal bias from being introduced. Allow the production function to take the form

$$y = a\ f(g_1(x^*),g_2(x)) \tag{23}$$

where x^* is a vector of fixed factors and x is a vector of variable factors and a represents the neutral technical change parameter. If f is homogeneous of degree 1, then (23) is equivalent to

$$y = f(a\ g^1(x^*),a\ g^2(x)). \tag{24}$$

The cost minimization problem, however, is to minimize

$$C^* = \mathbf{bWX}, \tag{25}$$

only the variable factors in equation (24). This equation, then, is equivalent to

$$y = f(g_1(x^*),a\ g_2(x)). \tag{26}$$

In this case, equation (11) becomes

$$x^* = g_3(Y^*,x^*)\ 1/a\ x(w). \tag{27}$$

Comparing this equation with the similar expression for cost-reducing technology in equation (19b) shows the expressions to be essentially the same with $b = 1/a$. It is easiest to think of cost-reducing technology as reducing the price of inputs. It is a change that occurs in the manufactured inputs supply sector and is passed through to the farmer via a lower price of the input. However, technical change affecting only the variable inputs (cost-reducing change) can occur within the firm (agricultural sector) as well. If land is considered the fixed input, an example would be the use of computers if they assisted farmers in searching for the cheapest available inputs or technologies. 5/

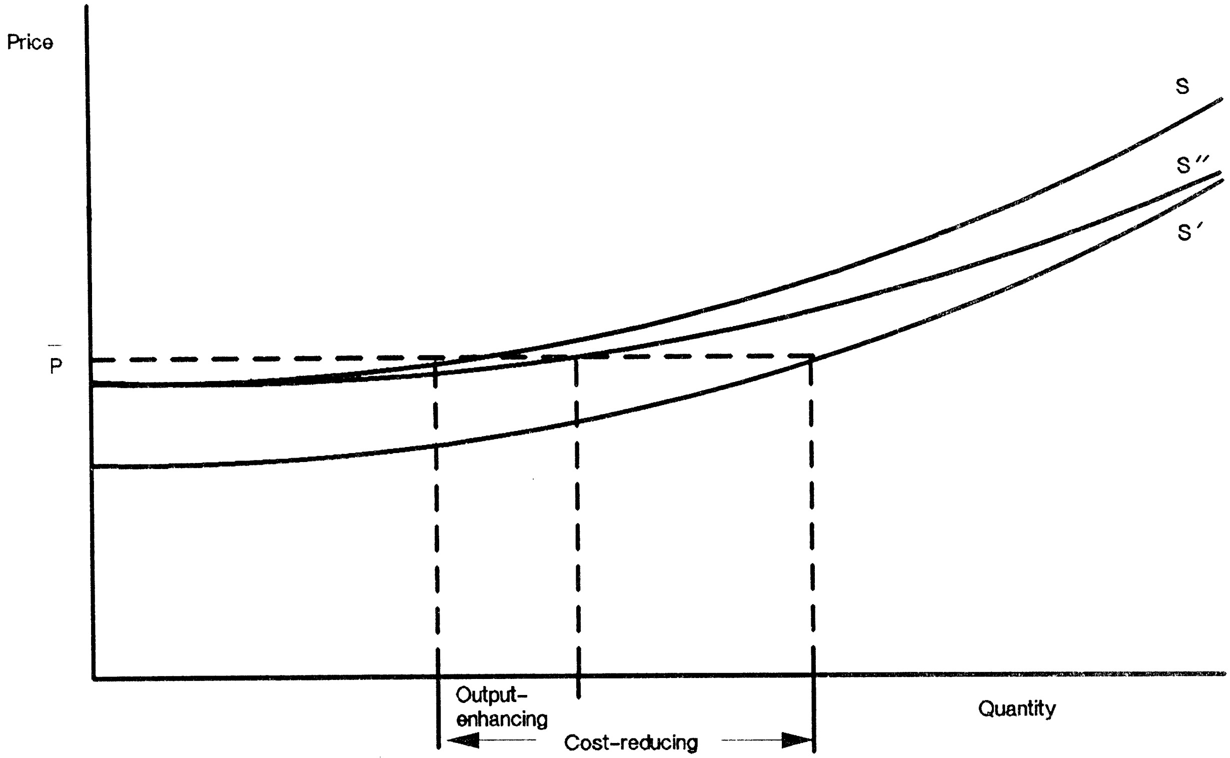
EQUIVALENT CHANGES AND ALTERNATIVE CONCEPTS OF OUTPUT-ENHANCING AND COST-REDUCING TECHNICAL CHANGE

Output-enhancing change is an additional effect beyond the cost-reducing effect, as currently formulated. This formulation falls naturally from alternatively focusing on the production function itself and on the cost constraint. One might instead view the additional output effect due to the output-enhancing effect as the pure output-enhancing effect, the second term alone in equation (22a). This approach is equivalent to characterizing output-enhancing change as affecting only the fixed factor and the cost-reducing change as affecting only the variable factors. Figure 2 represents this formulation.

5/ As a final theoretical question, one might ask whether the existence of quasi-fixed factors creates a dynamic effect. One might, for example, expect instantaneous output response with an output-enhancing technology, but with the output response only gradually reaching this level with cost-reducing technology. The issue is not, however, that straightforward. Penetration of a new technology takes time. One reason is that the change may involve long-lived equipment. If so, one should not propose a quasi-fixed factor and instantaneous technology penetration. The technology may be embodied in the factor being described as quasi-fixed. Alternatively, if the technology is not embodied in a quasi-fixed factor itself but its productivity is related to an associated quasi-fixed factor, its adoption may not occur until the quasi-fixed factor is replaced. The interrelatedness associated with the concept of a package of practices is an example. Thus, generalizations concerning the dynamics of output adjustment may or may not be an additional factor beyond the time necessary for the technology to penetrate.

Figure 2

Pure output-enhancing technology



The curves may better represent popular notions of cost-reducing and output-enhancing technical change because, as production tends toward zero, the reduction in cost in the output-enhancing case will tend toward zero.

If there is some range of production where the fixed factor is for practical purposes not a constraining factor, then an output-enhancing change will result in no cost decrease (or price decrease) in that range. 6/ In contrast, the cost-reducing change represents a discrete reduction in costs at all levels of output. The problem with this definition, however, is that identifying an actual technology that acts only on the fixed factor is nearly impossible. The green revolution changes, including hybrid seed, chemical fertilizers, and pesticides, are viewed as output-enhancing types of change by those who make a distinction. Because most of the variable costs of production vary with the number of acres planted rather than with the bushels harvested, variable costs per bushel harvested drop with increased output per acre associated with these changes (such as machinery hours for tillage, labor hours, fuel, pesticides, and fertilizer). 7/ Thus, these technical changes do not appear to conform with the pure output-enhancing definition.

6/ This range is generally not relevant. Within the range, the rent to the fixed factor will be zero. Futhermore, because price does not decrease, there is no change in demand or output. Thus, the technological change has zero value because it saves on a factor that is not scarce.

7/ Fertilizer is a possible exception because many of the output gains with hybrid seeds require more fertilizer.

How to define an output-enhancing change as equivalent to a cost-reducing change is also difficult. One possibility is equal percentage changes in the parameters a and b. Thus, an output-enhancing change that leads to a 10-percent increase in output would be defined as equivalent to a cost-reducing change that, for a given output, reduced variable factor costs by 10 percent. This definition, however, creates an apples and oranges standard with output-enhancing change defined in terms of output and cost-reducing change defined in terms of cost. Choosing either cost or output requires that equivalence be defined at a point on the supply curve. Figure 3 illustrates the choices.

If output is chosen, the question of the effect of equivalent changes on output is irrelevant because the changes have been defined such that the effects are equal. Defining equivalent changes in terms of cost is somewhat counter to the popular notion of output-enhancing change (that it affects output and not cost). Thus, the remaining sections follow the convention of defining equivalent changes as equal (absolute value) percentage changes in a and b.

QUANTIFYING THE DIFFERENCE: AGGREGATE PRODUCTION FUNCTION ESTIMATES

Much work in applied agricultural production theory assumes the existence of an aggregate production function for the sector and estimates an associated dual cost function. 8/ Within such a framework, one can demonstrate the differential effect between cost-reducing and output-enhancing technical change. A frequently used functional form is the translog cost function. 9/

This function can be generally represented as

$$\begin{aligned} \ln C = \alpha \ln \mathbf{w} + \alpha_1 \ln \mathbf{ww'} + \alpha_2 \ln \mathbf{wz'} + \alpha_3 \ln t\mathbf{w} + \gamma \ln \mathbf{z} \\ + \gamma_1 \ln \mathbf{zz'} + \gamma_2 \ln t\mathbf{z} + \varsigma_1 \ln \mathbf{w}\, Y + \varsigma_2 \ln \mathbf{z}\, Y + \varsigma_3 \ln Y \end{aligned} \tag{28}$$

where t is time and serves as a proxy for technical change and $\mathbf{z}$ is the vector of fixed factors. With cost-reducing technology, the coefficient vector $\mathbf{z}_2$ is a vector of zeros. With homothetic production, the vectors ς_1 and ς_2 are vectors of zeros. If one assumes the vector Z, which includes the measured fixed factors, fully accounts for increasing costs, the cost function will exhibit constant returns to scale which implies homotheticity and $\varsigma_3 = 1$. Even after we account for the known fixed factors, some features of production that generate nonconstant returns to scale or nonhomotheticity may remain. The value of a natural resource input like land is the rental value of land; the rental return to the asset is due purely to its scarcity because it has no production cost. If available in unlimited quantity, the rent would be zero. In estimating an equation like (28), one implicitly estimates the rental return to the explicitly fixed factor(s), such as land. Land use does vary, but under the assumption of fixity the variability is due to changes unrelated to its agricultural use. Exclusion of a quantity index could lead to bias in estimates including bias in the scale effect. 10/ Caves, Christensen, and Swanson (1981) show the relationship

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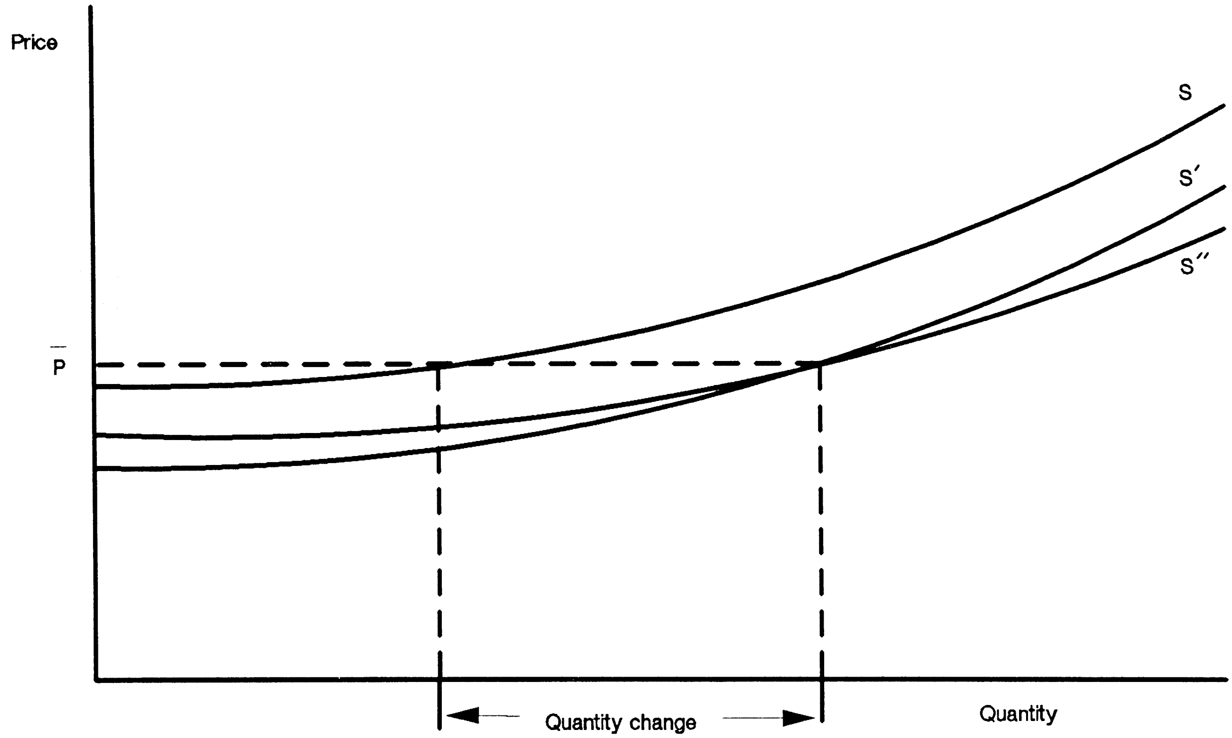
8/ See, for example, Capalbo and Vo (1984).

9/ By specifying a production function with separable output, this discussion thus far has implicitly assumed homotheticity of the technology. Specification of the cost function directly allows a convenient expression of nonhomothetic production technology. Nonhomotheticity necessarily implies nonhomogeneity. Nonconstant returns to scale result from nonhomogeneity.

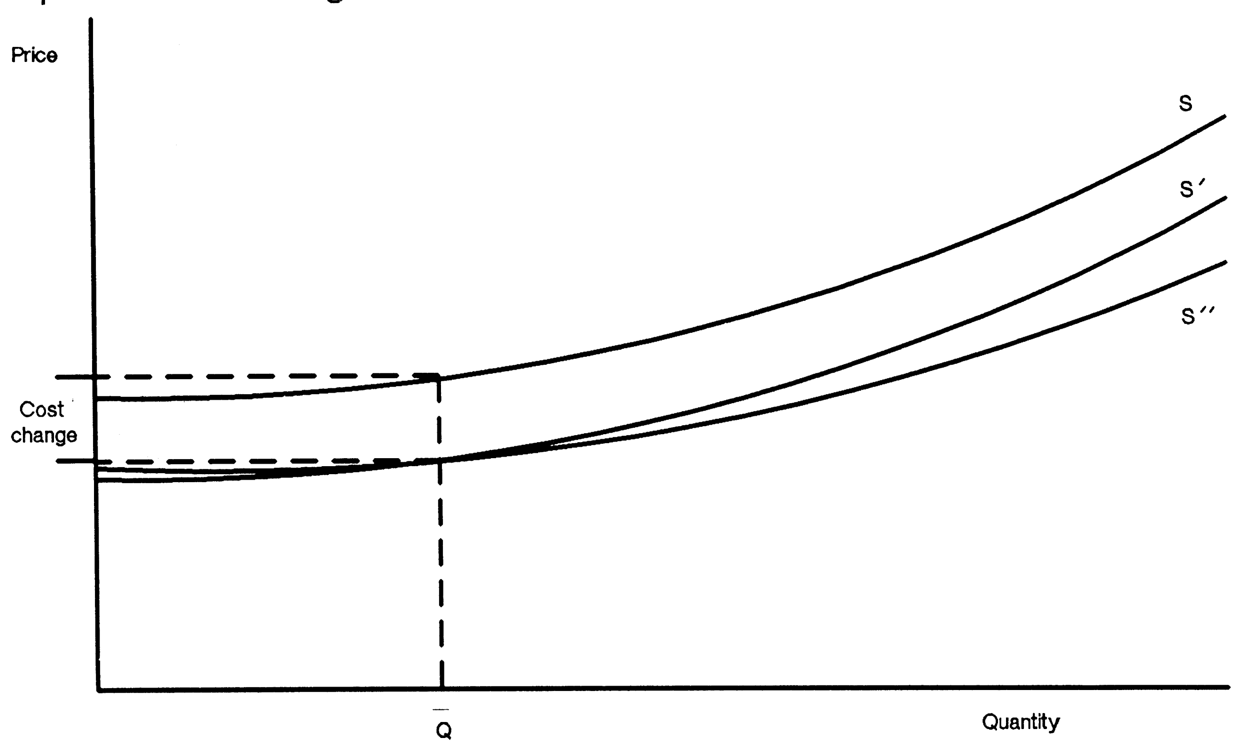
10/ Land used by agriculture changes due to a small but observable conversion to residential, industrial, park land, and roadway uses and due to Government programs to remove land from production.

Figure 3

Equivalent output change



Equivalent cost change



between the shortrun returns to scale estimate, the inverse of the (sum of the) coefficient(s) associated with output, and the longrun returns to scale that would be obtained if the resource were fixed and constant and therefore could be excluded from equation (28). 11/ If given the estimated production function, one can analyze the effect of hypothetical cost-reducing and output-enhancing technical changes. If such changes actually occurred, they would be represented in the estimated cost function as $\alpha_{3i} = \alpha_{3j} = b$ for all i and j and $\gamma_{2k} = \gamma_{2l} = 0$ for all k and l for cost-reducing change and as $\alpha_{3i} = \alpha_{3j} = \gamma_{2k} = \gamma_{2l} = a$ for all i, j, k, l for output-enhancing change. Solving the first-order condition for profit maximization from the variable cost function given in (28) under the assumption of output-enhancing and cost-reducing change yields the supply function

$$Y = a(P/\ RTS^{-1}\ 1/a\ f(w))^{RTS-1} \tag{29a}$$

$$Y = (P/\ RTS^{-1}\ \ b\ f(w))^{RTS-1} \tag{29b}$$

where RTS is returns to scale. The shortrun or unadjusted returns to scale (RTS1) is

$$RTS1 = (\sum_i^g \varsigma_{1i} + \sum_i^h \varsigma_{2i} + \varsigma_3)^{-1},$$

and the longrun returns to scale or the measure of returns to scale adjusted for the fact that the level of the fixed factor is changing (RTS2) is

$$RTS2 = (1 - \sum_i^h \gamma_1 + \sum_i^{h^2} \gamma_{1i})\ RTS1.$$

For purposes of assessing the effect of technical change equivalent to the expression given in equations (22a and 22b), RTS1 is the desired measure. If we assess the change in output for a change in technology as given by equations (22a and 22b) and multiply by b/Y or a/Y to create an elasticity of output with respect to changing technology (E_{Yb}, E_{Ya}), we will arrive at

$$E_{Ya} = \ (1/RTS1^{-1} - 1) + 1 \tag{30a}$$

$$E_{Yb} = \ 1/RTS1^{-1} - 1\ . \tag{30b}$$

This expression appears to be independent of the share of returns to the fixed factor which is counter to the results shown in equations (22a and 22b), but the share to the fixed factor is implicit in the estimate of returns to scale. 12/

Several authors have estimated translog cost functions for U.S. or regional agriculture specifically estimating returns to scale (table 1). Ray (1982) and Capalbo (1986) have estimated translog cost functions for U.S. agriculture, and Weaver (1983) has estimated these

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11/ Caves, Christensen, and Swanson (1981) treat the case of a quasi-fixed input. Halvorsen and Smith (1986) use the relationship developed by Caves, Christensen, and Swanson with a fixed input (natural resource) more directly relevant to the case examined.

12/ $\partial \ln C/\ \partial \ln zi = -P_i\ z_i/C$ derived for equation (28) and

$$\partial \ln C/\ \partial \ln z_i = \sum_i^h \gamma_i + \sum_i^{h^2} \gamma_{1i}$$

which appears in the expression for RTS2 (Caves, Christensen, and Swanson, 1981).

Table 1--Estimates of cost/output elasticity

Researcher	1940	1950	1960	1970	1977	1982
Capalbo	N.E.	1.69	1.43	1.13	1.06	0.93
Ray 1/	1.57	1.53	1.41	1.27	1.20	N.E.
Weaver:						
North Dakota	N.E.	1.48	1.49	1.48	N.E.	N.E.
South Dakota	N.E.	1.46	1.65	1.56	N.E.	N.E.

N.E. = No estimate.
1/ Ray reported estimates for 1939, 1949, 1969, and 1977.
Sources: Capalbo (1986), Ray (1982), Weaver (1983).

functions for North Dakota and South Dakota. 13/ Each of these authors estimated a nonhomothetic cost function; thus, returns to scale varies over time. Ray and Capalbo found a consistent trend over time with early years indicating a sharply increasing-cost technology and later years tending toward a constant-cost technology. Weaver found an increasing cost technology for North and South Dakota. His estimate varied over time, but there was no clear trend for the period of estimation (1950-70).

Hypothetical, equivalent changes in technology can be compared using equations (30a and 30b). For example, a 10-percent change in technology (a 10-percent reduction in cost for a cost-reducing technology or a 10-percent increase in output for given inputs for an output-enhancing technology) indicates that a cost-reducing technical change could induce a 15-percent output response (Capalbo, 1986, 1950 estimate) to a 170-percent output response (Capalbo, 1986, 1977 estimate) whereas an output-enhancing change would induce a 25-180-percent increase in output. The estimates indicate the responsiveness of output to changes in both cost-reducing and output-enhancing technologies and the difficulty of maintaining a support price in the face of technical change. If one accepts the 1977 Capalbo estimate, a once-and-for-all technical change reducing costs by 10 percent would require an increase in annual Government purchases equal to 170 percent of annual production before the change (assuming demand is unchanged). The 10-percentage-point addition due to the output-enhancing effect is relatively minor.

Ray's estimate for 1977 indicates increases of 50 percent (cost-reducing) and 60 percent (output-enhancing). Although Ray's estimates were less than the responses indicated by Capalbo, stockpile increases would still be untenable if a constant support price were maintained in the face of technical change.

The validity of these estimates is, however, questionable. One might expect supply to become more inelastic as one moves up the supply curve. Using the point estimate over a discrete range may overstate the output response. However, Capalbo's estimate for 1982 indicates actual decreasing costs. With or without technical change, such an estimate implies that output will expand without limit with a Government support price. Again, one would expect the supply curve to become less elastic and turn up at some point.

13/ Many authors maintain an assumption of constant returns to scale.

The estimation question, however, is why one would find agriculture at a point where the supply curve is downward sloping given the extent of Government support prices. Moreover, although the existence of a fixed input explains increasing costs, decreasing costs are difficult to explain. For an individual firm, large, indivisible investments are usually posed as an explanation. But, unless the investments are large in relation to industry output, such a condition should lead to firms that are large enough to exhaust economies of scale. Industrywide increasing or decreasing costs are a separate issue from individual firm cost structure. Economies of scale at the industry level (with obvious nondecreasing costs at the firm level observable through the existence of numerous firms) are sometimes explained as due to agglomeration effects. This explanation is not particularly satisfying for U.S. agriculture. Any agglomeration effects would seemingly have long since been exhausted, rather than becoming important only in the past few years. 14/

Regardless of the general difficulties of estimating returns to scale or difficulties with the specific estimates reported above, the evidence indicates significant output response with technical change. Thus, if a fixed factor exists, it is not dominating in its effect. Technical change that is biased away from the fixed factor (cost-reducing) will probably have a large output effect. By allowing technical change to affect the fixed factor as well (output-enhancing change), the output effect is greater, but the additional increase is almost certainly less than the cost-reducing effect alone and will probably be minor in comparison.

CHANNELS OF OUTPUT EXPANSION: ADJUSTMENT AT THE FARM LEVEL

Aggregative analyses have the advantage of comprehensively assessing changes in outputs and inputs that have actually occurred and then decomposing the observed variability in output to the separate effects of included explanatory variables. The weaknesses of the approach are the strong assumptions necessary to justify aggregation and validity of the statistical method, difficulty in measuring variables of interest (in particular, an index of technology), and the difficulty of relating the aggregate concepts to specific production decisions and behavioral responses of individual farm managers. In this section, the ways in which an individual farmer might respond are illustrated by way of a specific example.

The example is based on corn production and data on production costs are drawn from published estimates of a representative farm derived from the 1985 Farm Costs and Returns Survey. After imputing returns to land and capital, the published estimates show net farm losses. This result is inconsistent with an assumption that the sector is in longrun equilibrium. To separate the effects of the hypothetical technical change we wish to examine, we assume the farm is initially in equilibrium. The zero profit condition of longrun equilibrium was achieved by assuming that land is a fixed factor, hence the returns to land are residual earnings rather than the published imputed cost. 15/ Table 2 contains the data for this example. Input and output quantities are normalized to unity. I assumed that the specific technological advances are new corn varieties. The cost-reducing corn variety is one that is highly resistant to pests so that no chemical inputs are required, but yield does not change. The output-enhancing hybrid is a new higher yielding variety with a direct increase in output per acre. I assumed that the production technology is

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14/ Although Capalbo did not provide a formal statistical test, the estimates of decreasing cost are almost certainly statistically indistinguishable from constant returns to scale. Thus, one might want to accept constant returns to scale as a lower limit.

15/ Under the assumption that all other factors are at their equilibrium value, negative net returns using the imputed land cost implies either that the estimated land value was too high or that land prices are expected to appreciate.

Table 2--Initial position, assuming longrun equilibrium

Item	Unit cost (1)	Quantity (2)	Cost (1X2)
	Dollars	Number	Dollars
Variable inputs:			
Seed	18.47	1	18.47
Fertilizer	50.03	1	50.03
Lime and gypsum	1.53	1	1.53
Chemicals	17.58	1	17.58
Fuel, lubrication, and electricity	13.49	1	13.49
Repairs	11.25	1	11.25
Hired labor	1.70	1	1.70
Unpaid labor	12.06	1	12.06
Miscellaneous	29.48	1	29.48
Overhead, taxes, and related expenses	32.45	1	32.45
Capital replacement	33.70	1	33.70
Fixed and quasi-fixed inputs:			
Nonland capital	12.92	1	12.92
Land	36.75	1	36.75
Output	260.17	1	260.17
Implied investment: 1/			
Land	846.77	N.A.	N.A.
Nonland	297.70	N.A.	N.A.
	Percent		
Competitive return rate	4.34		

Note: Inputs and output are defined so that the quantity per acre at initial equilibrium equals one.

N.A. = Not applicable

1/ The implied investment amount is heavily dependent on the assumption of longrun equilibrium. Returns to land were recalculated as a residual return. Expected future prices equal current prices.

Source: 1985 Farm Costs and Returns Survey.

represented by a constant elasticity of substitution (CES) production function with an elasticity of substitution of 0.3. I further assumed that the new varieties are available at no additional cost and that no other changes in management practice or production technique are required to obtain the direct benefits of the new varieties.

The Microeconomics of Adjustment

The basis of the popular distinction between cost-reducing and output-enhancing technical change is illustrated in table 3. The behavioral response is termed myopic; the technology

Table 3--Myopic response to a new technology

Item	Cost-reducing technology			Output-enhancing technology		
	Unit cost (1)	Quantity (2)	Cost (1X2)	Unit cost (1)	Quantity (2)	Cost (1X2)
	Dollars	Number	----Dollars----		Number	Dollars
Variable inputs:						
Seed	18.47	1	18.47	18.47	1	18.47
Fertilizer	50.03	1	50.03	50.03	1	50.03
Lime and gypsum	1.53	1	1.53	1.53	1	1.53
Chemicals	17.58	0	0	17.58	1	17.58
Fuel, lubrication, and electricity	13.49	1	13.49	13.49	1	13.49
Hired labor	1.70	1	1.70	1.70	1	1.70
Unpaid labor	12.06	1	12.06	12.06	1	12.06
Miscellaneous	29.48	1	29.48	29.48	1	29.48
Overhead, taxes and related expenses	32.45	1	32.45	32.45	1	32.45
Replacement capital	33.70	1	33.70	33.70	1	33.70
Fixed and quasi-fixed inputs:						
Nonland capital	N.A.	1	N.A.	N.A.	1	N.A.
Land	N.A.	1	N.A.	N.A.	1	N.A.
Output	260.17	1	260.17	260.17	1.072	279.01
Fixed input returns:						
Unallocated residual	67.26	N.A.	N.A.	68.52	N.A.	N.A.
				Percent		
Implied rate of return	5.88	N.A.	N.A.	5.99	N.A.	N.A.

N.A. = Not applicable.

adopter plants the new corn variety and does not alter use of other inputs except in the cost-reducing case where the obvious response, eliminating chemical expenses, occurs. To maintain equivalency of the new technologies, the direct yield response to the output-enhancing corn variety is assumed to be 7 percent, the percentage cost reduction obtained by eliminating chemicals from the production process. In both cases, the farm manager's financial position is improved. The improved financial position is summarized by the unallocated residual returns which include a return to land and nonland capital and profits beyond a normal return on investment. These profits draw additional resources into the industry. One way to view the profits is as a return to the initial land and nonland capital investment; the implied return is 5.88 percent in the cost-reducing change case and 5.99 percent in the output-enhancing case.

A shortrun profit maximization response assumes that nonland capital is fixed in the short run (table 4). In this case, land and nonland capital are used more intensively,

Table 4--Shortrun profit maximization response

	Cost-reducing technology			Output-enhancing technology		
	Unit cost (1)	Quantity (2)	Cost (1X2)	Unit cost (1)	Quantity (2)	Cost (1X2)
	Dollars	Number	----Dollars----		Number	Dollars
Variable inputs:						
Seed	18.47	1.198	22.13	18.47	1.196	22.09
Fertilizer	50.05	1.198	59.94	50.03	1.196	59.83
Lime and gypsum	1.53	1.198	1.83	1.53	1.196	1.83
Chemicals	0	0	0	17.58	1.196	21.02
Fuel, lubrication, and electricity	13.49	1.198	16.16	13.49	1.196	16.13
Hired labor	1.70	1.198	2.04	1.70	1.196	2.03
Unpaid labor	12.06	1.198	14.45	12.06	1.196	14.42
Miscellaneous	29.48	1.198	35.31	29.48	1.196	32.26
Overhead, taxes, and related expenses	32.25	1.198	38.88	32.45	1.196	38.80
Replacement capital	33.70	1.198	40.37	33.70	1.196	40.30
Fixed and quasi-fixed inputs:						
Nonland capital	N.A.	1	N.A.	N.A.	1	N.A.
Land	N.A.	1	N.A.	N.A.	1	N.A.
Output	260.16	1.139	296.25	260.16	1.221	317.72
Fixed input returns:						
Unallocated residual	65.14	N.A.	N.A.	66.01	N.A.	N.A.
				Percent		
Implied rate of return	.0569	N.A.	N.A.	N.A.	.0577	N.A.

N.A. = Not applicable.

thus yielding an output response of 14 percent in the case of the cost-reducing corn variety and a further output response (rising from 7 percent to 22 percent) in the case of the yield-increasing corn variety. The restrictiveness of the CES production technology assumption, apparent in the equal percentage increase in all inputs, highlights the illustrative nature of the example. The implied rate of return on the investment remains above the assumed normal rate of 4.34 percent leaving economic incentives for further adjustment.

In the longrun response, nonland capital is allowed to vary leading to further output responses (table 5). The assumption that land is fixed in the long run is maintained,

Table 5--Longrun response

Item	Cost-reducing technology			Output-enhancing technology		
	Unit cost (1)	Quantity (2)	Cost (1X2)	Unit cost (1)	Quantity (2)	Cost (1X2)
	Dollars	Number	---Dollars---		Number	Dollars
Variable inputs:						
Seed	18.47	1.206	22.28	18.47	1.198	22.13
Fertilizer	50.03	1.206	60.35	50.03	1.198	59.96
Lime and gypsum	1.53	1.206	1.85	1.53	1.198	1.83
Chemicals	0	0	0	17.58	1.198	21.07
Fuels, lubrication, and electricity	13.49	1.206	16.27	13.49	1.198	16.17
Hired labor	1.70	1.206	2.05	1.70	1.198	2.04
Unpaid labor	12.06	1.206	14.55	12.06	1.198	14.45
Miscellaneous	29.48	1.206	35.55	29.48	1.198	35.32
Overhead, taxes, and related expenses	32.45	1.206	39.15	32.45	1.198	38.89
Replacement capital	33.70	1.206	40.65	33.70	1.198	40.39
Fixed and quasi-fixed inputs:						
Nonland capital	12.92	1.206	15.59	12.92	1.198	15.48
Land	N.A.	1.000	N.A.	N.A.	1.000	N.A.
Output	260.16	1.182	307.63	260.16	1.268	329.92
Fixed input returns:						
Unallocated residual	74.91	N.A.	N.A.	77.67	N.A.	N.A.
New land value	1,366.92	N.A.	N.A.	1,432.82	N.A.	N.A.
Nonland	359.12	N.A.	N.A.	356.76	N.A.	N.A.

N.A. = Not applicable

allowing above-normal profits on the original land investment. The final adjustment leading to a full erosion of above-normal returns is an increase in land value. Land prices will be bid up such that the return equals the normal rate of 4.34 percent. Thus, the benefits of technological change are capitalized into land values, ultimately eliminating any improvements in the financial position of the farm sector. Farmers who held land prior to an unanticipated technological advance of the type described receive above-normal returns on their original investment, but land value appreciation serves as a further barrier to entry-level farmers. This analysis assumes the commodity price remains unchanged as might occur if price supports are effective and unchanging. 16/

The example suggests that the output response of new technology may be slow (only over several growing seasons). The gradual or phased effect on output, observed for the individual farmer, is separate from the normal technology penetration effects due to differing speeds of adoption of new technologies among farmers. The specific dynamic effects in the example occur in discrete steps. The adjustment is more likely to be gradual. The farmer will probably make some effort to immediately achieve shortrun profit maximization output levels. However, there will probably be a learning-by-doing effect that necessarily requires some experience with the technology. In addition, the wide variety of capital equipment of different vintages is normally replaced at the end of its operating life. The two categories, variable and fixed inputs, are highly simplified, and the length of time involved to achieve longrun adjustment depends on the vintage of the equipment at the time of adoption.

There are at least two caveats to the phased output effect. First, adoption of a new technology provides an economic incentive to retire long-lived equipment early. Thus, the full output effect may occur before the end of the normal operating life of the equipment. Second, the farmer may anticipate the changes in long-lived equipment associated with the new technology and may time adoption to coincide with major equipment replacement. In the obviously beneficial technologies in the example above, strategically timing adoption to coincide with capital replacement may be unlikely. The advantages of some new technologies, however, may depend greatly on the type of equipment used. Some technologies may have little benefit or negative economic or yield effects unless a full complement of new equipment is also purchased. For example, yield increases may require timely watering that can only be achieved in some climates through installation of an irrigation system.

The specific output response in the tables above also depends on the degree to which corn yield depends on farm management decisions which are in turn related to economic variables. The elasticity of substitution is the essential parameter governing this technical relationship. If the yield of the new corn variety does not respond to increased fertilization, closer cropping, better irrigation, better targeted fertilization and irrigation schedules, and other improved management techniques or if the farm manager does not recognize the economic incentives to incorporate these practices, the yield increase will be negligible via the channels described above. In a similar vein, some types of inputs may have little or nothing to do with yield. In the general case, the efficient response may include increasing some inputs considerably while not changing or reducing the other inputs.

Other Adjustment Channels

The examples above do not exhaust the channels by which output may increase in the case of either cost-reducing or output-enhancing technical change. Other channels depend to some extent on the particular characteristics of the new technology and of the crop.

16/ In the absence of effective price supports, the effect on land values depends on the relative elasticity of supply and demand for the commodity. Herdt and Cochrane (1966) originally investigated the proposition that technical change increased the value of land. Pope, Kramer, Green, and Gardner (1979) more recently reestimated Herdt and Cochrane's model.

The reduction in cost will provide economic incentives to bring marginal land into production. The yield on marginal land may be so low that it was previously uneconomical to plant a crop on the land. Lowering the cost of production or increasing the yield (revenue) will encourage production on those lands near the break-even point.

Other land may be able to provide a high yield but would require a significant capital investment to do so. Improved profitability associated with technical change justifies capital expenditures, such as irrigation, drainage, or clearing, to improve some of this land.

Technical change in one crop like corn will clearly lead to some switching of cropland from other crops. Such switching may occur on land that is equally suited for corn and other crops (for example, corn and soybeans). Switching may also occur on land on which corn production was not economical but which, with technical change, would become economically competitive with the other crop (for example, land suitable for wheat production but requiring irrigation to support corn production). A special case of crop switching involves crop rotation schemes. Improved corn production technology will tip economic incentives away from other crops in a rotation schedule; thus, land may be more intensively used for corn over time.

Specific characteristics of the technology may also result in yield increases. Some farm managers have resisted extensive use of chemical pesticides because of their concern for their personal exposure to the chemicals or because of general environmental concern. A pest-resistant corn variety may be fully acceptable to such a farm manager and will lead to lower crop losses to pests and a direct increase in effective yield.

Farm management expertise may also affect the control of pest damage with chemical means or with the hypothetical pest-resistant corn variety. Failure to apply chemical pesticides before crop damage occurs due to infrequent monitoring, weather, or competing demands on the applier's time leads to crop losses, whereas the pest-resistant variety is not subject to such losses. In principle, this consideration depends on technological changes, as described by the production function. In practice, experimental trials with carefully controlled chemical applications may not reveal these farm management constraints.

Analyzing the incentives and opportunities open to the individual farm manager supports the aggregate econometric estimates showing significant output response for cost-reducing technical change and for output-enhancing change. The output effects occur through a variety of channels that add a dynamic effect to output response to technical change apart from the specifics of technology penetration. The aggregate econometric estimates cannot predict the output effects of a specific new technology, because the estimates are based on historical data. The farm manager's decisions depend on the specifics of a new technology and on the farmer's existing situation, adding to the difficulty of estimating aggregate output effects starting from a highly disaggregated analysis.

A POLICY OF SUPPORTING COST-REDUCING TECHNOLOGY?

The process of technical change in agriculture is complex and multifaceted. Within the relatively simple neoclassical economic model of production, one can represent popular notions of output-enhancing and cost-reducing change. The presumption that a duality of representations of the primal production function and cost functions makes distinctions between cost-reducing and output-enhancing technologies meaningless is incorrect if the sector exhibits nonconstant returns to scale. The popular notion that cost-reducing technical change will lead to no output increase is, however, similarly incorrect. If decreasing returns to scale exist (as might occur if there is an economy-wide fixed factor like land and if agriculture is a big user of the input), then cost-reducing technologies will result in smaller output increases than output-enhancing technologies. This result is equivalent, however, to biasing technical change away from the fixed factor. Thus, if there is concern about surplus agricultural products, technical change that is biased away from the fixed factor will produce a smaller output increase and presumably a smaller increase in surplus stocks. The additional increase will be 20 percent or less of the cost-reducing effect. Significant output effects occur with cost-reducing and with output-enhancing technical change.

The ultimate question is, however, whether R&D policy should be steered toward cost-reducing technology over output-enhancing technology. The answer is generally no. R&D funds should go to those projects with the expected highest return to society. The value of technical change to society is that it allows the production of more with less. Technical change, whether output-enhancing or cost-reducing, will tend to increase output and reduce costs of products. Government stockpiles of agricultural products result from other programs and policies directed toward income stabilization and adjustment in the sector. Surpluses would be more effectively addressed by restructuring these policies rather than agricultural R&D.

If a case can be made that output is expanding too rapidly causing high adjustment costs among farmers, reductions in Government-financed R&D may be appropriate. However, the most efficient way to reduce R&D costs is to cut the least effective projects. That is, purchase the desired rate of technical change at the least cost. By definition, the least effective projects are those that yield the smallest output increase for a given reduction in cost (including the R&D costs). R&D policy should not depend on whether a technology reduces costs or enhances output.

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Note

Emboldened print is used throughout the text to distinguish vectors and matrices from scalars.

errata

p. 2: *The partial derivative expression for equation (2), defined to be increasing in a_i, should be*

$$\partial Y/\partial a_i = (\partial y_1/\partial h_1)(\partial h_i(x_i,a_i)/\partial a_i).$$

p. 3: *In equation (8), f should be emboldened.*

p. 4: *Note that in equation 9 the inequality sign is inadvertently reversed. The* $\mathbf{x(w)}$ *in (10) and (11) are not the same function and* $\mathbf{x(w)}$ *where it appears on pp. 4-8 is emboldened. The expression following (11a) should be numbered (12).*

p. 8: *The superscripts in equation (24) should be subscripts.*