Evaluating Agricultural Research and Productivity

Proceedings of a Symposium
Atlanta, Georgia
January 29-30, 1987

Miscellaneous Publication 52-1987
Minnesota Agricultural Experiment Station
University of Minnesota

EVALUATING AGRICULTURAL RESEARCH AND PRODUCTIVITY

Proceedings of a Symposium
Sponsored by IR-6 and the Farm Foundation

HELD IN ATLANTA, GA

January 29-30, 1987

As a Miscellaneous Publication of the Minnesota Agricultural Research Station, this publication is intended for a very limited and specialized audience. Initial distribution was made by the University of Minnesota's Department of Agriculture and Applied Economics. Copies of this publication may be obtained by writing: Publications, Department of Agriculture and Applied Economics, University of Minnesota, 1994 Bufford Avenue, St. Paul, MN 55108. Copies will be available until the initial printing is exhausted.

TABLE OF CONTENTS

FORWARD

This publication includes a set of papers presented at a symposium on Evaluation of Agricultural Research and Productivity held in Atlanta, Georgia on January 29th and 30th, 1987. The Symposium was planned and organized by the Technical Committee of IR-6 (an Interregional Research Committee on National and Regional Analysis and Evaluation of Agricultural Research). The symposium was co-sponsored by the Farm Foundation which also underwrote a portion of conference expenses.

The two major objectives of the Atlanta Symposium were to develop and present a conceptual and empirical update on research designed to evaluate research and productivity in agriculture and forestry.

The Atlanta Symposium follows in a tradition of past symposia on agricultural research evaluation and analysis which originated in Minneapolis in 1969 (see Walter F. Fishel, Editor, Resource Allocation in Agricultural Research, University of Minnesota Press, 1971), and which have been conducted periodically since that time. A second symposium, held at Airlie House in January 1975, had the broader international arena of agricultural research and research systems as its focus. The proceedings of the Airlie House symposium were reported in Resource Allocation and Productivity in National and International Agricultural Research, edited by Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan and published by the University of Minnesota Press in 1976. A third major symposium was held at the University of Idaho in May, 1978. The proceedings of this symposium, which emphasized appraisal of productivity of extension as well as research, was published in March 1980 in Research and Extension Productivity in Agriculture, edited by A. A. Araji and published by the Idaho State Agricultural Experiment Station. Proceedings of a fourth symposium held in Minneapolis on May, 1980 were reported in Evaluation of Agricultural Research, Miscellaneous Publication 8-1981, Minnesota Agricultural Experiment Station.

On behalf of the Technical Committee of IR-6, I would like to express our thanks to the Farm Foundation, to those individuals whose papers are included in this proceedings report and to all other symposium participants. A particular word of thanks is due to Susan Pohlod and Linda Littrell who retyped and proofed the individual symposium papers and who prepared this proceedings report.

W. Burt Sundquist
Chairman, Technical Committee IR-6
and Symposium Coordinator

AGRICULTURAL PRODUCTIVITY MEASURES FOR U.S. STATES 1950-1982

Robert E. Evenson, Daniel Landau and Dale Ballou*

Productivity measures are of interest for two purposes. First, under certain carefully documented situations they can be used for comparative purposes. That is, one can compare productivity levels in one period with levels in another period or productivity levels in one region with productivity levels in another region. Second, productivity measures can be used to facilitate the statistical association of productivity change with determining variables (the term productivity decomposition is used here to describe this analysis). For both purposes productivity measures at a relatively detailed level are useful.

At present the USDA provides measures of total factor productivity at a ten region level for U.S. agriculture. These measures, available for the period 1939-1983, have been subject to critical review in the past, but the USDA has not responded to the criticisms offered by revising its procedures.[1] The only prior total factor productivity series computed at the State level is by Landau and Evenson for the 1949-71 period.[2] This series served as the basis for decomposition analysis in previous work by Evenson, Waggoner and Ruttan in which returns to agricultural research, extension and schooling were computed.[3]

In this paper we report a new total factor productivity series at the state level for the 1950-1982 period. Part I of the paper outlines the methodological issues inherent in productivity measurement. Part II addresses particular issues for state level productivity measurement. Part III summarizes the new state measures, compares them with the regional USDA measures, and discusses their reliability. Part IV provides concluding comments.

I. PRODUCTIVITY MEASUREMENT

There are basically two formal procedures for deriving total factor productivity (TFP) indexes. The first, and in many ways simplest, is to derive the measure from an economic accounting measure. The second is to derive the measure from a production function or from the cost function associated with the production function. The relationship can also be derived from the output supply and factor demand equations associated with the profits function. In the case of the accounting derivation no knowledge of the production "curvature," i.e., the form of the production or transformation function, is presumed. In the case of the production and cost function derivations such knowledge is presumed but an approximating index formulation (the Divisia) is often used rather than actual estimates of these functions. This Divisia index is the same index form derived for the accounting relationship.

The Accounting Derivation

Suppose that an economic sector is in long run equilibrium. Firms may be technically efficient and they may be minimizing costs and maximizing profits, but they need not be. In equilibrium, firms will not be making profits (i.e., abnormal profits). This produces the accounting relationship where

$$(1) \quad \sum_i P_i Y_i = \sum_j R_j X_j$$

---

* Robert E. Evenson is Professor of Economics, Economic Growth Center, Yale University, Daniel Landau is Professor of Economics, University of Connecticut and Dale Ballou is Graduate Research Assistant, Economic Growth Center, Yale University.

where the Y_i are outputs with prices P_i, and the X_j are inputs with prices R_j. (Note that "quasi-fixed" factors such as land or buildings are treated as having a "rental" or service price.)

Now differentiate (1) totally with respect to t

$$(2) \quad \sum_i Y_i \frac{\partial P_i}{\partial t} dt + \sum_i P_i \frac{\partial Y_i}{\partial t} dt = \sum_j X_j \frac{\partial R_j}{\partial t} dt + \sum_j R_j \frac{\partial X_j}{\partial t} dt$$

This expression is exact for infinitely small changes. For discrete or finite changes, index number problems must be dealt with.

Divide the left-hand side of (2) by $\sum_i P_i Y_i$ and the right-hand side by $\sum_j R_j X_j$ -- the two sums are equal. Then multiply the first term of (2) by P_i/P_i, the second by Y_i/Y_i, the third by R_j/R_j, and the fourth by X_j/X_j. Note that

$Y_i P_i / \sum_i P_i Y_i = S_i$, the output share of the ith output

and $X_j R_j / \sum_j R_j X_j = C_j$, the input cost share of the jth input.

Let $\hat{X}_j = \frac{1}{X_j} \frac{\partial X_i}{\partial t} dt$ be a rate of change.

This produces:

$$(3) \quad \sum_i S_i \hat{P}_i + \sum_i S_i \hat{Y}_i = \hat{p} + \hat{y} = \sum_j C_j \hat{R}_j + \sum_j C_j \hat{X}_j = \hat{r} + \hat{x}$$

where $\hat{p}$, $\hat{y}$, $\hat{r}$ and $\hat{x}$ are now rates of change of aggregated output prices, output quantities, factor prices and factor quantities respectively. The rate of change in total factor productivity $\hat{T}$ is now defined as

$$(4) \quad \hat{T} = \hat{y} - \hat{x} = \hat{r} - \hat{p}$$

The motivation for this definition is that $\hat{T}$ captures efficiency gains. The following six interpretation of these gains can be given:

(a) Suppose all inputs stay constant (i.e., $\hat{x} = 0$), $\hat{T} = \hat{Y}$ measures the increase in output (or output index) achievable at constant input levels.

(b) If all outputs are constant, $\hat{y} = 0$, $\hat{T} = \hat{x}$ then measures the reductions in input requirements at constant output levels.

(c) If both inputs and outputs change, then $\hat{T} = \hat{y} - \hat{x}$ is the increase in total factor productivity. Note that the change in the output/input ratio (or factor productivity for a single factor is

$$\frac{\partial}{\partial t} \left[\frac{\hat{Y}}{X}\right] \Big/ \left[\frac{\hat{Y}}{X}\right] dt = \hat{Y} - \hat{X} = \frac{\partial}{\partial t} \log Y - \frac{\partial}{\partial t} \log X$$

Thus the rate of productivity growth is the rate of change in the ratio of output to input or in the ratio of an output index to an input index.

(d) Suppose all output prices to be constant ($\hat{P} = 0$). This arises when all goods are traded and their prices cannot change or when we consider an individual firm in the large market. Then $\hat{T} = \hat{r}$. Total factor productivity growth is then the rate of increase in <u>factor prices</u> or <u>factor rewards</u> or <u>factor incomes</u> made possible by efficiency gains.

(e) Suppose all input prices constant, $\hat{r} = 0$. This case would arise if all factors were traded but goods were not. Then $\hat{T} = -\hat{P}$. The rate of total factor productivity change is measured by the reduction in output prices made possible by the efficiency gains

(f) Suppose both input and output prices change

$$\hat{T} = \hat{r} - \hat{P} = \left[\frac{\hat{r}}{p}\right] .$$

Total factor productivity change is the increase in <u>real factor incomes</u>, deflated by the output price (or an index thereof).

Note further that to measure factor productivity we can use both sides of the equation (4) and should arrive at the same answer.

These interpretations provide a general content to the TFP index. Note that one cannot describe the TFP index as a technology change index. Public sector infrastructure investments and closing of the technology gap via extension and schooling investments also produces TFP gains.

Before turning to the productivity description specifications, however, it will be useful to discuss the production and cost function foundation for TFP measures and then to discuss index number problems.

<u>Production Function Derivations</u>

Suppose a single output Y, several inputs (X_1--X_n), and production technology is described by a production function:

$$(5) \quad Y = F(X_1, \ldots, X_n, t)$$

Suppose further that (5) is a linear homogeneous function describing the maximum product technically feasible for any given set of inputs. Note that several things are "held constant" in the background behind this expression. Specifically, the technology set available to farmers, the existing infrastructure (roads, markets) and transactions costs (legal system, etc.) are all treated as constant in (5). One of the purposes of productivity analysis is to <u>infer</u> from data only on Y and the X's the probable contributions to output that changes in these factors in the background contribute.

Differentiate (5) totally with respect to time to obtain:

$$(6) \quad \frac{\partial Y}{\partial t} dt = \sum_j F_j \frac{\partial X_j}{\partial t} dt + F_t dt$$

where $F_i = \partial Y / \partial X_i$, the marginal product of the ith factor of production. The first order conditions for profit maximization are:

$$F_j = P_j / P_y$$

where P_j and P_y are prices of inputs and outputs. Substituting these in for the F_j and dividing by Y to obtain:

$$(7) \quad \frac{\partial Y}{\partial t}\frac{1}{Y}\,dt = \sum_j \frac{P_j}{P_j Y}\frac{\partial X_j}{\partial t}\,dt + \frac{F_t}{Y}\,dt$$

Multiplying each term in this summation by X_j/X_j and making use of the property that $\Sigma P_j X_j = P_y Y$ (i.e., that the value of total inputs equals the value of output; this is the "no profit" condition that holds in a competitive economy) we obtain

$$(8) \quad \frac{\partial Y}{\partial t}\frac{1}{Y}\,dt = \sum_j C_j \left(\frac{\partial X_j}{\partial t}\frac{1}{X_j}\right) dt + \frac{F_t}{Y}\,dt$$

where C_j is the cost share for the jth factor.

This expression holds for small changes when the "background variables" are constant. It relates growth in output to growth in factors or inputs. When this equation does not hold, the logic of this development tells us that the background variables have not remained constant. This is the basis for the definition of total productivity change $\hat{T}$ as:

$$(9) \quad \hat{T} = \frac{F_t}{Y}\,dt = \hat{y} - \sum_j C_j \hat{X}_j = \hat{y} - \hat{x}$$

This development thus leads to the same expression as did the accounting expression. Note that scale economics were imposed to obtain this relationship. Technical errors by farmers in obtaining maximum output, profit maximizing errors and scale economics may, in practice, be included in measures of T.

Cost Function Derivation

The producer minimizing costs subject to the production function (5) solves this economic problem by choosing the cost minimizing combination of factors for any given output.

These cost minimizing quantities can be expressed as functions of prices and quantities of fixed factors. Thus when substituted into the cost relationship, the minimum cost function can be expressed as:

$$(10) \quad C^* = G(R_j, F, t)$$

This expresses minimum unit costs as a function of input prices and fixed factor quantities, F.

Now differentiate (10).

$$(11) \quad \frac{\partial C}{\partial t}\,dt = \sum_j G_j \frac{\partial R_j}{\partial t}\,dt + G_F \frac{\partial F}{\partial t}\,dt + G_t\,dt$$

The term $G_t dt$ measures the reduction in unit costs of production holding prices constant. This is a natural definition of productivity change. Transforming to proportional changes gives $\hat{T} = \hat{r} - \hat{c}^*$, and since in competition $c^* = P$ we have the relationship derived earlier. (Note that fixed factors may or may not be given rental values. If not, this is a variable factor productivity measure.)

This relationship can be further developed in terms of factor demand functions. The Shephard-Hotelling lemma states that the first partial derivative of (10) with respect to factor prices are the factor demand curves. These factor demand curves are:

$$(12) \quad X_j = X_j\,(R, t)$$

differentiating

$$\frac{\partial X_j}{\partial t}\,dt = \sum_j \sum_k X_{jk} \frac{\partial R_{jk}}{\partial t}\,dt + X_{jj}\,dt$$

In proportional changes we define $\hat{T} = \sum_j C_j \hat{T}_j$ where $\hat{T}_j = \hat{X}_j dt/Y$.

Profit Function Derivation

Recent developments in profits functions or duality models now enable much richer analysis than afforded by the earlier developments. They allow for the analysis of production of more than one farm output. They also allow an estimate of research and other effects on the supply of each output produced and the demand for each input used. These can then be combined into a productivity effect. (It is also possible to estimate the impact of research on the rent to fixed factors.)

The multiple output model begins with a very general specification:

$$(13)\quad g(Y,X,F,E) = 0$$

where Y is a vector of outputs,
X is a vector of variable inputs,
F is a vector of fixed inputs, and
E is a vector of background variables characterizing technology and other factors affecting production (including research and extension outputs or inputs).

Variable profits are defined as:

$$(14)\quad \pi = PY - RX$$

where P is a vector of output prices and R a vector of variable input prices.

Maximized variable profits π^* are obtained by maximizing (14) subject to (13). The first order conditions for the Y and X vectors can be expressed as functions of P,R,F, and E. Substituting these into (14) yields the maximized profits function.

$$(15)\quad \pi^* = \pi^*(P,R,F,E)$$

Note that maximized profits are now expressed as functions of the exogenous variables only. The choice variables Y and X do not enter into (15) because they are expressed as functions of exogenous variables.

The Shephard-Hotelling lemma states that the first derivatives of (15) with respect to each output price yields the supply function for that output. (See Chapter III.) The first derivatives of (15) with respect to input prices yields the input demand functions. Thus a system of output supply and factor demand equations is derived.

$$(16)\quad \partial\pi^*/\partial P_i = Y_i = Y_i(P,R,F,E)$$

$$\partial\pi^*/\partial R_j = X_j = X_j(P,R,F,E)$$

Note that the E variables, including research variables, enter into each equation in the system (16) as well as in (15).

Differentiating (16) we obtain

$$(17)\quad \frac{\partial Y_i}{\partial t}\,dt = \sum_i Y_i \frac{\partial P_i}{\partial t}\,dt + \sum_i Y_{ij} \frac{\partial R_j}{\partial t}\,dt + Y_{iE}\frac{\partial E}{\partial t}\,dt + Y_{iF}\frac{\partial F}{\partial t}\,dt$$

$$\frac{\partial X_j}{\partial t} dt = \sum_j X_j \frac{\partial P_i}{\partial t} dt + \sum_j X_{ij} \frac{\partial Ri_j}{\partial t} dt + X_{jE} \frac{\partial E}{\partial t} dt + X_{jF} \frac{\partial F}{\partial t} dt$$

Treating the $\frac{\partial E}{\partial t}dt$ terms as indexing productivity change, i.e., the vector E as containing all of the relevant productivity variables, and converting to rate of change we have:

$$(18) \quad \hat{T} = \sum_i S_i \hat{T}_i - \sum_j C_j \hat{T}_j$$

where $\hat{T}_i = Y_i \frac{\partial E}{\partial t} dt/Y$ and $\hat{T}_j = X_j \frac{\partial E}{\partial t} dt/Y$

Index Numbers and Functional Forms

The basic TFP index postulated in (3), $\hat{T} = \hat{Y} - \hat{x} = \hat{r} - \hat{p}$, and other versions derived require an index number to aggregate outputs, inputs and prices. The accounting derivation suggested a natural index for T when changes are "small": $\hat{y} = \sum_i S_i Y_i$, $\hat{x} = \sum_j C_j \hat{x}_j$, etc.

Most TFP measures are "cumulated" on a base (as well as being expressed in rates of change for short periods). This cumulation does not present a problem with the Theil-Tornqvist approximation since "weights" are changed each period.

This natural index is known as a Divisia index. The Theil-Tornqvist discrete approximation to this index is

$$\hat{Y} = \ln(Y_t/Y_{t-1}) = \frac{1}{2} \sum_i (S_{it} + S_{it-1}) \ln(Y_{it}/Y_{it-1})$$

$$\hat{x} = \ln(X_t/X_{t-1}) = \frac{1}{2} \sum_j (C_{jt} + C_{j,t-1}) \ln(X_{jt}/X_{jt-1})$$

When changes are not small, any index number formula will impose implicit "curvature" on production technology. This comes about because the index number for a quantity aggregate is designed to "purge" that aggregate of price change effects. If prices do not change or if all prices change proportionately, this does not become a problem. In practice, of course, prices do change from one period to the next. If one knows the actual form of the production or transformation function, one can use an appropriate index number formula.

For example, if production technology is Cobb-Douglas, a geometric index with constant share weights over time is exact. If the technology is Leontief, i.e., fixed coefficient, the linear Laspeyres or Paasche indexes are appropriate. If the technology is linear homogeneous translog, the appropriate index is the Theil-Tornqvist index.

In practice, not only is the Theil-Tornqvist index a discrete approximation to a Divisia index and the appropriate index when technology is linear homogeneous translog (either for the production function, the cost function, or the profit function), but it is also the appropriate index for a second order differential approximation to any arbitrary non-homothetic production technology. This is because the translog function is a "flexible" function form in the sense that it is a second order approximation to any arbitrary production, cost or profit function.

Because of these properties, the Theil-Tornqvist index is superior to other indexes for TFP measurement. Index numbers cannot handle the problem of scale economies, however. Antle and Capalbo (1987) discuss this problem and show that when economies of scale exist (as in U.S. agriculture, for example) and there are changes in firm size, TFP measures will include a mixture of realized scale economies and general scale constant productivity gains. Furthermore, TFP measures derived from cost functions (where output is held constant) will diverge from TFP measure derived from profits function (where it is not).

This distinction, however, is in general not of strong practical interest. First, with appropriate data this scale component can be estimated. Second, from the perspective of productivity decomposition, the scale component requires decomposition in much the same way as the more general component.

Estimating $\hat{T}$ with Trend Variables

A substantial body of literature has attempted to estimate $\hat{T}$ or TFP growth by incorporating a time trend variable in estimated production, cost or profits function systems. While this has some appeal for purposes of comparative work, it is not generally of value to decomposition work. Where the interest is in a single average or mean time trend to be given a particular interpretation, it has merit. Obviously, time trend estimation is a poor estimate of a productivity <u>series</u> since it imposes smoothness. For some purposes, (see below) a short period mean estimate of TFP may be desirable. However, since such a number will have a lower ratio of errors or "noise" to its real component than will a single annual change number. Generally the best way to deal with the noise ratio problem, however, is to use cumulated TFP indexes (see below). Estimation of $\hat{T}$ with trend variables requires the same considerations that are entailed in <u>integrated</u> estimation and these issues are discussed below.

Integrated Estimation vs Two-Stage Decomposition

The analyst has effectively two options in decomposition work. The two-stage option is to first compute TFP measures for particular observations (this could be a farm, or a "constructed" farm based on county, district or state data for a particular year or season). The second stage is to develop a decomposition specification in which the TFP measures are statistically related to "determining" variables. These determining variables will include variables characterizing productivity enhancement investments: research (both public and private); extension (both public and private); schooling and infrastructure variables (roads, markets, electrification, etc.). They can also include "bias" and "error correction" variables. For example, one could include factor share and price variables (or perhaps "predicted" variables to control for simultaneity bias) to correct for possible errors in TFP measurement.

The <u>integrated</u> approach incorporates these determining variables directly into an estimated production, cost or profits function or in the derived product supply and factor demand functions. The advantage of the integrated approach is that a more direct estimate of the effects of determining variables can be made. Furthermore, these determining variables are appropriate variables to enable estimation of price effects in these estimates.

There are, however, several disadvantages to the integrated approach. Under certain circumstances, one may actually "purge" or control for price effects using TFP calculations than doing so implicitly in an estimating equation. For example, one may estimate a production function (or output supply equation) using a "pooled" time-series cross-section data set from several districts. The estimation imposes the same coefficients for farms across districts. The TFP calculation allows for the implicit coefficients to differ by district and year. Probably the greatest advantage to the two-step procedure is that it allows the pooling of "price purged" TFP measures for a range of observations over which the proposition of constant production curvature is untenable.

Consider the estimation of a profits function based system:

$$Y_i = Y_i(P,R,F,E)$$

$$X_j = X_j(P,R,F,E)$$

The ideal data for estimating E impacts would be data with no variations in P,R, and F and substantial variations in E. It is generally not possible to obtain data where F (land size and other fixed capital) does not vary, but regression techniques can estimate F impacts along with E impacts in data where only P and R do not vary. (Of course, such data cannot be used to estimate P and R impacts.) Some large cross-section farm surveys (or censuses) for a single year could be used to estimate E impacts efficiently because one may have little variation in P and R. (These data sets may have other limitations regarding the estimation of research timing effects.)

To date, most studies of this type have used secondary cross-section time-series data bases in order to achieve enough variation in the E variables to identify their impacts. They have been forced to estimate P and R impacts as well because P and R do vary in these data sets. The price response measures are of great interest in and of themselves of course (actually the measures of the E impacts are generally not highly sensitive to the functional form specifications used for the P and R variables). Secondary data on outputs and on inputs are usually available and can be used to construct average farm observations. Note that data showing how much of each input is used to produce each output is not required to estimate these systems.

Profits function residual productivity measures can be "pooled" from different regions to attain more variation in the E variables without imposing constant coefficients for the P,R, and F impacts over these regions. The analyst may wish to estimate separate systems for different regions to avoid problems with "corner" solutions. The residuals, i.e., predicted minus actual values of the dependent variable where the predicted values do not include E variables impacts (even though they may have been estimated), may then be pooled from one region and regressed on E variables specified consistently over several regions.

The analyst may also use P,R, and F (or some subset) coefficient estimates that he regards to be reliable to compute "productivity" residuals from other data to enable estimation of E variable effects. For example, a sample of farms may provide good estimates of a system where E variables are roughly constant. The P,R, and E coefficients may be well estimated. They can be used to convert secondary data from larger regions where E varies into productivity residuals suited to estimation of E impacts.

The problem of "corners" can be partially avoided by judicious pooling of residuals. Other procedures for correcting for the selectivity bias from this problem are available as well (see Huffman, 1984).

Recent work with profits function systems are beginning to exploit the fact that most agricultural research programs are unit-cost reducing in impact. That is, they usually do not change the quality of the product (in ways that are not measurable) but reduce the cost of production. Commodity specific research then has effects on supply that are similar to price effects. A ten percent reduction in the cost of producing a unit of soybeans, for example, will have the same effect on producers as a ten percent rise in the price paid for soybeans. This means that research impacts will be "symmetric" across commodities and related to price effects by a scalar. Symmetry means that the effects of soybean research that reduces costs by one percent on corn supply is the same as corn research that reduces the cost of producing corn by one percent on soybean supply.

II. PROBLEMS AND ISSUES IN USDA REGIONAL PRODUCTIVITY MEASURES AND IN STATE PRODUCTIVITY MEASUREMENT

In 1980 an AAEA Task Force reviewed the USDA productivity series in the Gardner report. Several criticisms were levied against the USDA indexes. One was the use of Laspeyres indexes instead of Divisia type indexes. In constructing a state series, we have attempted to respond to the Gardner report criticisms. The state series is thus, in our judgment, an improvement over the USDA series in several respects. There are, however, some data limitations that affect the state series to a greater degree than they affect the regional series. In this section, we note some of the most important differences between our series and the USDA's. For details and additional points, the reader is referred to Appendix I.

The USDA publishes indices of farm output, input, and total factor productivity annually in Changes in Farm Production and Efficiency. Some information about the procedures used to construct these indices is available in Agricultural Handbook No. 365 (1970); more details appear in the Gardner report cited above. The output and input indices are Laspeyre's quantity indices with base-period price weights; the base periods are changed every ten years or so and the historical series spliced together. Following the Task Force recommendation, we used instead the Tornqvist-Theil approximation to the Divisia index, obtaining an index of total factor productivity as the ratio of outputs to inputs.[4] It should be noted that the Task Force also recommended replacing Laspeyre's with Divisia indices in the construction of certain composite inputs like agricultural chemicals and fertilizers. Due to limited data we were unable to adopt this procedure at those levels of aggregation.

Our output index is composed of thirty-four categories of farm products. Most major national crops and livestock categories are represented. Products of minor importance from the national perspective are picked up in residual, miscellaneous categories. In some states these products (e.g., truck crops) may be of disproportionate importance so that our index is less well suited to the agricultural sector there. Output was measured as calendar-year production. The difference in the logarithm of current and lagged outputs was used as an approximation to relative change. The Tornqvist-Theil index used value-of-production weights. We constructed the value of production as current output times the lagged price. We then used the mean of this year's value of production and the past year's value as the index weight.

Our input index is based on eight input categories: land, labor, fertilizer, feed, seed, service flow from capital stock, machinery operation and repair, and miscellaneous. These categories closely match the production expenditure categories in the USDA's Farm Income Statistics, the principal source of data at the state level. Lack of data forced us to include agricultural chemicals with miscellaneous items. Feeder livestock does not appear as an input category; thus we omit any value added outside the farm sector. The USDA adjustments for production of commercial hatcheries is superior to our approach in this matter, but the resources we could devote to what appeared a relatively minor component were severely limited. The use of different data sources means that our procedures deviate from those of the USDA in many respects, both large and small. Our construction of input flows is described at length in Appendix I. Two of the more important differences are summarized below.

Labor: The USDA measures labor manhours by summing over all planted acres or units of livestock on imputed labor input. The labor input is based on benchmark figures for the time an average agricultural worker takes to cultivate an acre of the crop in question or raise the sort of livestock involved. The benchmark figures are infrequently revised. The resulting figures are grossed up by 15% for general farm overhead.

Instead of tying labor input to production figures, we based our estimate on direct measures of labor employment. We used two sources. For hired labor, we used expenditures on labor published in the USDA Farm Income Statistics. We divided by the average wage for agricultural laborers working for cash wages to obtain hired manhours. We based an estimate of unpaid family and operator labor on the surveys of the Statistical Reporting Services published in Farm Labor. From the Task Force report: "If the SRS data were moved to a monthly survey instead of the current quarterly sampling, it would be our choice as a basis for the national labor input." Our approach adjusts the quarterly series for the information contained in the earlier monthly series.

Feed Grains: The USDA employs a net measure of productivity, netting out from both outputs and inputs farm-grown intermediate products. Most notably, they compute feed input as a proportional constant times quantity of liveweight production. (The constant varies by livestock type.) Of this total, a certain fraction is taken to represent value added outside the farm sector by commercial processors. The rest is considered an intermediate product and is not counted as an input. An equal quantity is subtracted from feed grain output. A couple of critical considerations led us to prefer a gross measure of productivity which retains feed grains as both inputs and outputs. First, as noted by the Task Force: "The fully gross approach has two practical benefits: (1) the data used to net out farm-produced feed are dubious in many respects, and (2) the fully gross measure facilitates growth accounting by means of production functions or other methods." To these considerations we would add that the net approach seems particularly ill-suited to development of productivity indices at the state level. Understanding differences across states will be impeded rather than aided by an approach that obscures whether productivity improvements originate in the use of fertilizer and machine power to grow crops or in the development of specialized feedlots and the conversion of grain to animal weight.

In addition we utilized somewhat different procedures to measure the service flow from real estate, power and machinery. For land we constructed a service flow based on deflated cash rent series. Property taxes were retained in our land service flow measure. We utilized the state income service depreciation data for structure and used a constant 5 percent real interest rate in computing service flows for capital stock. Our machine operating expenses and repairs were not combined with service flows as in the USDA index.

III. STATE TOTAL FACTOR PRODUCTIVITY INDEXES

Table 1 reports growth rates of the TFP index by state and USDA region for several sub-periods and for the 1950-82 period. Actual state indexes are reported in Appendix 2. These indexes are compared with USDA indexes in Section IV. That comparison generally shows consistency with the USDA indexes and indicates little reason to conclude that major biases exist in the state indexes. Accordingly, some discussion of the indexes in merited.

It may first be noted that there is a fair amount of state heterogeneity within regions even though our regional aggregates are closely correlated with the USDA regional series. The fastest TFP growth region is the Delta region. Two states in this region, Mississippi and Arkansas, are also the two leading states in TFP growth. Alabama and Georgia are next, and they are in the second ranked region, the Southeast. Florida, also in the Southeast, however, has a relatively poor record of TFP growth.

The Mountain region clearly stands out as the region of lowest TFP growth but four states in the region, Montana, Idaho, Colorado and New Mexico, exhibit modest growth. New York and New Jersey in the Northeast also show low growth rates (New England States are not included).

In most regions, TFP growth was lowest in the 1970s. All regions and most states show rapid growth in the 1980-82 period. However, this is only a 3-year period and thus subject to weather influence. The Appalachian region shows particularly strong performance in this period.

These TFP growth patterns reflect many forces. The underlying rate of real technology generation varies by commodity, time period and region. The structural efficiency of farms, i.e., size and specialization, varies over time and by region as well. In addition, structural and institutional changes are related to technology generation. Much of the technology produced by public and private sector institutions is designed to enable productivity gains through structural change.

The regional pattern of gains is thus related to investments in technology enhancing activities (research, extension, and schooling) and to geographic diffusion or transfer of produced technology. Previous work on productivity change in U.S. agriculture (Evenson 1982) has utilized the geo-climate region specification depicted in Figure 1. This figure defines 16 regions and 34 sub-regions based on soil and related classifications in the 1957 Yearbook of Agriculture. It is thus a useful exercise to calculate growth rates for these 16 regions by proportionate weighting of state indexes. This exercise is reported in Table 2.

The rates of growth reported in Table 2 are somewhat more regular than are the state indexes. As expected, they show the Mississippi Delta to have outpaced other regions in most periods. Regions 3 and 13 rank lowest in part because of poor performances during the 1970s.

Table 3 reports comparisons of the average annual growth rate over the 1950-82 period of our state output, input and TFP series aggregated to a regional level and the USDA regional series. As can be seen, at the aggregate U.S. level, our state series has effectively the same TFP growth rate as the USDA series. The state output and input series both grow faster than the USDA series largely because of the treatment of feed fed on farms as both an output and an input in the state series. There are, however, some differences at the regional level in the two series.

Table 4 reports a comparison by region of the state Divisia TFP index growth (aggregated to regions), the state TFP index computed using a Laspeyres formula and the USDA index. Average growth rates by period of 3 years moving averages are reported as well as an estimated

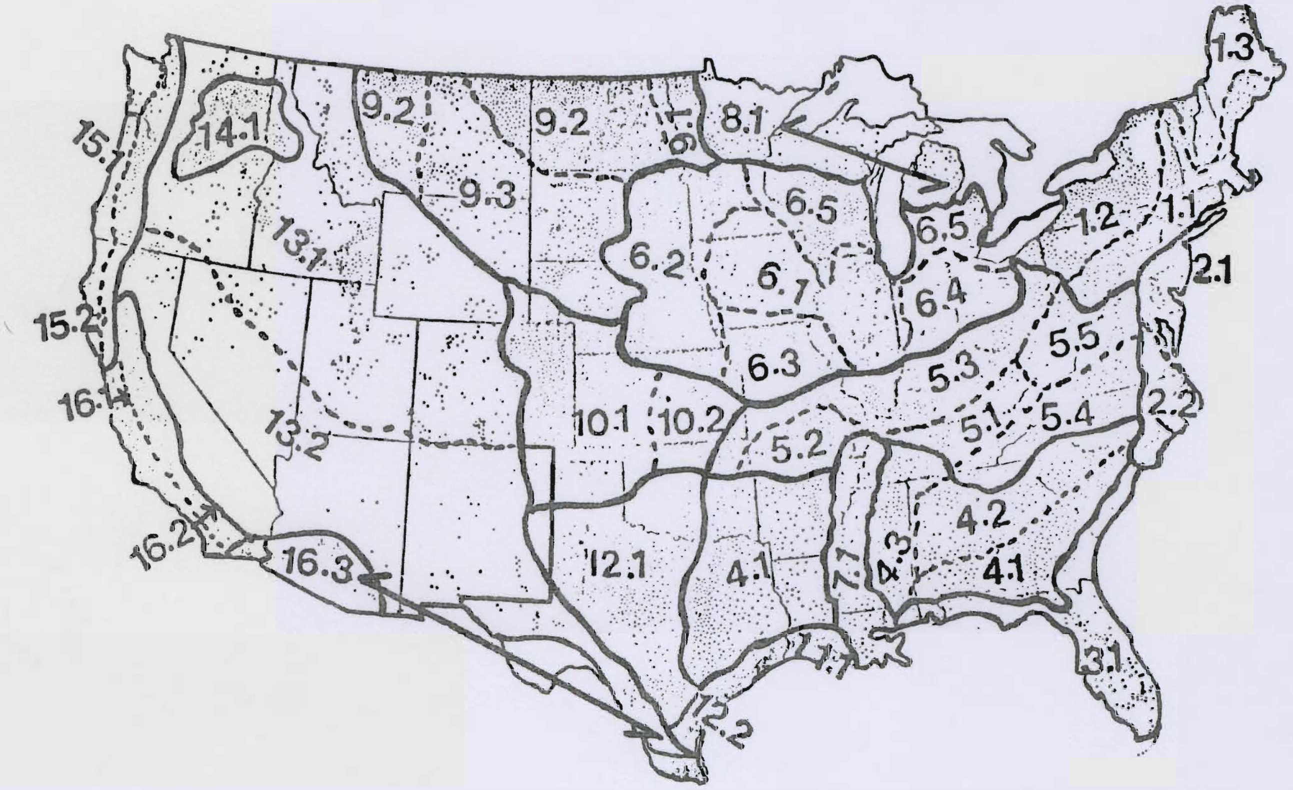
TABLE 1: Total Factor Productivity Growth by State for the 1950's, 60's, 70's, 80's and Entire Period

Northeast Region	1950-59	1960-69	1970-79	1980-82	1950-82
New York	.010	.017	-.004	.022	.009
New Jersey	.025	.022	-.033	.056	.009
Pennsylvania	.021	.027	.013	.034	.021
Delaware	.034	.031	.009	.028	.025
Maryland	.016	.030	.002	.040	.018
Regional Total	.021	.025	-.003	.036	.016
Lake States Region					
Michigan	.016	.022	.027	.047	.024
Minnesota	.024	.011	.025	.021	.020
Wisconsin	.020	.004	.024	.009	.015
Regional Total	.020	.012	.025	.026	.020
Corn Belt Region					
Ohio	.016	.011	.023	.034	.018
Indiana	.016	.023	.005	.060	.019
Illinois	.023	.011	.012	.020	.015
Iowa	.020	.006	.010	.010	.012
Missouri	.025	.004	.027	.018	.019
Regional Total	.020	.011	.015	.028	.017
Northern Plains Region					
North Dakota	.016	.038	.011	.069	.026
South Dakota	.016	.029	.010	.028	.019
Nebraska	.032	.022	.014	.010	.021
Kansas	.036	.029	.007	.011	.023
Regional Total	.025	.029	.010	.030	.022
Appalachian Region					
Virginia	.023	.028	.011	.023	.021
West Virginia	.024	.017	.023	-.003	.019
Kentucky	.011	.027	.011	.110	.025
North Carolina	.037	.034	.013	.042	.029
Tennessee	.021	.014	.018	.068	.022
Regional Total	.023	.024	.015	.048	.023
South Eastern Region					
South Carolina	.029	.036	.015	.041	.028
Georgia	.046	.039	.007	.034	.031
Florida	-.004	.015	.007	.021	.007
Alabama	.044	.026	.023	.039	.032
Regional Total	.029	.029	.013	.034	.025

TABLE 1 (continued)

	1950-59	1960-69	1970-79	1980-82	1950-82
Delta Region					
Mississippi	.049	.034	.032	.023	.037
Arkansas	.047	.026	.023	.029	.032
Louisiana	.009	.035	.026	.030	.024
Regional Total	.035	.032	.026	.027	.031
Southern Plains					
Oklahoma	.029	.015	.020	.032	.022
Texas	.019	.009	.017	.003	.014
Regional Total	.024	.012	.018	.018	.018
Mountain Region					
Montana	.023	.024	-.015	.079	.017
Idaho	.007	.029	.004	.030	.015
Wyoming	.024	.005	-.009	.024	.008
Colorado	.019	.012	.012	.018	.015
New Mexico	.016	.001	.002	.055	.011
Arizona	-.013	.012	.002	.012	.0002
Utah	.0002	.011	-.014	.059	.004
Nevada	-.020	.011	.001	.028	.0003
Regional Total	.007	.013	-.003	.038	.009
Pacific Region					
Washington	.025	.028	.017	.047	.025
Oregon	.025	.023	.016	.019	.021
California	.021	.022	.018	.004	.019
Regional Total	.023	.024	.017	.023	.022

FIGURE 1: U.S. Agricultural Geo-Climate Regions and Sub-Regions. (1 dot = 25,000 Acres Cropland, 1964)



1. Northeast Dry Region
2. Middle Atlantic Coastal Plain
3. Florida and Coastal Plain
4. Southern Uplands
5. East-Central Uplands
6. Midland Feed Region
7. Mississippi Delta
8. Northern Lake States
9. Northern Great Plains
10. Winter Wheat and
11. Coastal Prairies
12. Southern Plains
11. Coastal Prairies
12. Southern Plains
13. Grazing-Irrigation Region
14. Pacific Northwest Wheat Region
15. North Pacific Valleys
16. Dry Western Mild Winter Region

TABLE 2: Total Factor Productivity Growth by Geo-Climate Region for the 1950's, 60's, 70's, 80's, and for Entire Period

	Total Factor Productivity Growth				
Geo-Climate Region	1950-59	1960-69	1970-79	1980-82	1950-82
1. Northeast Dairy Region	.016	.022	-.0001	.031	.014
2. Middle Atlantic Coastal Region	.026	.028	.0003	.037	.020
3. Florida and Coastal Flatwoods	.004	.020	.008	.025	.012
4. Southern Uplands	.033	.026	.018	.028	.026
5. East-Central Uplands	.023	.019	.015	.045	.021
6. Midland Feed Region	.022	.015	.017	.024	.018
7. Mississippi Delta	.034	.031	.027	.030	.031
8. Northern Lake States	.020	.012	.025	.025	.020
9. Northern Great Plains	.020	.028	.009	.053	.022
10. Winter Wheat and Grazing Region	.030	.021	.009	.014	.020
11. Coastal Prairies	.015	.020	.020	.014	.018
12. Southern Plains	.022	.010	.017	.013	.016
13. Grazing - Irrigated Region	.012	.016	.002	.033	.012
14. Pacific Northwest Wheat Region	.021	.027	.014	.038	.022
15. North Pacific Valleys	.024	.024	.017	.022	.021
16. Dry Western Mild-Winter Region	.014	.018	.014	.006	.015

TABLE 3: Growth Rates 1950-81: TFP, Output, Inputs

Region	Northeast		Lake		Corn Belt		North Plains		Appalachian		Southeast	
	State	USDA	State	USDA	State	USDA	State	USDA	State	USDA	State	USDA
TFP	1.55	1.76	1.99	1.99	1.57	1.71	2.09	2.08	2.48	1.68	2.17	2.10
Output	.91	.66	1.97	1.90	1.97	2.05	2.82	2.38	1.90	1.07	2.95	2.08
Inputs	-.63	-1.10	-.02	-.09	.40	.34	.73	.30	-.58	-.61	.78	-.02

Region	Delta		South Plains		Mountain		Pacific		U.S.	
	State	USDA	State	USDA	State	USDA	State	USDA	State	USDA
TFP	3.12	2.37	1.89	1.78	1.19	1.84	2.04	2.03	1.97	1.92
Output	3.08	2.06	2.38	1.51	2.13	2.09	3.02	2.42	2.38	1.98
Inputs	-.04	-.31	.49	-.27	1.04	.25	.98	.39	.41	.06

TABLE 4: Compound Annual Growth Rates of TFP in Percent

REGION	Northeast			Lake States			Corn Belt		
PERIOD	STDV	STLSP	USDA	STDV	STLSP	USDA	STDV	STLSP	USDA
1950-60	1.97	2.31	2.62	2.24	2.05	2.42	2.04	1.81	2.22
1960-70	1.83	1.73	1.82	1.60	1.37	1.67	1.38	1.26	0.99
1970-81	0.91	0.73	0.92	2.12	1.73	1.88	1.32	1.00	1.91
1950-65	2.09	2.30	2.24	2.14	1.91	2.09	1.81	1.59	1.88
1965-81	1.04	0.87	1.31	1.85	1.54	1.89	1.34	1.12	1.55
1950-81	1.55	1.56	1.76	1.99	1.72	1.99	1.57	1.34	1.71
TREND 1950-81	1.48	1.45	1.66	1.92	1.66	1.90	1.42	1.25	1.62

REGION	Northern Plains			Appalachian			Southeast		
PERIOD	STDV	STLSP	USDA	STDV	STLSP	USDA	STDV	STLSP	USDA
1950-60	2.79	2.94	2.36	2.45	2.41	1.76	2.88	2.89	2.54
1960-70	2.42	2.19	2.30	2.57	2.43	1.64	2.61	2.86	1.71
1970-81	1.61	0.62	1.62	2.43	2.26	1.64	1.13	1.30	2.04
1950-65	2.58	2.52	2.30	2.57	2.45	1.69	3.01	2.96	2.25
1965-81	1.64	1.27	1.87	2.40	2.28	1.67	1.39	1.72	1.95
1950-81	2.09	1.88	2.08	2.48	2.36	1.68	2.17	2.32	2.10
TREND 1950-81	2.14	1.87	2.10	2.35	2.25	1.69	2.19	2.37	1.95

REGION	Delta			Southern Plains			Mountain		
PERIOD	STDV	STLSP	USDA	STDV	STLSP	USDA	STDV	STLSP	USDA
1950-60	4.30	4.15	3.30	3.54	2.96	2.70	0.92	.097	1.86
1960-70	3.04	3.15	2.17	0.57	0.63	0.04	1.70	1.34	2.03
1970-81	2.10	1.32	1.71	1.59	1.24	2.51	0.96	0.67	1.67
1950-65	4.20	4.08	3.25	2.74	2.30	2.14	1.12	0.97	1.90
1965-81	2.10	1.65	1.56	1.09	0.93	1.44	1.25	0.99	1.79
1950-81	3.12	2.82	2.37	1.89	1.60	1.78	1.19	0.98	1.84
TREND 1950-81	2.97	2.80	2.23	1.89	1.71	1.76	1.18	0.93	1.60

REGION	Pacific			U.S.		
PERIOD	STDV	STLSP	USDA	STDV	STLSP	USDA
1950-60	1.62	1.81	1.60	2.36	2.29	2.24
1960-70	2.45	2.21	1.77	1.98	1.90	1.61
1970-81	2.05	2.13	2.66	1.61	1.34	1.91
1950-65	1.59	1.61	1.76	2.26	2.14	2.08
1965-81	2.47	2.47	2.28	1.70	1.53	1.77
1950-81	2.04	2.05	2.03	1.97	1.83	1.92
TREND 1950-81	2.24	2.17	1.86	1.95	1.82	1.84

trend for the 1950-81 period.

These comparisons show that the state Divisia index is generally closer to the USDA Laspeyres index than the state Laspeyres index. This appears to indicate that the practice of shifting weights in the USDA index once each decade allows the USDA index to approximate a Divisia index. The state index when computed on a Laspeyres basis, i.e., with one set of weights (1950) diverges significantly from the Divisia index. It is lower in every period.

TABLE 5: Annual Compound Rates of Change of Labor Input: Divisia and USDA Series for 10 Regions and the U.S. 1950-81

Regions	N.E.	LAKE	CORN BELT	N. PLAINS	APPA.	S. EAST	DELTA	S. PLAINS	MOUNT.	PACIF.	U.S.
					(Percent)						
Div.	-3.2	-2.9	-3.3	-2.3	-4.6	-3.6	-5.4	-3.5	-1.7	-1.2	-3.2
USDA	-5.0	-4.5	-4.6	-3.2	-4.8	-4.2	-5.7	-4.5	-3.4	-2.0	-4.1
Diff.	-1.8	-1.6	-1.3	-0.9	-0.2	-0.6	-0.3	-1.0	-1.7	-0.8	-0.9

Regional comparisons show that all indexes generally rank the regions similarly with region 7 (Delta) ranking first, region 5 (Southeast) second and region 9 (Mountain) last.

The regions of closest agreement are the Lake States, the Northern Plains, and Southeast, the Southern Plains, and the Pacific. Inside these regions, our state results often show a wide range of TFP growth rates, indicating the regional level indexes will be misleading for some uses. For regions where we found that TFP increased significantly faster than the national average - Appalachian and Delta regions - our results show a faster rate of increase that the USDA.

One possible explanation for these differences is our use of a Divisia index where the USDA uses Laspeyres indexes. We calculated Laspeyres indexes using our series on quantities and prices with the USDA procedure of taking a base of the average of 3 years which is updated every 10 years. Where our results are close to the USDA, these Laspeyres indexes are usually further from the USDA figure. Where our indexes show a slower rate of TFP increase than the USDA, these Laspeyres indexes either equal our Divisia result (i.e., in the Northeast) or show an even greater difference from the USDA figure (i.e., in the Corn Belt and Mountain states). Where our results indicate faster rates of TFP increases, the Laspeyres indexes are slightly closer to the USDA figure for the Appalachian states and split the difference for the Delta states. In sum, of the five cases where our results differ markedly from the USDA, only in one case can the use of Divisia instead of Laspeyres indexes account for a significant share of the difference.

A second possible source of the differences for the 5 regions is the treatment of feed grains. We used a gross output, gross input procedure counting all grain produced as output and all grain feed as input. The USDA attempts to use a net output, net input procedure with feed grains, counting as an input only the value added by commercial processors of feed concentrates. Thus our procedures produces a faster rate of output and input increase than the USDA. (See Table 3.) One would expect the USDA procedure to distort the rate of TFP increase for feed surplus and feed deficit regions. We recalculated our indexes using as an approximation to the USDA approach. We used 10% of purchased feed to replace our series of all purchased and farm-fed feed. This changed our TFP series generally in the direction of diminishing the difference with the USDA series, but the change was less than 10% of the difference between our indexes and the USDA. Thus the different treatment of feed by itself does not account for the differences between our regional results and the USDA.

We also investigated a third possible source of the differences in regional results, the labor input series. The USDA uses manhours per acre of head of livestock times the number of acres planted or head of livestock raised. The manhours per unit are based on benchmarks which are grossed up 15% for general farm overhead labor. Our procedure uses the SRS surveys of actual farm labor usage with adjustments to allow for the switch from monthly to quarterly surveys. Table 5 gives the compound annual rates of change in labor input for the 10 regions and the U.S. used by the USDA and our series. Both series show a sharp fall in labor input over the 1950-81 period (calculated from 3 year moving averages). However, the USDA series shows a much faster rate of decrease in labor input for every region and the country as a whole. The national differences in the compound rates of decrease is 0.9% per year. For the regions where we found faster TFP growth (the Appalachian and Delta regions) the difference in rates of labor input change is only 0.2 or 0.3 percent while for the regions where we found slower TFP increase (Northeast, Corn Belt, and Mountain states) the difference in labor input growth rates runs from 1.3 - 1.8% per year. Thus it would appear the difference in the labor input series could account for much of the discrepancy in cases where we found slower regional TFP growth than the USDA, but not where we found faster regional TFP growth.

IV. CONCLUDING COMMENTS

Productivity measurement is a useful exercise. A number of insights into national and regional issues can be obtained from carefully measured and computed productivity indexes. In this paper we report total factor productivity indexes at the state level and compare them with USDA indexes. We follow some procedures generally regarded to be superior to those used by the USDA (Gardner report). Our indexes have some limitations because of the state data base.

We believe them to be useful in two broad senses. First, on the whole, these indexes tend to support and verify the reported USDA indexes. We do not find major differences in aggregate growth rates between state and USDA indexes. The USDA shifting of weights each ten years produces a result not far from the Divisia result. Our results do not, however, support the failure of the USDA to change its procedures along the lines suggested by the 1980 AAEA Task Force report. Clearly the USDA has been remiss in not responding to that report.

The second use for the state indexes is in further decomposition analysis. In this regard, they are much richer than more aggregated indexes because they enable the analyst to take advantage of state and geo-climate regional differences in investments and other factors to analyze determinants of productivity change. Appropriate statistical procedures will enable this analysis even in the presence of errors of measurement. In the long-run, we believe that this second use will be the more important.

FOOTNOTES

[1] See the AAEA Task Force Report on Measuring Agricultural Productivity (The Gardner Report), ESCS Technical Bulletin No. 1614, February 1980.

[2] Landau and Evenson (1973) report a state series. This unpublished work in summarized in Evenson 1982.

[3] The Evenson, Waggoner, Ruttan 1979 paper summarizes statistical productivity decomposition studies for early periods as well as for the 1949-71 period.

[4] See the discussion of index numbers and functional forms.

REFERENCES

AAEA Task Force Report on Measuring Agricultural Productivity (The Gardner Report), ESCS Technical Bulletin 1614, February 1980.

Antle, J. and Susan Capalbo, Measuring U.S. Agricultural Productivity, Washington, D.C.: Resources for the Future, 1987.

Evenson, R.E. "Agriculture," Ch. 5 in Governent and Technical Progress, ed. R.R. Nelson, New York: Pergamon Press, 1982.

Evenson, R.E., V.W. Ruttan and P. Waggoner. "Economic Benefits from Research: An Example from Agriculture," Science 205 (14 September, 1979).

Huffman, Wallace. "Agricultural Productivity in a Multiple-Output Framework: An Econometric Methodology for Disaggregating Methods for Measurement of Agricultural Productivity," Economic Growth Center Discussion Paper, Yale University, 1984.

Landau, D. and R.E. Evenson. "Productivity Change in U.S. Agriculture: Some Further Computations," unpublished manuscript, Economic Growth Center, Yale University, 1973.

U.S. Department of Agriculture. Agricultural Handbook, No. 365 (1970).

U.S. Department of Agriculture. Changes in Farm Production and Efficiency, Technical Bulletin, ERS, annual.

U.S. Department of Agriculture. Agricultural Handbook, No. 365 (1970).

U.S. Department of Agriculture. Farm Labor, various issues.

U.S. Department of Agriculture. Yearbook of Agriculture, 1957.

APPENDIX I

CONSTRUCTION OF THE 1949-1982 STATE-LEVEL DATA SET FOR U.S. AGRICULTURE

INTRODUCTION

This appendix describes the construction of the 1949-1982 state-level data set. We have commented on some of the deficiencies of the approaches we used; other will certainly be obvious to the reader.

I. INPUTS

Labor

The labor variable is an estimate of the manhours of labor input to agricultural production. It includes both hired labor and unpaid operator and family labor.

Hired Labor

Our source for hired labor was the expenditure on labor (EXPLABOR) published in the production expenditures series in State Farm Income and Balance Sheet Statistics (formerly State Farm Income Statistics and Farm Income Situation, State Estimates). This figure includes cash wages, non-cash perquisites, and payroll taxes. To convert dollar expenditures to labor manhours we used the hourly wage paid to employees working for cash wages only (WAGE) published in Farm Labor.[1] Typically, workers who receive some combination of room and board and other non-cash perquisites receive a lower cash wage. We assumed that the differential in cash wage rates equaled the cash value of such perquisites. Consequently it was appropriate to retain the value of perquisites in the expenditure figure, prior to dividing EXPLABOR by WAGE to obtain an estimate of manhours of hired labor. However, retaining payroll taxes in the total wage bill would lead to an overstatement of manhours, since such taxes were not included in WAGE; thus we sought to remove them prior to dividing expenditures by the wage rate. From the Social Security Bulletin we obtained the percentage of wages that employers were required by law to contribute to social security (SOC). We reduced total expenditures on hired labor by this percentage (EXPLAB2 = EXPLABOR(1-SOC) to obtain the portion of the wage bill that went to workers. We then divided EXPLAB2 by WAGE to obtain an estimate of manhours (HRD2).

This procedure creates two sources of measurement error. First, we have overstated social security contributions by including non-cash perquisites in the wage base and by assuming that all farm workers were covered by social security over the entire sample period. However, our second measurement error is to neglect other payroll taxes besides social security contributions, thus understating the sum diverted to the federal government. The two errors work in off-setting directions, but the extension of social security, workman's compensation, and other state-secured benefits to more and more farmworkers over time suggests that in early years we are apt to be overcorrecting EXPLABOR for the payroll tax component, even if the errors are nearly off-setting in a later part of the period.

Unpaid Operator and Family Labor

State-level estimates of unpaid operator and other family labor used on farms have been published by the USDA for 1965-1980 in Farm Labor. These estimates are based on a mail survey conducted monthly prior to 1974 and quarterly from 1974 to 1980. After a one-year hiatus the survey was resumed in 1982 on a much more limited basis; conducted once a year, in mid-summer. The respondents were asked to report, for the week prior to the receipt of the survey, the number of persons employed on the farm in each of the following categories--operator, other unpaid family, and hired--as well as the average number of hours worked by a person in each category. Published results were not the raw sample figures, but projections of state-wide totals for workers and hours based on sample information. At the time the survey was converted from monthly to quarterly, the sampling technique was put on a probability frame basis. Presumably the procedure for converting sample responses to state-wide estimates was put on a sounder footing by using the probability frame.

To make use of this data we had to solve a number of problems: (1) converting estimates for 12 (or 4) weeks of the year to estimates of annual operator and family labor input; (2) smoothing discontinuities in the series created by the change in sampling procedure in 1974; (3) extrapolating data to the missing years, 1949-1964 and 1981-82.

Problem (1). For 1965-1973 we computed total family (including operator) hours per month as the number of family workers times the average hours worked by a family worker times 4.3 (grossing up the observation for a single week to a 'monthly' total). Thus we assumed the week observed was characteristic of the 4.3 weeks around it. We obtained an annual figure (FAM) by summing the twelve 'monthly' totals. For 1974-1980 we had only one observation per quarter to work with. The assumption that a single week is characteristic of the entire quarter in which it appears is more problematic than the assumption that it is representative of its month. It seems likely that such an assumption would create cross-sectional biases stemming from the fact that all states were sampled during the same calendar week rather than at the same point in their crop year. Thus an early-April observation is likely to show more agricultural activity and a higher labor input in southern states than in northern states because planting gets underway earlier there, and should not be taken as an indication that labor input is higher in the south by the same proportion throughout the spring. To avoid creating such a bias, we took a set of intermediate steps to derive annual estimates from the four quarterly observations. For example, we took the ratio of all January observations on workers and hours to the sum of the January, February, and March observations for the 1965-1973 period. Then for 1974-1980, when only the January observation was available, we multiplied it by this ratio, hoping by this procedure to capture the extent to which the January observation was representative of the winter quarter in each state. We proceeded in a like way for the April, July, and October observations, multiplied the results by factors of 4.3 and 13 (to convert to quarters) and added the four quarters to obtain the annual total (FAM).

Problem (2). The change in sampling methods in 1974 did indeed introduce discontinuities in the reported series. For 1974 the USDA reported estimates based on both the old and new sampling methods, and in nearly every state there was a sizeable drop in unpaid manhours calculated from the new figures. We spliced together the two parts of the series by lowering the earlier period numbers by the amount of the discontinuity at 1974 (SHIFT), on the assumption that the sampling procedure during the latter period was better. However, rather than taking the actual difference between the two 1974 figures, we used the difference between the 1974-fitted values for each sub-period of manhours regressed on time. We used fitted instead of actual values because the latter might be unduly influenced by large, one-time measurement error, while the difference between fitted values presumably better reflected the extent to which the observations in the latter period were systematically lower than those in the earlier period. The regressions were run on each state separately.

Problem (3). To extrapolate the series to 1981 and 1982 we used the intercept and slope terms from the regression of the 1974-1980 observations on time to predict values for 1981 and 1982. To extrapolate the series backwards to pre-1965, a different approach was taken due to the availability of some additional data for those years which enabled us to put the extrapolations on a surer basis. During 1949-1964 farm labor surveys were taken on the same monthly schedule as in the 1965-1973 period; however, respondents were asked only for the number of workers of each type, not the average hours worked. Still, this provided a basis for extrapolating the manhours series backwards. We averaged the number of hours worked by a family member per week over the whole year, for the period 1965-1967. We assumed that this average also characterized the years 1949-1964.[2] Our extrapolation was therefore simply to take the annual average number of family workers (MFW) times the 1965-1967 average hours per week (MFH) times 52. Like the estimates of manhours for 1965-1973, this figure was lowered by the difference between 1974 fitted values to splice together the two parts of the sample.

The estimate of unpaid family and operator labor arrived at by these procedures (FAM2) was added to the estimate of hired labor (HRD2) to give an estimate of total manhours (LABORN).

Seed

Expenditure on seed is published yearly in State Farm Income Statistics (EXPSEED). Prices of individual seed varieties are published in Agricultural Prices. The only available index of seed prices is a national index also published in Agricultural Prices. Because of the varying composition of output across states, we decided it would not be appropriate to use the national index at the state level. This left us with two problems: (1) determining an appropriate price index; (2) determining the quantity of seed used at the state level. We consider these problems in reverse order.

The Quantity of Seed Used

We constructed the quantity of seed used (SEED) as the product of acreage planted times seeding rates for the following crops: winter wheat, spring wheat, durham wheat, corn, oats, barley, sorghum, rice, potatoes, soybeans, dry edible beans, cotton, peanuts, and hay. Seeding rates for each state for 1956 and 1982 were taken from Agricultural Statistics for all crops and hay. We assumed any changes in rates were evenly distributed over time and so estimated seeding rates for the years between 1956 and 1982 as simple linear interpolations. The estimated annual changes were extrapolated backwards to the years 1949-1955. The estimate of seed use is associated with the year in which the crop was harvested; thus, winter wheat seed use for 1981 is the quantity of seed planted in 1980 for the crop harvested in early summer of 1981.

No seeding rate is published for hay. Since the value of hay seed sold in many states is on the order of 10% of EXPSEED, we decided it was too large an item to ignore and arrived at a pseudo-seeding rate as follows. We took national production of alfalfa seed, less exports, as alfalfa seed available for domestic use. We then assumed that this seed was planted in the following year. The ratio of this figure to all alfalfa acres harvested nationwide gave us a national alfalfa "seeding rate." We used harvested acreage because planted acreage was unavailable. Thus the ratio obtained is not strictly speaking a seeding rate, but a "disappearance per harvested acre," or pseudo-seeding rate. To obtain estimates of hay seed used on the state level, we multiplied the national pseudo-seeding rate times harvested hay acreage (of all varieties) in each state. Thus we were ignoring differences in seeding rates over different hay varieties and different regions. We also implicitly assumed a constant ratio of harvested to planted hay acreage across states.

We converted all units to millions of pounds and summed to obtain total seed use. Aside from difficulties already noted, this procedure was subject to error arising from the omission of some crops: tree and bulb crops, rye, sunflowers, flax. This biases SEED downward.

Seed Price

Rather than constructing an index of seed prices as a quantity-weighted average of prices of individual varieties, we took the more expedient course of defining the price of seed as the total value of seed used (VSEED) divided by SEED. VSEED is not the same as EXPSEED since some seed is taken out of stocks from previous years' production. Estimates of wheat, rice, soybeans, peanuts, dried beans, and potatoes used as seed on the farms where they were grown have been published by the USDA in its Field Crops Production, Disposition, and Value series. Estimates of corn, sorghum, oats, and barley used either for feed or seed have been published in the same source. However, due to missing observations and the costs of data collection, we did not use this data exactly as we found it.

We assumed all feed grains used on the farm where grown were used as feed. Thus the value of seed for corn, sorghum, oats and barley is assumed to be wholly included in EXPSEED. To the extent this is untrue, VSEED is biased downward.

We used published figures when available for wheat and soybeans used as seed, and extrapolated to years of missing observations. (See the discussion under FEED for details of the extrapolation procedure.)

Like wheat and soybeans, farm use of peanuts, beans, potatoes, and rice for seed were published through 1974. Due to the costs of data collection, we used the published figures for 1949, 1954, 1959, 1964, 1969, and 1974 only. We took the ratio of these quantities to total seed used in the following year and assumed that any changes in these ratios occurred evenly over time. That is, we computed the ratio of farm use for seed/total seed required for 1950, 1955, 1960, 1965, 1970, and 1975 and made a linear interpolation of this ratio over the intervening years. For 1949 we used the 1950 ratio; for all years after 1975, the 1975 ratio. We then applied this ratio in each year to total seed required for the crop in question, giving us an estimate of the total amount of seed that was not purchased. We then evaluated non-purchased seed at the season average price for the year in which it was applied as an input. Moreover, we corrected EXPSEED, which is expressed on a calendar-year basis, for the value of winter wheat seed, subtracting seed used in the current year for next year's crop, and adding seed used in the previous year for the current crop. The corrected measure is denoted as EXPSEEDC. We then obtained VSEED as

$$VSEED = EXPSEEDC + VPESEED + VPOSEED + VRISEED + VWHSEED + VSYSEED$$

where VPESEED through VSYSEED are the values of non-purchased seed, determined as indicated above. Then PSEED = VSEED/SEED.

As noted above, both VSEED and SEED are probably understated. To some extent these errors are offsetting when it comes to estimating PSEED.

Land and Rent

Land input was measured as land in farms (LAND). This is the sum of all types of land. The data source for all years except 1981 and 1982 was Farm Real Estate Market Developments. For the latter two years the source was Agricultural Statistics, 1982.

The service flow from land was assumed to be a constant proportion of the quantity of land in farms. (The proportional constant washes out of the calculation of the relative change in service flow from one year to the next; hence it is immaterial what its value is taken to be.) To obtain a value for this service flow, we used data on rents. Series on rents are not complete, however. For the entire period of interest, 1949-1982, the USDA compiled a series of the cash rent in dollars per acre paid on farms rented for cash. The series covered all states east of the Mississippi, plus Minnesota and North and South Dakota. In addition, Nebraska was covered through 1966, Kansas through 1975, and Texas through 1966. The series was discontinued for New York, West Virginia, Florida, Louisiana, and Oklahoma beginning with 1982. The series was based on a mail-survey of crop reporters in which respondents were asked to report the going rental value for farmland in their locality. They need not themselves have been party to a rental agreement.

For western states, separate series were complied on the rent paid on dryland, irrigated land, and grazing land. This series began in 1960. Not all western states were covered in every category. In addition to rent paid, respondents were asked for the value of land rented, permitting calculation of a third series, ratio of rent to value. This was true of the eastern as well as all three western series.

Data on all series from 1960-1979 was published in "A Comparison of Cash Rents and Land Values for Selected U.S. Farming Regions," John P. Doll and Richard Widdows, NED Staff Report No. AGES820415, April, 1982. Unpublished data for other years was furnished by the Economic Research Service. Different problems arose for eastern and western data. We consider them separately.

The East

To use the cash rent series as a measure of the service flow from land, statewide, we had to make two assumptions:

(1) The rented farms which survey respondents took note of were representative of the locality with respect to the quality of land and the composition of farms (cropland versus

pasture).

(2) The rent was a return to land per se and contained little or no rent for service structures or dwellings.

For West Virginia, Florida, Oklahoma, Louisiana, and New York, missing values in the USDA series were replaced with extrapolations based on the rate of change of neighboring states. Kansas observations after 1966 were missing and were imputed using changes in the ratio of rent to value in Missouri (see below).

The West

The problems were:

1. There were no data before 1960.
2. There were separate series for cash rent for dryland, grazing land, and irrigated land, but no single cash rent series.
3. There were missing values for some states in some years.
4. The grazing land rents were unstable, with large jumps between some years, probably due to smallness of the sample.
5. Differences between rents in neighboring states seemed implausible. They were probably not indicators of the average difference in quality, but rather reflected the unrepresentativeness of the samples in one or more states.

We took the following steps:

1. Missing values were interpolated as simple averages of neighboring values.
2. Grazing land rents which deviated by more than 100% from observations in the nearest two years were dropped and replaced by the closer of the surrounding values.
3. Regional grazing land rents were computed as simple averages of the rents for the states in that region. The regions were the Pacific Northwest (Washington, Oregon, Idaho), Mountain States (Montana, Wyoming, Colorado, Utah), Southwest (Arizona, New Mexico). A revised state rent was then computed as 1/3 the rent for that state plus 2/3 the rent for the region in which the state was located. This smoothed differences across states, addressing problem 5 above. No smoothing was applied to grazing rents in California, Texas, or Nebraska.
4. From the Agricultural Censuses the number of acres planted to crops and the number of acres used for range or pasture were obtained. From cropland the number of acres irrigated was separated. Straight-line interpolation was used to obtain values for intercensal years. The share of each type of land use in total land was computed.
5. Average cash rent on farm land was obtained as the sum of the cash rents on grazing land, dryland, and irrigated land, weighted by the shares computed in the preceding step.
6. For the years before 1960, cash rent was extrapolated based on the average ratio of rent to per-acre land value during 1960-1965, for each state.
7. For the years 1980-1982, a similar extrapolation was based on the ratio of rents to land value from 1975-1979. The rents used for this step and the preceding step were the average rents computed in step 5. The land value was the average value of an acre, as reported in Farm Real Estate Market Developments.

In addition, due to the peculiarities in the treatment of some states, the following measures were taken:

1. All Nevada observations were missing. Cash rents for Nevada were computed as the average of rents to value per acre for New Mexico and Utah, times the value of an acre of farmland for Nevada, in all years.
2. Nebraska was handled as an eastern state from 1949-1966, and a western state thereafter.
3. Observations for Texas were missing from 1949-1966, and were computed as the Oklahoma ratio of rent to value, times Texas value per acre, times the average ratio of the Oklahoma rent/value to the Texas rent/value for 1967-1969.
4. Kansas observations after 1966 were missing and were computed as Missouri ratio of rent to value times Kansas value per acre, times the average ratio of the Missouri rent/value to

the Kansas rent/value for 1963-1966.

Capital

There are two capital categories. The first is based on expenditures on operation and repair of machinery and buildings, which may be thought of as a variable expense. The second is a measure of the quasi-fixed factor, capital, consisting of machinery and service structures. The input to production from this quasi-fixed factor is its service flow.

1. Repair and operation of machinery and buildings.

Expenditures on this item (EXPCAP) are reported in the State Income series. Repair of operators' dwellings is excluded. We divided this dollar figure by an index of the 'price' of operation and repair to convert it to real terms. This price was based on two indices prepared by the USDA at the national level and published in Agricultural Prices: the index of the price of farm and motor supplies (IFM), and the index of the price of building and fencing supplies (IBF). IFM was not available prior to 1965. In earlier years the same groups of inputs were handled in two separate series: the price of machinery supplies (IMS), and the price of farm supplies (IFS). To splice together the earlier indices with IFM, and to weight the various components in an overall index of the cost of operating and repairing capital items, we used the weight given to each index in the 1958 composite index of prices paid by farmers for commodities and services, interest, taxes, and wage rates. These weights were:

IMS	3.5%
IFS	2.8%
IBF	2.9%

Adding the first two gave us

IFM 6.3%

for the 1965-82 period. We extrapolated IFM to the pre-1965 period by computing the percentage change in IMS and IFS relative to their 1965 values, weighting the two as follows -- % change in IMS x (35/63) + % change in IFS x (28/63)--and multiplying the result by IFM for 1965. We then computed an index of the costs of operation and repair of capital items (PCAPOP) for the whole period as IFM x (63/92) + IBF x (29/92).

Operation and repair in real terms was computed as expenditures (EXPCAP)/(PCAPOP) = CAPOP.

2. The stock of capital was based on unpublished USDA figures giving depreciation of various capital items annually at the state level. They are depreciation on service structures (SERDEP), trucks (TKDEP), tractors (TRDEP), automobiles (AUDEP), and other equipment (EQDEP). All depreciation is calculated at current replacement cost. Only the share of truck and automobile depreciation corresponding to farm (as opposed to household) use is included.

The USDA arrives at state depreciation figures by allocating national depreciation across states according to various criteria. The national depreciation figures themselves are computed on a straight-line basis from national estimates of the value of the capital in each category. We took the straight-line depreciation percentages and divided them into the state depreciation figures to obtain estimates at the state level of the stock of capital in each category. That is, we computed

value of automobiles (VAU) = AUDEP/.22
value of trucks (VTK) = TKDEP/.21
value of tractors (VTR) = TRDEP/.12
value of other equipment (VEQ) = EQDEP/.14

where .22, .21, .12, and .14 are the USDA's depreciation rates on automobiles, trucks, tractors, and other equipment, respectively.

The depreciation rate on service structures has not been constant over time. We computed the national rate (SDRATE) as the national service structure depreciation divided by the national value of service structures, published in the Farm Balance Sheet statistical series. We then used this estimate to obtain the value of service structures at the state level as VSER = SERDEP/SDRATE.

We estimated the nominal service flow from these capital items as depreciation plus a fixed percentage (.04) of their current value at replacement cost. 4% was used as a proxy for farmers' view of the long-term interest rate to which the marginal product of capital should correspond. That is, defining

FARMDEP = AUDEP + TKDEP + TRDEP + EQDEP + SERDEP
VMACH = VAU + VTK + VTR + VEQ

we obtained the value of the service flow from capital as

VCAPSER = FARMDEP + .04 (VMACH + VSER).

We converted this to real terms using the USDA national indices on prices paid for automobiles and trucks (IAU), tractors (ITR), farm equipment (IMA) and building and fencing supplies (IBF). IAU was not available for the years before 1965. In the earlier period, trucks, automobiles and tractors were treated together in IMV, an index of the prices of motor vehicles. Examination of the separate series in the post-65 period showed they moved quite similarly until the last few years. We assumed therefore that they moved similarly in the earlier period as well and used the single series IMV to deflate VTR, VTK, and VAU pre-1965. Two different series were published for farm machinery items not covered in the motor vehicle indices. One of these was discontinued in the 1960's, replaced by what is now called the index of prices paid for other machinery and implements. Despite a change in some of the items covered in the two series, we took them to be measures of the same things. This approach seems reasonable since the two had very similar values during the overlapping years in which both were published:

	old series	new series	
1965	426	424	(1914=100)
1966	442	437	

The real service flow from the capital stock was then computed as

= (AUDEP + .04 VAU)/IAU
+ (TRDEP + .04 VTR)/ITR
+ (TKDEP + .04 VTK)/ITK
+ (EQDEP + .04 VEQ)/IMA
+ (SERDEP + .04 VSER)/IBF.

In this calculation, as in previous steps, all indices were converted to 1977=100 to ensure consistency.

Feed

There are three classes of feed inputs: (1) purchased, commercially-prepared feeds; (2) harvested grain, soybeans, and hay; (3) forage and silage. The second class can be subdivided into grain, etc. that is (2a) purchased from another farm and (2b) fed to animals on the farm where it was grown. For brevity, we refer to the latter as "farmfed" output.

Discussion of our procedures is facilitated by regrouping these classes into two: purchased feed inputs and non-purchased feed inputs.

Purchased Feed

Production Expenditures published in the State Farm Income series include expenditures on feed (EXPFEED). These expenditures were for items in classes (1) and (2a) above.

To convert this measure of value to a measure of quantity, we divided by the price of 16% protein dairy feed (PFEED) observed in June for each state as reported in Agricultural Prices. Occasionally this variable was not available for some states, in which cases we used observations from a neighboring state. We then obtained FEED = EXPFEED/PFEED.

Non-Purchased Feed

Class (2b): Harvested grain, soybeans and hay fed to animals on the farms where grown (farmfed).

1. Data on hay production were unavailable. USDA estimates of hay sales in each state (HAS) were available. We assumed all sales were intrastate. HAS was divided by the state price of hay and counted as an output, while HAS on the input side is included in EXPFEED. Farmfed hay was counted neither as an output nor as an input. (See remarks below on silage and forage.)

2. From 1949-1980 the USDA published estimates on wheat, soybeans, and the four feed grains used on the farms where grown (in our notation WHUSED, SYUSED, COUSED, BAUSED, OAUSED, and SOUSED, respectively). From 1949-1974 the figures for wheat and soybeans were further broken down into use for feed (WHFEED, SYFEED) and use for seed (WHSEED, SYSEED). This left us with the problem of filling in missing values.

(i) We assumed all feed grains used on farms were fed to animals.

(ii) We extrapolated the xxUSED series to 1981 and 1982 by computing the average ratio of xxUSED to xx production over 1978-1980 and applying this ratio to 1981 and 1982 production.

(iii) For soybeans and wheat, we made a second extrapolation extending the breakdown of total use into seed and feed to the post-1974 period.

For soybeans, we computed the ratio of SYSEED to SYUSED for 1969-1974, and applied this ratio of SYUSED in the years after 1974. We then computed SYFEED = SYUSED-SYSEED.

We attempted the same procedure for wheat. This gave implausible results, however, as the quantity of wheat used for feed is unstable, rising sharply when wheat prices fall near the price of corn, corrected for the difference in nutrient value. We therefore based our approach on the assumption that WHSEED is more likely to be a stable fraction of the total amount of seed required to plant the year's wheat crop, than the proportions of WHSEED and WHFEED in WHUSED are apt to be stable. Thus, we computed the ratio of WHSEED to total seed input for the current crop (WHSD) for 1969-73 and applied this ratio to WHSD for 1974-82 to extrapolate the WHSEED series. We then computed WHFEED for these years as the residual, WHUSED-WHSEED.

(iv) The next set of assumption concerned the timing of feeding. We assumed that 1/4 of the farmfed corn, sorghum, and soybeans were fed in the year of harvest (roughly October through December), and the remainder fed the following year. We made no attempt to measure stocks that might have been held over to later years.

For wheat, oats and barley, which are harvested in mid-year, we made a analogous assumption: half the farmfed grain was assigned to current year use and half to the following year.

(v) Farmfed grains and soybeans were valued at the season average price received by farmers for the crop being fed. Thus, 1978-crop corn fed to animals in 1978 was valued at the season average price for the 1978 crop, as was 1978-crop corn fed in 1979.

(vi) Lacking reliable series on the quantity and value of silage and forage, we ignored these input items. However, we also omitted them from the output side. Aside from the (minor) effect on the weights attaching to measured inputs and outputs, their omission from both sides will not affect measurement of total factor productivity. The same applies to unsold hay output.

Final estimates of feed quantities and prices were obtained by summing appropriately lagged or averaged WHFEED, SYFEED, COFEED, BAFEED, OAFEED, SOFEED. This quantity plus FEED = TOTFEED. Valuing the quantities as indicated under (v), we obtained their total value (in $ million) as VTOTFEED and divided by TOTFEED to obtain PTOTFEED.

All quantities were converted to millions of tons prior to summing.

Fertilizer

From Production Expenditures in the State Farm Income series we obtained calendar year expenditures on fertilizer (EXPFERT). There is considerable diversity among states in the breakdown of these expenditures among types of fertilizer. In consequence, there are differences in the appropriately weighted price to be used to convert dollar expenditures into a measure of the quantity of fertilizer. We assumed that this diversity is not nearly so great within production regions as across regions, however, and therefore proceeded to obtain an appropriate regional price as follows.

The USDA's Production and Efficiency Statistics published annual estimates of fertilizer use in ten major production regions (e.g., the Corn Belt, the Southeast) by major component--that is, how many million tons of nitrogen, potassium, and phosphate were used. We added these figures and divided the total into the regional subtotal of EXPFERT, obtaining a regional price per ton of chemical ingredient (PFERT). This is in effect a quantity-weighted index of fertilizer prices where the weights reflect the regional mix of nitrogen, potassium and phosphate in a 'representative' ton of fertilizer, as well as cost differences arising from the use of cheaper sources of nitrogen (e.g., anhydrous ammonia) in some regions compared to others.

Miscellaneous Inputs

Production Expenditures in State Farm Income include a catch-all item for miscellaneous inputs (EXPMISC). We divided EXPMISC by IPR, an index of prices paid for all production items, computed at the national level and published in Agricultural Prices, to obtain a measure of the quantity of miscellaneous inputs, MISC.

II. OUTPUTS

Price and quantity data for the following outputs are reported at the state level. Price is the season average price received by producers.

Cotton (CN)
Tobacco (TO)
Sugar cane (SC)
Sugar beets (SB)
Dry edible beans (DB)
Milk (MI)
Broilers (BR)
Turkeys (TU)
Eggs (EG)
Corn (CO)
Sorghum (SO)
Oats (OA)
Barley (BA)
Wheat (WH)
Rice (RI)
Apples (AP)
Grapes (GR)
Oranges (OR)
Grapefruit (GF)
Hay sold (HAS)
Cattle & calves (CC)

Hogs & pigs (HO)
Sheep & lambs (SL)
Soybeans (SY)
Peanuts (PE)
Cottonseed (CS)
Lettuce (LE)
Onions (ON)
Tomatoes (TM)
Potatoes (PO)
Other crops (OCR)
Other livestock products (OLP)
Other fruits (OFR)
Other vegetables (OVE)

Quantities

For most output categories, quantity is production as reported by the USDA. For crops, production is the harvest of that year.

Where inventories carried over from one year to the next are negligible relative to annual production, we constructed a measure of production as calendar year receipts from sales divided by the season average price. This was true of milk, eggs, broilers, and turkeys. We followed this procedure as well for oranges and grapefruits, and for the residual "other" categories. (See the discussion under prices.)

Since we used meat animal production as our measure of output, we dropped feeder livestock from the category of inputs. Production is in terms of pounds added=the weight of slaughtered animals less change in inventory (including net inshipment of feeder livestock). Since we are using a net rather than gross measure of output, it is appropriate to drop such inventory changes on the input side.

Prices

Prices are not reported for states where the output in question was not produced.

We sought a measure of expected price for the value weights in the output index. We used 1-year lagged prices as a proxy for expected prices for crops with well-defined growing seasons and meat animals with long gestation and feeding periods. We used current prices for outputs produced continuously through the year (dairy and poultry products) and for outputs whose main current production decisions concern harvest and marketing. The latter include tree and vine crops: apples, grapes, oranges and grapefruits. In the long run, of course, their output depends on farmers' expectations of the long-run "normal" price, but we did not attempt to approximate this.

The USDA has not always published a single season average price at the state level for crops where several varieties are grown. For tomatoes, onions, potatoes, and tobacco our price is a quantity-weighted average of the prices of the individual varieties when no such price was published.

Neither quantity nor price data per se were available for the "other" categories. We used dollar receipts data, divided by price indices, to obtain quantities of "other" outputs. The price indices used were

ILP = index of price of all livestock products
ICR = index of the price of all crops
IVE = index of the price of vegetables
IFR = index of price of fruits.

They are nationally-weighted price indices.

FOOTNOTES (Appendix I)

[1] No Wage data are available for 1981. We interpolated the 1981 wage as the simple average of the 1980 and 1982 values.

[2] This is probably false. The farmer's working day likely grew shorter over this period. However, the years for which we have data on both the number of workers and the average number of hours show that by far the biggest source of reduction in manhours has been the fall in the number of workers, not the number of hours. Inasmuch as we have a measure of the number of workers for 1949-1964, we have by far the most important component of variation in labor input over this period.

APPENDIX II

State TFP Indexes, 1949-82

by Region

NORTHEAST

YEAR	DELAWARE	MARYLAND	NEW JERSEY	NEW YORK	PENNSYLVANIA
1949	100.000	100.000	100.000	100.000	100.000
1950	115.646	103.596	114.101	104.719	102.506
1951	104.303	99.647	115.794	97.393	101.752
1952	95.902	97.653	104.505	100.645	102.291
1953	106.070	105.187	121.572	106.159	109.420
1954	106.364	102.356	110.825	101.854	112.358
1955	111.346	99.228	99.548	104.689	111.195
1956	131.935	113.403	125.799	108.821	118.530
1957	123.221	100.588	115.765	108.833	113.639
1958	137.457	118.791	126.901	110.647	125.320
1959	140.306	116.861	128.799	110.732	123.443
1960	145.780	125.092	136.193	113.681	130.566
1961	148.188	128.125	142.803	118.212	135.499
1962	144.588	123.964	146.025	118.587	134.764
1963	143.166	122.214	132.888	116.483	134.797
1964	145.815	149.905	137.410	122.629	141.044
1965	169.694	158.301	160.616	130.095	149.303
1966	151.055	135.964	158.320	128.692	144.548
1967	182.554	155.050	170.964	132.387	160.706
1968	169.930	150.694	165.462	128.917	152.743
1969	191.501	157.391	160.524	130.764	161.152
1970	181.220	155.382	170.100	132.887	158.887
1971	183.310	150.090	148.126	130.244	160.842
1972	180.397	150.249	135.738	121.557	153.942
1973	170.776	144.988	139.335	118.389	148.154
1974	174.631	143.727	157.504	117.326	151.523
1975	173.631	146.989	136.869	118.502	149.315
1976	196.309	158.768	140.514	118.482	171.065
1977	196.641	154.189	128.885	123.046	174.867
1978	221.179	172.632	124.125	129.018	182.545
1979	209.061	160.967	115.600	125.125	182.971
1980	183.133	153.441	122.859	130.713	177.018
1981	212.691	181.260	134.000	131.866	202.658
1982	227.499	181.726	136.629	133.646	202.920

LAKE STATES

YEAR	MICHIGAN	MINNESOTA	WISCONSIN
1949	100.000	100.000	100.000
1950	98.896	98.550	102.276
1951	97.657	99.171	100.556
1952	98.798	103.069	104.008
1953	104.213	104.335	107.791
1954	100.194	108.814	106.506
1955	104.197	113.984	109.964
1956	108.593	121.279	113.093
1957	106.234	120.363	114.656
1958	114.860	142.336	115.381
1959	117.513	127.098	121.620
1960	115.605	128.829	119.130
1961	123.688	132.360	127.700
1962	126.960	124.127	126.502
1963	128.448	137.490	130.142
1964	134.563	128.826	137.529
1965	138.026	133.839	143.348
1966	140.809	140.996	141.387
1967	144.677	142.669	146.106
1968	142.355	146.949	147.552
1969	146.406	141.912	125.988
1970	145.297	147.788	148.286
1971	152.032	158.293	152.565
1972	162.810	153.089	148.616
1973	154.277	165.967	145.079
1974	158.570	147.599	149.676
1975	180.370	152.000	150.362
1976	176.157	145.176	152.618
1977	190.939	185.635	167.437
1978	193.441	185.162	165.721
1979	191.249	182.112	160.542
1980	199.586	181.016	162.939
1981	206.487	195.410	166.919
1982	220.296	194.048	164.785

CORN BELT

YEAR	ILLINOIS	INDIANA	IOWA	MISSOURI	OHIO
1949	100.000	100.000	100.000	100.000	100.000
1950	97.045	99.007	101.280	101.901	97.773
1951	101.457	103.609	93.352	94.238	95.854
1952	103.125	100.408	109.813	101.585	101.892
1953	103.888	105.164	101.224	101.721	106.869
1954	102.818	108.018	108.777	100.674	109.699
1955	113.691	108.224	109.371	117.902	109.464
1956	124.978	114.882	109.690	121.614	111.160
1957	114.378	108.487	119.121	108.922	104.551
1958	123.606	111.827	117.744	118.806	112.529
1959	125.350	117.200	122.691	128.094	116.782
1960	124.136	122.131	116.804	123.305	120.537
1961	128.599	121.665	117.732	122.795	122.194
1962	127.593	127.092	115.052	120.929	126.945
1963	134.518	131.059	123.286	128.682	127.988
1964	129.521	122.957	124.010	124.100	126.772
1965	141.605	141.313	125.227	135.332	140.034
1966	128.347	128.931	128.892	129.550	138.026
1967	146.428	140.908	134.545	135.809	139.625
1968	135.820	142.835	130.909	144.831	150.639
1969	139.331	147.935	130.186	133.492	130.522
1970	125.457	139.783	128.708	136.953	147.659
1971	149.644	158.453	140.814	155.739	161.582
1972	142.587	146.086	135.465	147.744	150.477
1973	141.335	145.628	137.138	148.950	134.528
1974	121.080	122.768	121.966	135.194	136.541
1975	157.405	150.800	132.455	150.988	159.896
1976	142.064	159.524	128.522	146.790	164.746
1977	147.277	151.639	135.016	175.339	158.866
1978	148.828	157.757	147.489	166.763	156.908
1979	156.352	156.284	144.533	174.515	164.595
1980	142.922	157.537	146.604	157.879	164.803
1981	166.713	164.404	161.219	188.716	150.446
1982	165.870	187.240	148.923	184.415	182.320

NORTHERN PLAINS

YEAR	KANSAS	NORTH DAKOTA	NEBRASKA	SOUTH DAKOTA
1949	100.000	100.000	100.000	100.000
1950	110.581	112.302	113.150	103.629
1951	96.943	114.335	101.711	110.318
1952	129.440	98.332	117.279	105.512
1953	100.240	103.952	107.603	116.334
1954	111.448	99.110	108.842	115.112
1955	97.823	127.902	105.325	115.762
1956	102.386	131.468	103.150	109.680
1957	108.080	131.661	136.840	135.063
1958	158.750	144.651	141.924	135.632
1959	143.930	117.545	137.467	117.572
1960	161.826	130.969	140.724	141.375
1961	157.796	104.510	130.176	133.995
1962	150.096	152.377	134.139	136.065
1963	148.826	143.796	137.264	144.674
1964	154.234	150.130	142.511	142.769
1965	162.402	169.534	144.082	152.381
1966	162.146	161.246	162.045	154.229
1967	170.677	161.475	161.487	164.379
1968	180.542	173.997	159.697	166.014
1969	191.850	172.626	170.712	156.541
1970	188.272	153.833	164.086	151.558
1971	208.044	202.285	173.294	167.481
1972	206.725	182.166	170.430	167.532
1973	202.067	189.347	166.525	171.069
1974	182.458	172.682	156.609	165.267
1975	193.290	192.283	179.791	161.574
1976	190.774	196.651	171.812	136.848
1977	202.209	189.637	187.243	177.797
1978	188.608	211.172	189.608	173.474
1979	205.294	193.558	196.252	172.240
1980	187.452	186.567	181.079	169.319
1981	203.696	242.347	212.711	190.398
1982	212.337	237.860	202.229	187.422

APPALACHIAN

YEAR	KENTUCKY	NORTH CAROLINA	TENNESSEE	VIRGINIA	WEST VIRGINIA
1949	100.000	100.000	100.000	100.000	100.000
1950	93.208	106.598	96.082	107.883	96.574
1951	100.765	125.826	99.096	109.981	101.064
1952	97.989	123.475	100.955	109.210	102.496
1953	102.732	120.884	109.881	111.618	108.170
1954	109.655	124.292	101.265	114.590	121.229
1955	101.952	132.888	113.657	111.803	111.862
1956	114.276	150.396	106.794	130.133	122.741
1957	105.234	129.386	103.619	115.078	118.167
1958	104.964	144.016	111.356	127.737	123.286
1959	111.460	144.074	123.006	126.269	126.492
1960	111.156	154.265	119.033	132.204	127.183
1961	117.765	156.828	123.831	135.420	126.800
1962	127.324	167.574	125.000	140.110	127.535
1963	136.175	171.523	131.775	134.726	130.621
1964	125.742	184.261	134.175	149.615	141.042
1965	129.898	172.211	140.381	155.339	143.756
1966	130.907	178.315	128.730	145.858	132.938
1967	134.184	199.558	134.205	161.639	143.969
1968	120.528	186.810	137.199	158.555	144.336
1969	145.449	202.708	141.340	167.601	149.563
1970	141.400	212.057	139.645	169.570	145.278
1971	147.742	205.758	144.640	163.097	143.478
1972	151.387	214.000	141.618	166.396	143.247
1973	141.137	222.259	140.465	172.274	137.906
1974	159.125	218.072	137.760	175.164	146.915
1975	156.345	238.256	160.316	174.728	158.085
1976	174.645	240.215	163.613	180.187	162.036
1977	166.075	222.353	167.232	180.800	149.547
1978	161.339	266.123	166.594	195.253	180.434
1979	161.558	231.831	169.806	187.435	188.015
1980	182.643	263.952	166.470	176.858	181.169
1981	219.104	269.043	202.940	211.290	185.904
1982	224.540	263.155	208.319	200.781	186.321

SOUTHEAST

YEAR	ALABAMA	FLORIDA	GEORGIA	SOUTH CAROLINA
1949	100.000	100.000	100.000	100.000
1950	97.444	101.784	104.262	93.665
1951	109.241	98.191	119.684	130.950
1952	106.120	100.535	109.042	120.814
1953	130.729	97.351	128.638	130.431
1954	108.647	87.117	110.996	110.496
1955	149.133	98.588	140.697	132.441
1956	141.435	97.740	151.630	134.487
1957	135.623	94.495	139.405	123.953
1958	143.265	90.097	147.887	124.675
1959	155.801	95.812	158.889	133.247
1960	163.477	99.111	168.549	138.557
1961	160.652	104.369	176.596	142.962
1962	162.540	105.737	174.213	154.130
1963	182.411	104.864	192.237	157.832
1964	185.024	104.854	195.673	167.318
1965	198.327	104.807	207.861	177.643
1966	185.504	110.072	211.334	169.685
1967	189.659	117.313	240.774	193.212
1968	195.364	107.172	222.099	164.882
1969	202.806	111.564	233.935	190.825
1970	206.562	106.536	230.847	184.011
1971	220.947	112.868	252.417	199.289
1972	216.385	113.088	239.340	187.460
1973	213.357	104.860	227.327	190.600
1974	217.709	109.868	237.030	203.960
1975	244.650	125.756	239.723	215.620
1976	250.884	132.418	252.476	219.884
1977	240.408	123.100	215.455	198.605
1978	256.384	121.219	248.452	219.029
1979	256.392	119.575	250.708	220.680
1980	235.667	123.230	223.667	198.325
1981	294.399	125.256	265.167	246.125
1982	288.564	127.505	277.340	249.313

DELTA

YEAR	ARKANSAS	LOUISIANA	MISSISSIPPI
1949	100.000	100.000	100.000
1950	91.440	90.910	101.869
1951	93.835	100.927	110.182
1952	101.667	106.589	126.039
1953	112.360	115.069	145.103
1954	116.602	110.003	125.607
1955	133.730	114.349	158.538
1956	135.345	114.145	144.425
1957	123.238	101.740	131.012
1958	127.119	100.763	134.761
1959	160.287	109.831	163.632
1960	154.106	115.088	165.485
1961	159.953	117.875	175.799
1962	165.623	118.134	176.170
1963	169.303	133.452	205.894
1964	185.040	131.079	213.408
1965	190.918	134.326	221.676
1966	184.874	141.869	207.881
1967	184.665	153.161	216.509
1968	202.303	165.271	233.611
1969	207.824	156.635	229.337
1970	201.743	169.338	242.314
1971	206.040	163.962	243.093
1972	208.288	167.995	254.355
1973	207.143	151.471	242.562
1974	201.331	155.922	229.967
1975	236.113	175.477	246.794
1976	233.797	191.857	261.526
1977	251.663	202.553	292.938
1978	254.004	192.755	283.909
1979	260.374	198.939	317.305
1980	223.654	167.348	260.191
1981	283.306	199.212	313.727
1982	283.957	217.464	340.134

SOUTHERN PLAINS

YEAR	OKLAHOMA	TEXAS
1949	100.000	100.000
1950	88.090	86.172
1951	92.021	87.849
1952	103.464	91.110
1953	105.140	96.417
1954	105.593	100.986
1955	97.471	103.561
1956	106.094	100.955
1957	99.699	108.907
1958	136.122	119.713
1959	133.420	121.279
1960	154.913	127.646
1961	146.830	130.824
1962	126.144	124.301
1963	131.837	126.184
1964	146.450	130.879
1965	164.761	140.549
1966	149.385	131.222
1967	146.941	132.042
1968	155.707	139.485
1969	154.953	132.645
1970	155.382	139.625
1971	143.986	131.829
1972	154.003	138.953
1973	163.442	145.570
1974	162.157	138.395
1975	171.615	152.873
1976	170.633	157.616
1977	187.861	174.837
1978	165.554	150.546
1979	188.600	156.799
1980	187.170	138.978
1981	192.768	167.576
1982	207.798	158.308

MOUNTAIN

YEAR	ARIZONA	COLORADO	IDAHO	MONTANA	NEVADA	NEW MEXICO	UTAH	WYOMING
1949	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
1950	94.539	91.586	107.144	119.800	110.961	88.316	101.771	109.278
1951	107.853	91.484	93.310	118.579	109.883	93.883	105.864	111.671
1952	109.714	99.785	96.890	116.055	99.542	90.281	101.072	114.379
1953	108.627	98.686	104.648	134.526	109.941	95.923	107.110	114.040
1954	100.948	86.269	104.247	124.854	106.640	98.549	101.807	112.712
1955	89.951	84.921	107.168	146.497	103.875	92.648	104.158	111.335
1956	91.821	87.845	103.669	127.105	98.075	97.815	108.845	115.904
1957	93.179	108.845	110.459	128.708	97.110	99.930	109.049	127.845
1958	88.853	122.796	110.020	137.950	81.421	112.865	97.863	127.110
1959	87.886	120.688	107.255	125.445	81.995	117.120	100.248	126.767
1960	96.241	121.377	104.829	127.997	80.312	115.488	100.047	121.646
1961	96.506	119.331	113.653	112.076	74.672	119.985	99.925	118.210
1962	95.829	112.098	107.936	128.039	77.198	116.474	103.749	116.352
1963	95.065	112.379	116.062	137.587	79.634	116.978	101.077	128.879
1964	94.793	119.782	109.327	145.837	88.913	111.727	100.307	130.128
1965	99.772	119.335	125.481	150.441	89.628	117.941	99.986	131.778
1966	93.674	122.484	125.703	151.340	89.989	119.373	105.229	134.142
1967	93.572	125.373	134.665	148.674	82.318	120.572	114.527	140.208
1968	98.377	127.362	136.061	160.147	88.517	114.035	111.552	138.313
1969	98.838	136.628	142.882	158.807	91.975	118.006	111.659	133.216
1970	97.999	139.838	146.099	153.708	92.956	126.018	114.779	132.900
1971	94.876	137.983	148.543	158.095	101.709	118.311	109.640	139.389
1972	99.837	138.877	141.823	152.564	101.325	122.700	109.064	136.346
1973	94.445	144.343	135.785	145.311	104.570	125.313	112.100	128.360
1974	114.557	139.705	140.987	149.931	99.824	119.936	112.386	137.321
1975	101.399	150.598	146.767	171.590	100.300	123.021	105.523	131.530
1976	114.735	149.812	145.631	177.610	97.681	136.212	115.183	143.409
1977	109.714	151.379	139.919	155.724	97.722	132.875	114.452	138.510
1978	109.361	157.137	152.539	168.193	99.031	124.759	113.011	138.861
1979	97.276	154.522	148.808	136.629	92.910	120.431	96.705	121.200
1980	107.699	161.724	162.904	150.533	99.975	139.920	103.414	133.641
1981	112.397	164.022	168.012	177.063	103.696	135.480	118.374	139.846
1982	100.733	162.881	162.926	172.967	101.163	141.875	115.360	130.273

PACIFIC

YEAR	CALIFORNIA	OREGON	WASHINGTON
1949	100.000	100.000	100.000
1950	101.010	101.775	112.522
1951	110.423	102.213	98.198
1952	109.052	105.731	104.006
1953	106.482	113.900	113.716
1954	104.114	113.589	115.529
1955	113.500	118.086	109.411
1956	120.775	121.923	107.658
1957	115.265	123.073	126.143
1958	115.092	120.769	121.514
1959	123.499	128.129	127.772
1960	122.887	120.341	121.571
1961	117.366	120.564	120.638
1962	124.631	123.114	125.985
1963	116.557	123.277	133.373
1964	126.372	127.693	133.072
1965	123.698	140.789	143.678
1966	135.465	144.530	157.033
1967	139.423	152.107	164.067
1968	151.971	146.552	156.328
1969	153.516	160.913	169.591
1970	151.007	159.548	165.224
1971	154.294	160.083	172.740
1972	163.584	168.352	180.244
1973	162.684	157.880	181.712
1974	176.653	177.417	186.435
1975	193.793	178.511	216.482
1976	182.479	192.307	212.860
1977	192.230	181.263	202.547
1978	174.198	183.979	223.306
1979	183.904	188.507	201.415
1980	188.756	203.863	227.577
1981	188.051	209.258	235.365
1982	186.219	199.482	231.836

COST STRUCTURES, PRODUCTIVITIES AND THE DISTRIBUTION OF TECHNOLOGY BENEFITS AMONG PRODUCERS FOR MAJOR U.S. FIELD CROPS

Stephen C. Cooke and W. Burt Sundquist*

PURPOSE

The purpose of this paper is to estimate the cost structures and resource productivities involved in production of four major U.S. field crops and to estimate the distribution among producers of benefits from production related technology. These field crops include corn, soybeans, wheat and cotton grown in selected homogeneous soil and rainfall areas of the U.S. The cost structure of each commodity is estimated relative to a Cobb-Douglas cost function. Productivity is assessed across time, regions and size of enterprise. The distribution of technology benefits is determined by region and enterprise size for each commodity.

LITERATURE

This research is related by subject matter and analytical model to the works of Binswanger (1974), Browne and Christensen (1981) and Ray (1982). Each of these studies applies a translog cost functional form to U.S. aggregate agricultural data as a means of estimating such things as productivity, size economies, factor bias, elasticity of substitution and elasticity of demand. One problem these studies share is the very high level of aggregation of the data. Ray's concluding remarks speak directly to this point.

> ...we need to realize that our model with two outputs [crops and livestock] (although a step in the right direction) is not disaggregative enough...Ideally, this study should have used farm level behavioral data. Use of aggregate data here (as in all similar models using economy wide observations) introduces a measure of aggregation bias (p. 497).

A recent attempt to apply a translog cost function to farm level data was made by Hazilla and Kopp (1984). This study used USDA Firm Enterprise Data (FEDS) enterprise budgets published in 1974 and 1978 as the source of data on input prices and expenditure shares.

Hazilla and Kopp proceeded to construct cost functions in corn production for homogeneous soil and rainfall areas in the Corn Belt. They used these cost functions to estimate intertemporal and interspatial productivity. The Hazilla and Kopp approach represents a major step forward in estimating total factor productivity using farm level data that is sufficiently disaggregated to a single commodity grown in relatively homogeneous soil and rainfall areas. However, there are still a couple of problems associated with the Hazilla and Kopp approach that deserve attention. Hazilla and Kopp used the FEDS enterprise budgets as published without correcting for inconsistency in their construction between 1974 and 1978. Changes in the assumptions imbedded in the parameters in the budget generator used to construct these budgets provided a significant impact on expenditure shares. For example, the procedure for determining the opportunity cost of land changed significantly between years.

Further, Hazilla and Kopp assumed constant returns to size in corn production when estimating changes in productivity. Therefore it is possible that some or all of the intertemporal productivity gains may be accounted for by enterprises simply getting bigger and thereby using all inputs more efficiently. Such size economies, if they exist, represent

---

* Stephen C. Cooke is Assistant Professor, Department of Agricultural Economics, University of Idaho and formerly Research Associate, Department of Agricultural and Applied Economics, University of Minnesota. W. Burt Sundquist is Professor, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul.

"noise" when one is trying to estimate total factor productivity across time. Similarly intertemporal productivity changes represent "noise" in the estimation of size economies. Changes in relative prices presents a similar problem as well.

Chan and Mountain (1983) conclude

> ...some of the observed average productivity increases which we customarily attributed to the rate of technical progress can now be attributed to the increasing returns to scale inherent in the Canadian agricultural production process (p. 667).
>
> ...in a study set up to measure technical economies of size, the factor prices...should remain the same across farm size as long as a resource quality (productivity) remains constant (Jensen, 1982, p. 26).

OBJECTIVES

The objectives of this study are five in number. First, we construct a profile of the individual cost components for the selected commodity-region-size-time period situations considered. Second, we estimate the Cobb-Douglas cost function using the above cost component estimates as data. Third, we construct an index of total factor productivity by time, region and size for each commodity. Fourth, we estimate economic surplus, consumer surplus and economic rent associated with the above estimated changes in total factor productivities. Finally, we estimate the distributional incidence of economic rent (producer surplus) by homogeneous production regions and by enterprise size.

Objectives four and five on estimating the returns to consumers and resource owners from gains in productivity represent an attempt to link the work being done in the area of estimating cost functions to the work previously done in estimating returns to research in agriculture.[1]

PROCEDURE

The procedure for this study begins with the 1974 "Cost of Producing Selected Crops" survey conducted by USDA paid enumerators in the winter of 1975. This survey was undertaken again in the winters of 1983 and 1984 for the '82/'83 crop years. These data are used to provide the underlying production practices and quantity of inputs information for this study. These data were sorted by commodity, homogeneous region for each commodity, and by enterprise size within each region. This sorted data was then applied to summary programs that aggregated the observations into a representative enterprise composite of production practices and input quantities for each commodity-time region-size category. These representative enterprise data were then coded into a format appropriate for the budget generator program. The output from the budget generator provided the basis for estimating price, quantity and expenditure for the reduced capital, labor, energy, fertilizer, materials and land or KLEFMA inputs. The KLEFMA categories represent the cost profile information that can be used as data for the Cobb-Douglas cost function. The cost functions are solved in such a way that the results produce estimates of total factor productivity across time, region and size. These estimates of total factor productivity then become data in the models of economic surplus and consumer surplus. The results from the estimates of consumer surplus and economic rent can then be distributed relative to production regions and enterprise sizes.

SCOPE

As mentioned above the commodities selected for this study include only the field crops of corn, soybeans, wheat and cotton.

The regions for each of these commodities are listed in Table 1 by the associated FEDS three digit area code signifying homogeneity of soil and rainfall. These sample areas were selected purposively based on importance of the area to production and/or to provide variability in farming systems and production technologies. Their geographic locations are shown in Figures 1 to 4.

Enterprise size is based on planted acres, which includes both owned and rented land. These acreages were then arrayed within each area from largest to smallest and three enterprise sizes were designated for study: very large, large and medium (Table 2). The small size category was not included in this study because it included some very small, part-time production units. As a result we felt any resulting depictions of cost category averages were not very representative of the farmers included. Size categories were determined on the basis of percentiles of the arrayed planted acres and the average enterprise size for each category is shown in Table 3.

Table 1. Geographical Production Regions Included in the Study

Commodity	Selected State	Homogeneous Area	Other
Corn	Illinois	300	
	Indiana	101	
	Iowa	201	
	Nebraska	400	Irrigated
Soybeans	Illinois	300	
	Iowa	201	
	Mississippi	100	
	Ohio	101	
Wheat	Kansas	100	Hard red winter following fallow
	Montana	200	Hard red winter following fallow
	North Dakota	200	Hard red spring continuous
	Washington	400	Soft white winter following fallow
Cotton	Alabama	600	
	California	500	Irrigated
	Mississippi	100	
	Texas	200	Irrigated
	Texas	200	

Table 2. Specification of Enterprise Size Categories

Size Category	Percentile of Arrayed Planted Acres
Very Large	91-100
Large	71-90
Medium	41-70
Small	0-40 (not included)

FIGURE 1

Selected Homogeneous Soil and Rainfall Areas in Corn Production

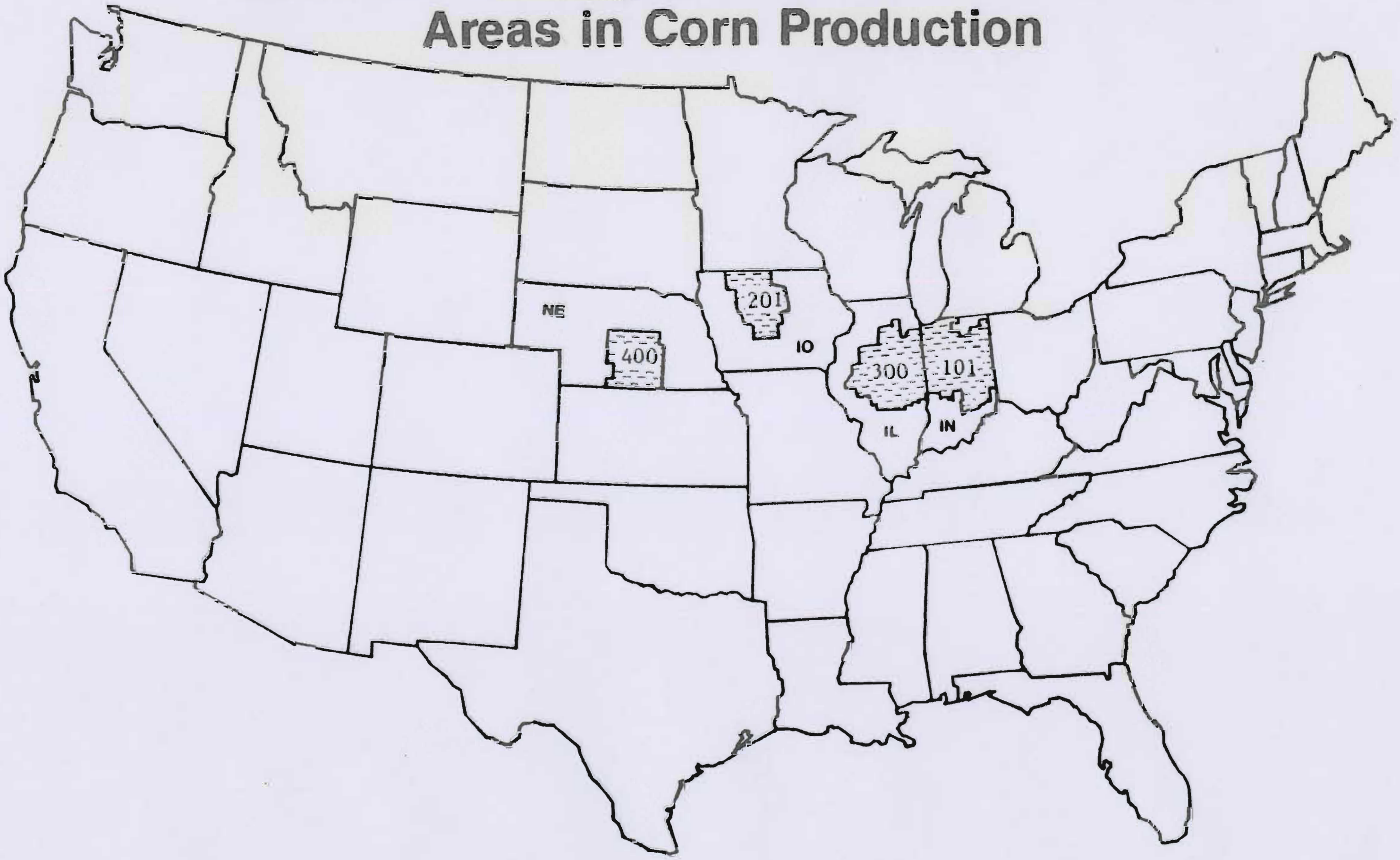


FIGURE 2

Selected Homogeneous Soil and Rainfall Areas in Soybeans Production

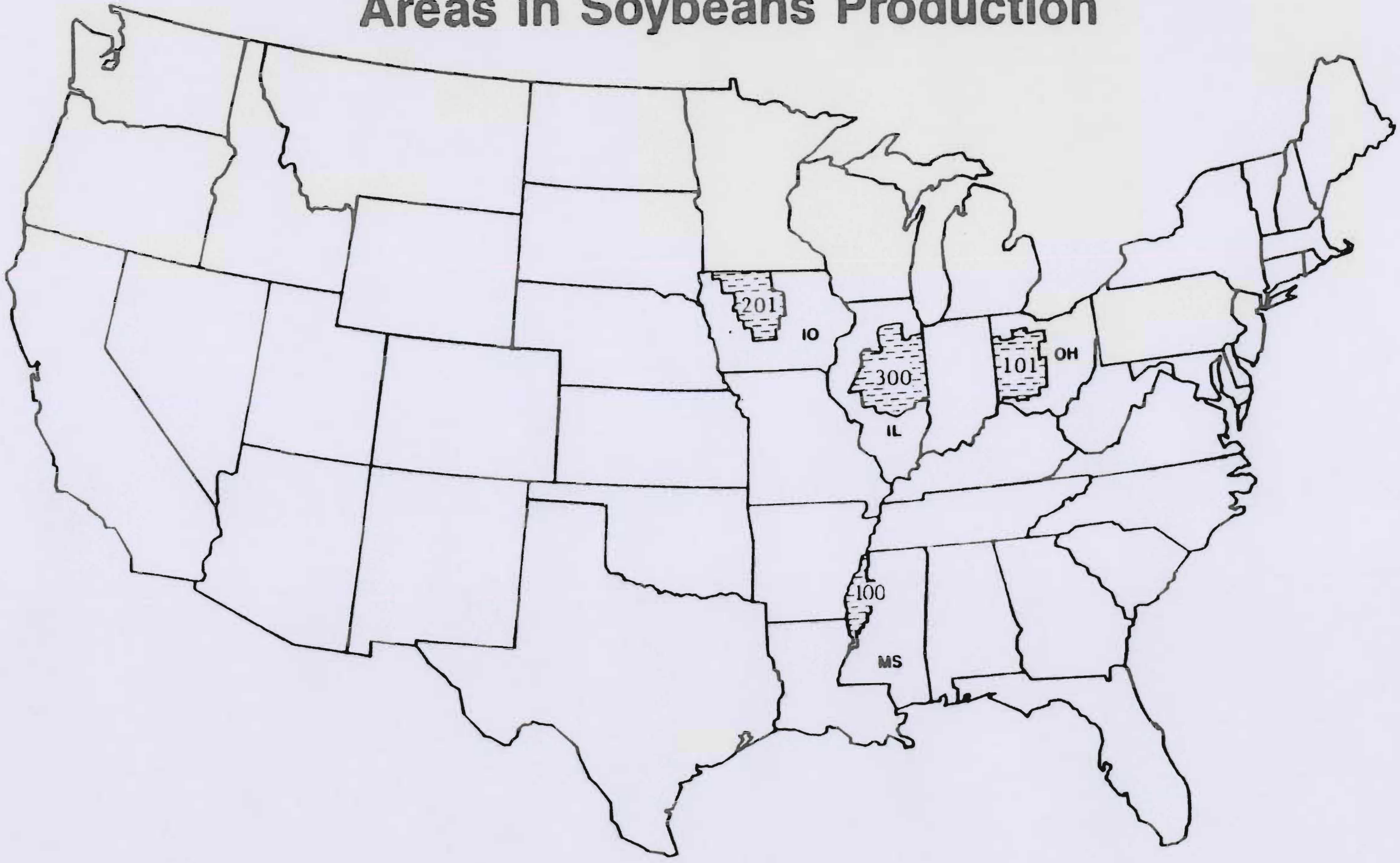


FIGURE 3

Selected Homogeneous Soil and Rainfall Areas in Wheat Production

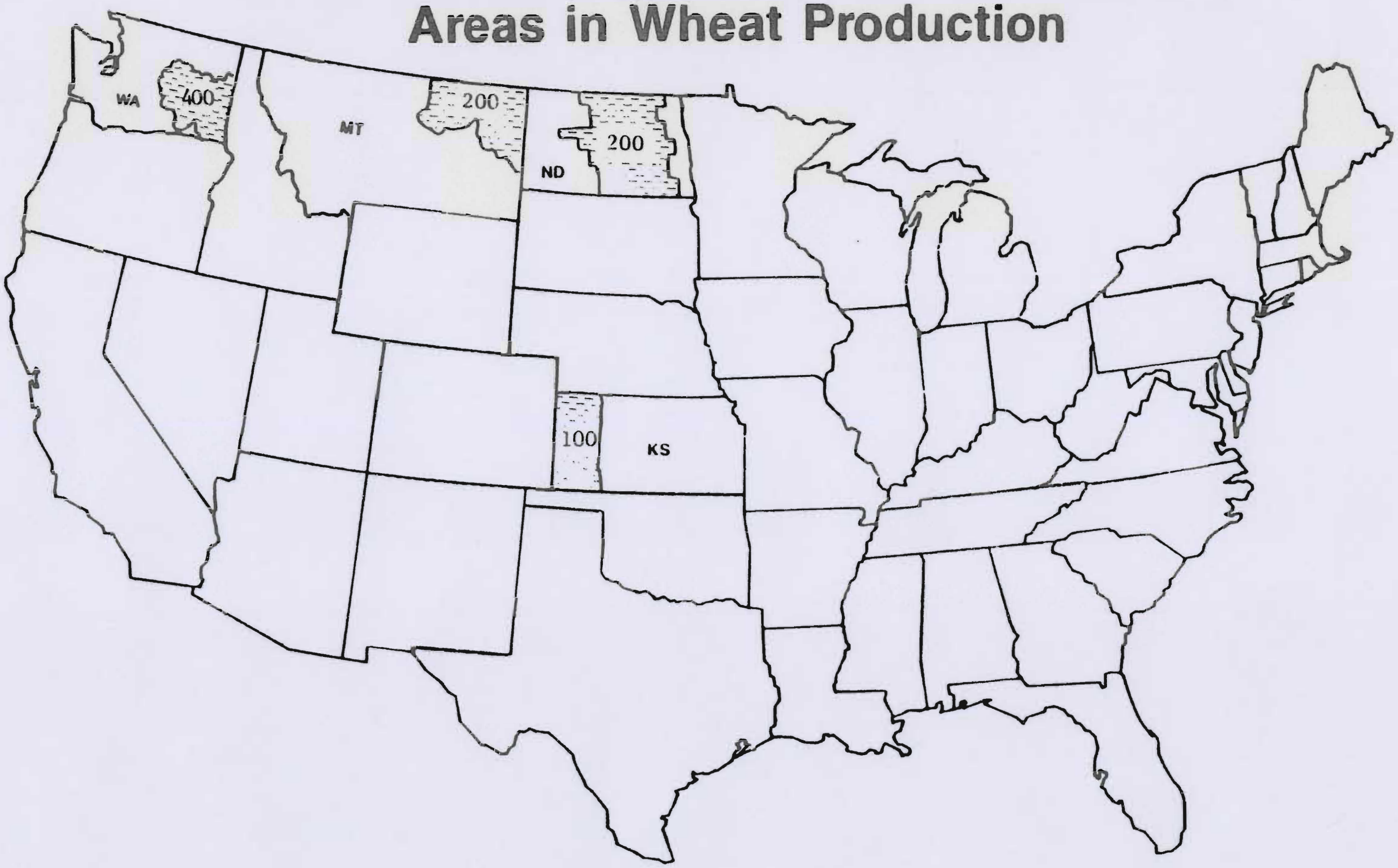


FIGURE 4

Selected Homogeneous Soil and Rainfall Areas in Cotton Production

Table 3. Average Enterprise Size (Planted Acres) by Commodity and Production Region Based on the 1982/83 FEDS Survey

	Corn	Soybeans	Wheat	Cotton	Cotton cont'd
	IL 300	IL 300	KS 100	AL 600	TX 200
VL	1113	684	3909	1842	5920
L	355	418	1429	917	1825
M	246	270	774	568	972
Wt. Ave.[1]	520	388	1796	1049	2714
	IN 101	IO 201	MT 200	CA 500[3]	
VL	903	707	1577	2833	
L	515	341	619	1432	
M	271	210	421	614	
Wt. Ave.[1]	444	291	1093	2237	
	IO 201	MS 100	ND 200	MS 100	
VL	576	1262	1283	2868	
L	249	894	630	1202	
M	170	795	338	754	
Wt. Ave.[1]	314	1050	672	1686	
	NE 400[3]	OH 101	WA 400	TX 200[3]	
VL	1715	897	2388	1707	
L	671	493	1104	929	
M	266	244	753	436	
Wt. Ave.[1]	685	436	1628	971	
	Wt. Ave.[2]	Wt. Ave.[2]	Wt. Ave.[2]	Wt. Ave.[2]	
VL	998	782	2659	2989	
L	403	455	1083	1317	
M	233	299	645	646	
Overall	470	438	1447	1926	

[1] Weights for average enterprise size within an area and across size categories are based on 1982 Census of Agriculture Table 41, "Specified Crops by Harvested Acres" as a ratio of production of this size category to the sum of production across size categories.

[2] Weights for average enterprise size across areas and within size categories are based on 1981-85 average county level SRS data as a ratio of an areas production to the sum of production across areas.

[3] Irrigated.

METHODOLOGY

There are two sets of analytical concepts used in this study. The first is that of estimating a Cobb-Douglas cost function solved in such a way as to estimate total factor productivity across time, region and enterprise size. The second relates to estimating economic surplus using the measure of total factor productivity as a necessary condition and as a datum in the analytical model.

A COBB-DOUGLAS COST FUNCTION

Most cost function models begin with the underlying relationship that total cost is a function of input prices and the level of output quantity.

(1) $TC_i = f(Q_i, P_{Ki}, P_{Li}, P_{Ei}, P_{Fi}, P_{Mi}, P_{Ai})$

where

TC_i = total cost per acre for commodity i
Q_i = yield per acre for commodity i
$P_{Ki} \ldots P_{Ai}$ = Price per unit of input for capital (K), labor (L), energy (E), fertilizer (F), material (M), and land (A) for commodity i

Equation (1) reflects a model of one output (Q_i) and six inputs (K, L, E, F, M, A). Further, equation (1) implies a set of four assumptions. First, the implicit decision rule is that producers act as if they cost minimize subject to an output constraint rather than profit maximize subject to a cost constraint. (For the implication of cost minimization versus profit maximization see Ferguson, p. 158.) In general, the results from cost minimization and from profit maximization are equivalent if the producer is operating at the minimum point on the average cost curve associated with the expansion path.

Second, it is assumed that the factor markets for the KLEFMA inputs are in equilibrium under conditions of perfect competition. This assumption implies that each input is used such that its marginal value product equals the input price and similarly that marginal cost or ratio of input price to its marginal product equals the output price.

Third, it is at least temporarily assumed that there are constant returns to size. This implies that the elasticity of cost with respect to scale of output equals one. Cost is assumed to change in a constant proportion with output change. If there were increasing returns to size then the rate of cost increase would be less than the rate of output increase. If there were decreasing returns to size then the rate of cost increase would be greater than the rate of output increase (Ferguson, p. 80).

Fourth, it is assumed that all observations made over time and between different regions are on the same cost function. This implies that there has been no shift in the cost function due to new technology introduced over time. This also implies that all regions of the U.S. are equally productive (i.e., have homogeneous resource endowments) relative to producing commodity i.

Assumptions three and four are particularly difficult ones to accept. Therefore we can modify our cost function to account for these problems.

(2) $TC_i = f(Q_i, P_{Ki}, P_{Li}, P_{Ei}, P_{Fi}, P_{Mi}, P_{Ai}, T_T, R_R, S_S)$

where

T_T = time period T
R_R = region R
S_S = enterprise size S

With the addition of these discrete variables T, R and S in equation (2), we no longer need to accept assumption four but rather can test it directly and use the test as a way of estimating total factor productivity across time and regions.

We need still to accept a modified version of assumption three. We must assume that there are constant returns to size within a size category. However, we will be testing whether size economies exist between size categories. As with time and region, relative size economies will be measured in terms of total factor productivity.

The functional form is transcendental logarithmic. A "translog" function implies that as an input price increases total cost increases at a decreasing rate as less expensive inputs are substituted for the more expensive ones to the extent possible. Equation (2) can be rewritten as follows (dropping the i^{th} commodity notation):

(3) $\ln TC = f(\ln Q, \ln P_K, \ln P_L, \ln P_E, \ln P_F, \ln P_M, \ln P_A, T_T, R_R, S_S)$.

Transcendental functions such as equation (3) can be approximated using a Taylor's series polynomial expansion (Thomas, 1962, p. 785). A Taylor series expansion takes the general form of

$f(x) = f(a) + f'(a)(x - a) + 1/2f''(a)(x - a)^2 + \ldots + \text{remainder}$

where

$f(x)$ is the transcendental function to be approximated
(a) is the base or reference point (some particular time, region, or size category).
$f'(a)$ is the first derivative of the transcendental function evaluated at the reference point
$f''(a)$ is the second derivative of the transcendental function evaluated at the reference point

A Cobb-Douglas cost function by definition is a "first order" or first derivative approximation of the cost function since a Cobb-Douglas function assumes that the "second order" or second derivative approximation equals zero (Binswanger, 1974b, p. 965).

A first order approximation of the translog cost function (TC_x) evaluated at (time, region or size) reference point (a) equals

$$(4)\quad \ln TC_x = \ln TC_a + \left.\frac{\partial \ln TC}{\partial \ln Q}\right|_a (\ln Q_x - \ln Q_a)$$

$$+ \left.\frac{\partial \ln TC}{\partial \ln P_K}\right|_a (\ln P_{Kx} - \ln P_{Ka}) + \left.\frac{\partial \ln TC}{\partial \ln P_L}\right|_a (\ln P_{Lx} - \ln P_{La})$$

$$+ \left.\frac{\partial \ln TC}{\partial \ln P_E}\right|_a (\ln P_{Ex} - \ln P_{Ea}) + \left.\frac{\partial \ln TC}{\partial \ln P_F}\right|_a (\ln P_{Fx} - \ln P_{Fa})$$

$$+ \left.\frac{\partial \ln TC}{\partial \ln P_M}\right|_a (\ln P_{Mx} - \ln P_{Ma}) + \left.\frac{\partial \ln TC}{\partial \ln P_A}\right|_a (\ln P_{Ax} - \ln P_{Aa})$$

$$+ \left.\frac{\partial \ln TC}{\partial T}\right|_a (T_{Tx} - T_a) + \left.\frac{\partial \ln TC}{\partial R}\right|_a (R_{Rx} - R_a)$$

$$+ \left.\frac{\partial \ln TC}{\partial S}\right|_a (S_{Sx} - S_a)$$

Equation (4) can be simplified in the following way. We know that

$$(5)\quad \frac{\partial \ln TC}{\partial \ln P_K} = \frac{\partial TC}{TC} * \frac{P_K}{\partial P_K} = \frac{P_K}{TC} * \frac{\partial TC}{\partial P_K}$$

From Shephard's lemma we know that

$$(6)\quad \frac{\partial TC}{\partial P_K} = X_K$$ (Binswanger, 1974a, p. 378).

We can see that this is a reasonable result simply by taking the partial derivative of the <u>total cost constraint of a profit function</u> with respect to each of its arguments. The total cost constraint equals

$$(7)\quad TC = P_KX_K + P_LX_L + P_EX_E + P_FX_F + P_MX_M + P_AX_A.$$

The partial derivatives of this cost constraint for each of the KLEFMA input prices equals

$$(8)\quad \frac{\partial TC}{\partial P_K} = X_K;\ \frac{\partial TC}{\partial P_L} = X_L;\ \frac{\partial TC}{\partial P_E} = X_E;\ \frac{\partial TC}{\partial P_F} = X_F;\ \frac{\partial TC}{\partial P_M} = X_M;\ \frac{\partial TC}{\partial P_A} = X_A.$$

Thus, the partial derivatives of the cost function with respect to price can be rewritten as a factor share S of expenditures on input i relative to total expenditures.

$$(9)\quad \frac{\partial \ln TC}{\partial \ln P_i} = \frac{P_i}{TC} * \frac{\partial TC}{\partial P_i} = \frac{P_iX_i}{TC} = \frac{P_iX_i}{\Sigma P_iX_i} = S_i.$$

We can further simplify the first order approximation by incorporating our assumption of constant returns to size within a size category. This assumption implies that the elasticity of the cost function with respect to output equals one. Therefore,

$$(10)\quad \left.\frac{\partial \ln TC}{\partial \ln Q}\right|_a = 1.$$

Finally, we will let time related differences in cost efficiency equal α_a for notational simplicity such that

$$(11)\quad \left.\frac{\partial \ln TC}{\partial T}\right|_a = \alpha_a.$$

We can assume also in this instance that region and size related differences in cost efficiency equal zero. We can assume this if we match up observations across time that are associated with the same region and size categories. Later on we will solve the cost function for regional or size cost efficiency by making the appropriate observational match ups across time-size or time-region. Therefore,

$$(12)\quad \left.\sum_R \frac{\partial \ln TC}{\partial R}\right|_a = \left.\sum_S \frac{\partial \ln TC}{\partial S}\right|_a = 0.$$

We can now rewrite equation (4) such that it incorporates the information and assumptions in equations (9), (10), (11) and (12). Further we can solve equation (4) in terms of the change in productivity across time between 1974 (x = 74) and 1983 (a = 83), where 1983 is arbitrarily assumed to be the reference time period.

$$(13)\quad \alpha_{83}(T_{74} - T_{83}) = \ln TC_{74} - \ln TC_{83} - (\ln Q_{74} - \ln Q_{83}) - S_{K83}(\ln P_{K74} - \ln P_{K83}) - S_{L83}(\ln P_{L74} - \ln P_{L83}) - S_{E83}(\ln P_{E74} - \ln P_{E83}) - S_{F83}(\ln P_{F74} - \ln P_{F83}) - S_{M83}(\ln P_{M74} - \ln P_{M83}) - S_{A83}(\ln P_{A74} - \ln P_{A83}).$$

Equation (13) is a first order approximation in logs of a rate of cost efficiency between 1974 and 1983 associated with one output and six KLEFMA inputs. This first order approximation implicitly assumes the second order effects are not significantly different from zero. The second order effects are of two types--those relating to technology bias[2] and those relating to the elasticity of input substitution (Binswanger, 1974b, p. 970).

There is no way of accounting for technology bias without estimating the second order approximation of the translog function. However, there is a means of dealing with the effects of incorrectly assuming unitary elasticity of substitution when variable elasticity is more nearly the case. Unitary elasticity of substitution between inputs implies that factor shares remain constant over time, regions and enterprise sizes as relative prices change. Conversely, variable elasticity of substitution implies that factor shares change with changes in relative prices.

If we assume that factor shares are constant, when in fact they are changing, then we risk ascribing to technological change productivity gains that are really the effect of changing relative prices. Or conversely, we may ascribe the absence of productivity gains to the absence of technological change when its effect is being offset by changes in relative prices of inputs. Therefore, it is essential that we hold the effect of changing relative prices constant when measuring productivity.

We can hold the effect of relative price change constant by taking the average of the factor share weights between the initial and reference period (time, region or size). If the Cobb-Douglas assumption of constant factor shares is correct then the averaging process leaves factor shares unchanged. If the Cobb-Douglas assumption is incorrect, then the averaging process holds the effect of relative price change constant by changing the factor share weights to equal the average between the two points of reference being considered.

The procedure for determining the average of the factor share weights proceeds in two steps. First equation (13) is re-estimated as before except that the initial and reference periods are reversed such that $x = 83$ and $a = 74$.

$$(14)\quad \alpha_{74}(T_{83} - T_{74}) = \ln TC_{83} - \ln TC_{74} - (\ln Q_{83} - \ln Q_{74}) - S_{K74}(\ln P_{K83} - \ln P_{K74}) - S_{L74}(\ln P_{L83} - \ln P_{L74}) - S_{E74}(\ln P_{E83} - \ln P_{E74}) - S_{F74}(\ln P_{F83} - \ln P_{F74}) - S_{M74}(\ln P_{M83} - \ln P_{M74}) - S_{A74}(\ln P_{A83} - \ln P_{A74}).$$

Second, by subtracting (14) from (13), we can derive the first order approximation of the average rate of cost efficiency between 1974 and 1983 adjusted for changes in relative prices but unadjusted for non-neutral technology bias.

$$(15)\quad 1/2\,(\alpha_{83} + \alpha_{74})(T_{74} - T_{83}) = \ln TC_{74} - \ln TC_{83} - (\ln Q_{74} - \ln Q_{83}) - 1/2\,(S_{K83}+S_{K74})(\ln P_{K74}-\ln P_{K83}) - 1/2\,(S_{L83}+S_{L74})(\ln P_{L74}-\ln P_{L83}) - 1/2\,(S_{E83}+S_{E74})(\ln P_{E74}-\ln P_{E83}) - 1/2\,(S_{F83}+S_{F74})(\ln P_{F74}-\ln P_{F83}) - 1/2\,(S_{M83}+S_{M74})(\ln P_{M74}-\ln P_{M83}) - 1/2\,(S_{A83}+S_{A74})(\ln P_{A74}-\ln P_{A83}).$$

Equation (15) can be reformulated for each set of discrete variables (time, region, size) and the associated combination of initial and reference time periods, regions and size categories. Since there are only two time periods considered in this study for each commodity, then equation (15) is the general equation for measuring productivity across time. There are three size categories for each commodity, which results in two general equations for measuring productivity between enterprise sizes. Using the medium size enterprise as the common denominator then

$$(16)\quad 1/2\ (\alpha_{MD} + \alpha_{VL})(S_{VL} - S_{MD}) = \ln(TC_{VL} / TC_{MD}) - \ln(Q_{VL} / Q_{MD}) - 1/2 \sum_{K} (S_{KVL} + S_{KMD})(\ln(P_{KVL} / P_{KMD}))$$

and

$$(17)\quad 1/2\ (\alpha_{MD} + \alpha_{LG})(S_{LG} - S_{MD}) = \ln(TC_{LG} / TC_{MD}) - \ln(Q_{LG} / Q_{MD}) - 1/2 \sum_{K} (S_{KLG} + S_{KMD})(\ln(P_{KLG} / P_{KMD})).$$

There are three general equations for measuring productivity between regions for corn, soybeans and wheat given that there are four selected regions for each commodity and one region is used as a common denominator for the others. There are four general equations for cotton because four regions were selected and two cultural practices (dryland and irrigation) in the Texas high plains were included. Since the selected regions for each commodity are largely unique to the commodity, we will not present all the associated interregional productivity equations. We will include the three for corn for illustrative purposes. Nebraska area 400 is used as the common denominator.

$$(18)\quad 1/2\ (\alpha_{NE} + \alpha_{IL})(R_{IL} - R_{NE}) = \ln(TC_{IL} / TC_{NE}) - \ln(Q_{IL} / Q_{NE}) - 1/2 \sum_{K} (S_{KNE} + S_{KIL})(\ln(P_{KIL} / P_{KNE}));$$

$$(19)\quad 1/2\ (\alpha_{NE} + \alpha_{IN})(R_{IN} - R_{NE}) = \ln(TC_{IN} / TC_{NE}) - \ln(Q_{IN} / Q_{NE}) - 1/2 \sum_{K} (S_{KNE} + S_{KIN})(\ln(P_{KIN} / P_{KNE})).$$

and

$$(20)\quad 1/2\ (\alpha_{NE} + \alpha_{IO})(R_{IO} - R_{NE}) = \ln(TC_{IO} / TC_{NE}) - \ln(Q_{IO} / Q_{NE}) - 1/2 \sum_{K} (S_{KNE} + S_{KIO})(\ln(P_{KIO} / P_{KNE}))$$

Equations (15) through (20) represent measures of the difference in cost efficiency. Cost efficiency is defined as the ratio of inputs to output. Total factor productivity on the other hand is defined as the ratio of output to inputs. Consequently, difference in total factor productivity is the inverse of difference in cost efficiency. It is perhaps more apparent that these equations represent cost efficiency if, for illustrative purposes, equation (20) is expressed in linear instead of logarithmic terms.

$$(21) \quad \left[\frac{R_{IO}}{R_{NE}}\right]^{1/2(\alpha_{NE}+\alpha_{IO})} = \frac{\dfrac{TC_{IO}}{TC_{NE}}}{\Pi_K \left(\dfrac{Q_{IO}}{Q_{NE}}\right) \left(\dfrac{P_{KIO}}{P_{KNE}}\right)^{1/2\,(S_{KNE}+S_{KIO})}}$$

$$= \frac{\Pi_K \left(\dfrac{q_{KIO}}{q_{KNE}}\right) \left(\dfrac{P_{KIO}}{P_{KNE}}\right)}{\Pi_K \left(\dfrac{Q_{IO}}{Q_{NE}}\right) \left(\dfrac{P_{KIO}}{P_{KNE}}\right)^{1/2\,(S_{KNE}+S_{KIO})}} \approx \frac{\Pi_K \left(\dfrac{q_{KIO}}{q_{KNE}}\right)}{\left(\dfrac{Q_{IO}}{Q_{NE}}\right)}$$ [3]

where

$$\Pi_K \left(\frac{P_{KIO}}{P_{KNE}}\right)^{1/2\,(S_{KNE}+S_{KIO})}$$

is a quadratic mean approximation of the relative price ratio of inputs in corn production between Iowa and Nebraska.

$$\left(\frac{P_{KIO}}{P_{KNE}}\right)$$

is the actual relative price ratio of inputs in corn production between Iowa and Nebraska.

Total factor productivity, on the other hand, equals the inverse of (21)

$$(22) \quad \left[\frac{R_{IO}}{R_{NE}}\right]^{-1/2(\alpha_{NE}+\alpha_{IO})} \approx \frac{\left(\dfrac{Q_{IO}}{Q_{NE}}\right)}{\Pi_K \left(\dfrac{q_{KIO}}{q_{KNE}}\right)}$$ [3]

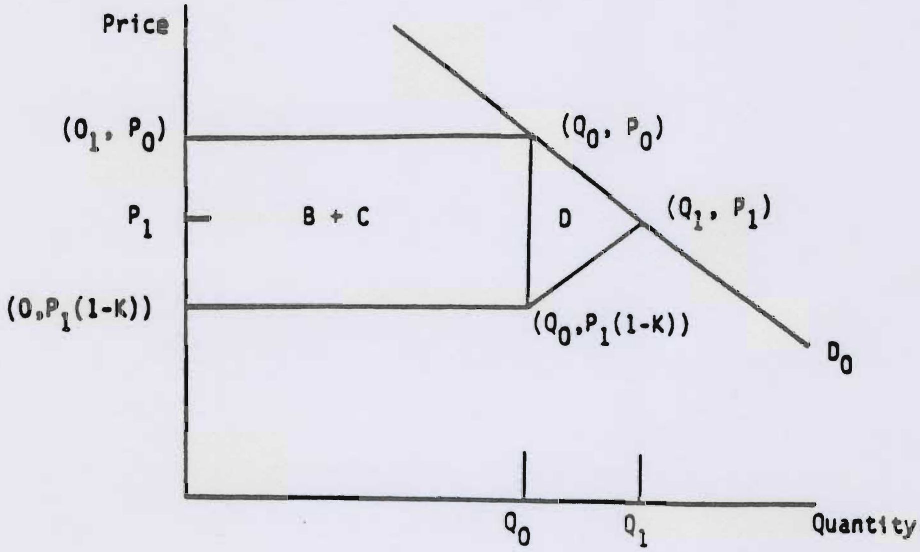
The expression $(1/2 \sum_K (S_{KNE} + S_{KIO})(\ln(P_{KIO} / P_{KNE}))$ in equation (20) is itself a price index calculation needed, in this case, to hold the relative prices of inputs constant between Nebraska and Iowa.

ECONOMIC SURPLUS

The second analytical concept used in this study involves estimating economic surplus. Total factor productivity is needed to estimate the economic surplus associated with a gain in productivity. Economic surplus is defined as the sum of consumer surplus and economic rent. Consumer surplus is defined as a cardinal measure of compensation consumers are able (if not willing) to give up subsequently and still be as well off as initially. Similarly, economic rent is defined as the compensation resource owners are able to forego and be as well off as initially (Cooke, 1985, p. 100).

The estimation of economic surplus for the commodities in this study required an *ex post* price and quantity (presumably in equilibrium), the elasticity of demand and supply and, finally, total factor productivity change. The measure of change in economic surplus (ΔES) is outlined by Lindner and Jarrett (1978), Rose (1980) and Cooke (1985). Economic surplus equals area B + C and area D in Figure 5 below.

FIGURE 5



(23) $\Delta ES = \text{Area } B + C + D$

(24) $\text{Area } B + C = 1/2\ Q_0[P_0 - P_1 + 2KP_1]$

and

(25) $\text{Area } D = 1/2\ [P_0(Q_1 - Q_0) + P_1(1 - K)(Q_0 - Q_1)]$

where

P_1 = the equilibrium price *ex post*
Q_1 = the equilibrium quantity *ex post*
P_0 = the equilibrium price *ex ante*
Q_0 = the equilibrium quantity *ex ante*
K = the difference in total factor productivity expressed as a ratio (Rose, 1980, p. 834)

The values of the ex ante equilibrium price and quantity are estimated using the equations developed by Pinstrup-Andersen, Londono and Hoover (1976, pp. 132-134).

(26) $P_0 = P_1 / [1 - KE / (E + N)]$

and

(27) $Q_0 = Q_1 / [1 + KEN / (E + N)]$

where

P_1, Q_1 and K are the same as defined above
E = the elasticity of supply
N = the absolute value of the elasticity of demand

The change in consumer surplus is measured as

(28) $\Delta CS = 1/2\ (Q_0 + Q_1)(P_0 - P_1)$

where

Q_0, Q_1, P_0 and P_1 are the same as defined above

Economic rent equals economic surplus less consumer surplus

(29) $\Delta ER = \Delta ES - \Delta CS$.

RESULTS

Next we turn to the actual estimates of total factor productivity across time, region and enterprise size as well as the associated economic surplus for corn, soybeans, wheat and cotton. In corn production, (Table 4) there are about 32,000 producers in the selected areas who produce about 20 percent of U.S. corn for grain, on an average enterprise size of about 470 acres. Illinois area 300 has a competitive advantage in corn production followed by Iowa area 201, Indiana area 101 and with Nebraska area 400 a distant fourth. Average intertemporal productivity in corn production increased about 15 percent between 1974 and 1983 or about 1.7 percent per year. Economic surplus from this increase in productivity over the period 1974 to 1983 is about $800 million (about $80 million per year) of which about 75 percent went to consumers and 25 percent went to resource owners. Size economies (Table 8) appear to exist in corn production both between medium and large size enterprises and between large and very large enterprises. Resource owners in Indiana area 101 were in a position to capture a greater amount of the economic rent per acre than in the other areas (Table 4). Also very large enterprise resource owners captured more economic rent per acre than large or medium size enterprise owners (Table 8). Total rents for the 1974 to 1983 period can be converted to an annual basis by dividing by 10.

In soybean production (Table 5), there are about 33,000 producers in the selected areas with an average enterprise size of almost 440 acres. Illinois and Iowa have a competitive advantage in soybean production relative to Ohio and Mississippi. Intertemporal productivity gain is about 15 percent on average across the selected areas and about the same as for corn production during the same period. Size economies in soybean production (Table 8) exist for very large enterprises relative to large and medium size ones in the selected areas. Very large and large enterprises received about the same share of economic rent per acre. Resource owners in Mississippi, Illinois and Ohio all received substantially higher economic rent on a per acre basis than those in Iowa.

There are just under 5,600 wheat producers in the selected sample areas (Table 6) producing about 9.1 percent of the nation's output on an average enterprise size of just under 1460 acres. We recognize that the wheat produced in these several sample areas is not the same commodity (see Table 1). Yet for some purposes interregional comparison's are still of interest. The Palouse region of Washington State has a competitive advantage in wheat

Table 4. Corn Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Illinois Area 300	Indiana Area 101	Iowa Area 201	Nebraska Area 400 (Irrigated)	Total/ Average
Percent of U.S. production[1]	%	7.54	4.50	5.34	2.64	20.02
Number of enterprises[2]		14,000	3,190	11,870	2,260	31,920
Enterprise size[3]	acres	520	444	314	685	470
Yield '72-'76[4]	bu/acre	113.1	100.2	102.5	116.6	109.2
Yield '81-'85[5]	bu/acre	126.7	114.9	123.3	130.7	123.7
TFP (Region)		.75	.80	.78	1.00	
TFP (Time)		.08	.15	.22	.22	.15
Elasticity of demand[6]		-.30	-.30	-.30	-.30	-.30
Elasticity of supply[7]		.31	.31	.31	.31	.31
P_1 '81-'85[8]	$/bu	2.72	2.72	2.72	2.72	2.72
Q_1 '81-'85[9]	1000 bu	558,317	337,477	365,721	194,469	1,455,983
Economic surplus	$1000	174,392	185,579	294,254	156,572	810,797
Consumer surplus	$1000	125,501	138,592	227,811	123,897	615,801
Economic rent	$1000	48,892	46,987	66,443	32,675	194,996
Rent/Ent (Region)	$	1,310	6,980	1,400	4,150	1,960
Rent/Acre (Region)	$	6.40	33.00	17.80	21.00	13.00

(See footnotes following Table 7.)

Table 5. Soybean Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Illinois Area 300	Iowa Area 201	Mississippi Area 100	Ohio Area 101	Total/ Average
Percent of U.S. production[1]	%	7.79	5.25	1.93	3.42	18.39
Number of enterprises[2]		14,800	10,450	1,000	6,470	32,720
Enterprise size[3]	acres	388	291	1,050	436	438
Yield '72-'76[4]	bu/acre	34.5	33.6	21.4	30.0	31.3
Yield '81-'85[5]	bu/acre	39.5	36.8	23.6	35.5	34.2
TFP (Region)		.91	.93	1.70	1.00	
TFP (Time)		.21	.04	.15	.21	.15
Elasticity of demand[6]		-.85	-.85	-.85	-.85	-.85
Elasticity of supply[7]		.25	.25	.25	.25	.25
P_1 '81-'85[8]	$/bu	6.23	6.23	6.23	6.23	6.23
Q_1 '81-'85[9]	1000 bu	157,384	99,566	38,086	70,560	365,594
Economic surplus	$1000	190,749	29,067	35,541	88,118	343,475
Consumer surplus	$1000	51,050	7,589	9,437	23,619	91,696
Economic rent	$1000	139,699	21,478	26,104	64,499	251,779
Rent/Ent (Region)	$	9,440	2,050	26,000	9,970	7,700
Rent/Acre (Region)	$	24.50	7.00	24.75	22.90	17.80

(See footnotes following Table 7.)

Table 6. Wheat Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Kansas Area 100	Montana Area 200	North Dakota Area 200	Washington Area 401	Total/ Average
Percent of U.S. production[1]	%	3.47	1.02	1.68	2.94	9.11
Number of enterprises[2]		1,490	800	2,230	1,070	5,590
Enterprise size[3]	acres	1,796	1,093	672	1,628	1,457
Yield '72-'76[4]	bu/acre	27.4	24.8	18.4	40.4	28.6
Yield '81-'85[5]	bu/acre	30.0	18.4	27.9	47.2	32.4
TFP (Region)		1.31	1.72	1.33	1.00	
TFP (Time)		.22	-.25	.47	-.06	.06
Elasticity of demand[6]		-.30	-.30	-.30	-.30	-.30
Elasticity of supply[7]		.20	.20	.20	.20	.20
P_1 '81-'85[8]	\$/bu	3.49	3.49	3.49	3.49	3.49
Q_1 '81-'85[9]	1000 bu	87,889	22,063	45,139	77,927	233,018
Economic surplus	\$1000	75,337	-32,405	69,907	-27,250	85,589
Consumer surplus	\$1000	41,270	-13,987	41,459	-12,134	56,608
Economic rent	\$1000	34,067	-18,418	28,449	-15,116	28,982
Rent/Ent (Region)	\$	22,830	-23,000	12,740	-14,200	5,200
Rent/Acre (Region)	\$	12.70	-21.00	19.00	-8.70	3.60

(See footnotes following Table 7.)

Table 7. Cotton Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Alabama Area 600	California Area 500 (Irrigated)	Mississ-ippi Area 200	Texas Area 200 (Irrigated)	Texas Area 200	Total/ Average
Percent of U.S. producion[1]	%	1.70	22.60	7.98	9.88	7.43	49.59
Number of enterprises[2]		220	560	400	950	500	2,630
Enterprise size[3]	acres	1,049	2,237	1,686	971	2,714	1,926
Yield '72-'76[4]	lbs/ acre	399.8	981.2	501.4	383.6	286.1	505.0
Yield '81-'85[5]	lbs/ acre	654.9	1,053.3	762.3	353.9	234.5	725.0
TFP (Region)		.72	.49	.60	1.09	1.00	
TFP (Time)		.63	.08	.60	-.19	-.29	.10
Elasticity of demand[6]		-1.84	-1.84	-1.84	-1.84	-1.84	-1.84
Elasticity of supply[7]		.25	.25	.25	.25	.25	.25
P_1 '81-'85[8]	$/lbs	.588	.588	.588	.588	.588	.588
Q_1 '81-'85[9]	1000 lbs	119,949	1,317,658	507,259	550,003	413,280	2,908,148
Economic surplus	$1000	27,915	61,380	115,580	-84,793	-120,276	-194
Consumer surplus	$1000	3,727	7,891	15,401	-10,482	-14,368	2,169
Economic rent	$1000	24,188	53,490	100,178	-74,311	-105,908	-2,363
Rent/Ent (Region)	$	109,100	96,000	250,000	-78,000	-212,000	-900
Rent/Acre (Region)	$	104.00	43.00	148.00	-80.00	-78.00	-.50

(See footnotes following Table 7.)

Footnotes for Tables 4-7

[1] Source: USDA/SRS data tapes on county level production 1979-1983 and USDA/ERS Ag. Info. Bull. No. 471 "Corn: Background for 1985 Farm Legislation," Appendix Table 7 on U.S. aggregate production 1979-1983. Also No. 472 "Soybeans;" No. 467 "Wheat;" No. 476 "Cotton."

[2] Source: 1982 Census of Agriculture Table 41 "Specified Crops by Harvested Acres" data reflects number of farms associated with very large to medium size categories only. The area-to-state production ratio is used to determine the number of enterprises within the area and across size categories.

[3] Source: Mean of USDA/ERS FEDS survey planted acres for very large, large and medium size enterprises.

[4] Source: USDA/SRS data tapes on county level harvested acres and production for 1972-1976.

[5] Source: USDA/SRS data tapes on county level harvested acres and production for 1981-1985.

[6] Source: George P.S. and G.A. King, "Consumer Demand for Food Commodities in the United States with Projections for 1980." Giannini Foundation Monograph No. 26, March 1971, University of California, Berkeley. p. 51.

[7] Source: Cochrane, W.W., "Conceptualizing the Supply Relation in Agriculture." JFE, 37(5), Dec. 1955.

[8] Source: USDA/ERS Ag. Info. Bull. No. 471 "Corn: Background for 1985 Farm Legislation," Appendix Table 7 on U.S. aggregate production 1979-1983. Also No. 472 "Soybeans;" No. 467 "Wheat;" No. 476 "Cotton."

[9] Source: USDA/SRS data tapes on county level production 1979-1983.

Table 8. Distribution of Economic Rent from Technology by Enterprise Size Across the Selected Areas from 1974 to 1983.[1]

Commodity	Very Large	Large	Medium	Total/Average
Corn				
Number of Enterprises	2,248	8,028	21,644	31,920
TFP	.88	.94	1.00	NA
Economic Rent ($1,000)	$50,541	$63,134	$18,322	$194,996
Rent/Enterprise	$22,500	$7,900	$3,750	$6,100
Rent/Acre	$22.50	$19.60	$16.10	$13.00
Soybeans				
Number of Enterprises	1,942	7,467	23,311	32,720
TFP	.94	.98	1.00	NA
Economic Rent ($1,000)	$50,886	$102,749	$98,144	$251,779
Rent/Enterprise	$26,200	$13,750	$4,200	$7,700
Rent/Acre	$33.50	$30.20	$14.00	$17.80
Wheat				
Number of Enterprises	763	1,401	3,426	5,590
TFP	.98	1.01	1.00	NA
Economic Rent ($1,000)	$-1,785	$8,036	$22,730	$28,982
Rent/Enterprise	$-2,350	$5,750	$6,650	$5,200
Rent/Acre	$-.90	$5.30	$10.30	$3.60
Cotton				
Number of Enterprises	429	779	1,423	2,630
TFP	.98	.99	1.00	NA
Economic Rent ($1,000)	$46,316	$-20,828	$-27,852	$-2,363
Rent/Enterprise	$108,000	$-26,700	$-19,600	$-900
Rent/Acre	$36.10	$-20.30	$-30.30	$-.50

---

[1] The study period for cotton enterprises was 1974 to 1982. See footnotes following Table 7 for explanation of weighting and distribution procedures.

production relative to western Kansas, central North Dakota and northeastern Montana. The intertemporal total factor productivity gain between 1974 and 1983 is about 6 percent on average across the selected wheat regions but the situation differs greatly between regions. We have, however, tried to minimize the effects of annual weather variability on productivity by averaging crop yields over 5-year periods centering on 1974 and 1983. Resource owners in North Dakota area 200 received the largest positive economic rents per acre during this period as did those on medium size enterprises. There is little indication of size economies (Table 8) in wheat production on average in the selected areas.[4]

There are about 2,600 cotton producers in the sample area who grow about 50 percent of the U.S. cotton crop, with an average enterprise size of over 1900 acres (Table 7). Producers in the Southern California and the Mississippi Delta sample regions have a competitive advantage in cotton production relative to northern Alabama and the Texas High Plains. Total factor productivity gain between 1974 and 1982 is about 10 percent in cotton production, again with some very large differences between regions. A combination of adverse weather and pest conditions combined with declining water resources in the Texas High Plains region resulted in productivity losses for that region during the period studied. The largest positive economic rent per capita goes to resource owners in the Delta area of Mississippi and to very large enterprise owners. Very large enterprises capture the largest portion of economic rent per acre, although technical size economies (Table 8) in cotton production appear to be rather fully exploited by the medium size farms in the selected areas. This suggests that even in the absence of size economies beyond the medium-size cotton enterprise, very large producers are still exploiting available technology for a total income advantage.

CONCLUSIONS

This study has applied the Cobb-Douglas cost function to farm level data. These data were stratified by enterprise size and cost estimates generated using a consistent set of assumptions for both the 1974 and 1982/83 FEDS survey data.

Methodologically, we have estimated a Cobb-Douglas cost function across regions, size and time. We have extended the first order approximation of the cost function to include a measure of the difference in total factor productivity between enterprise sizes. In so doing, we have separated out the effect of changes in productivity associated with factor endowment (interregional) adoption of new technology (intertemporal) and fuller exploitation of existing technology (size economies).

The results indicate that central Illinois in corn, central Illinois and north central Iowa in soybeans, the Palouse of Washington in wheat and southern California and the Mississippi Delta in cotton have competitive advantage relative to the other selected areas. Relative to the enterprise size categories specified in this study, size economies exist in corn and soybean production but not in cotton. The case for size economies in wheat production is uncertain given the data problems in the Palouse area of Washington. Intertemporal productivity for field crops between 1974 and 1983 is about 15 percent for corn and soybeans, and 6 percent for wheat. Between 1974 and 1982 it is about 10 percent for cotton. Regions with competitive advantage did not always receive the highest amount of economic rent per acre for resource owners. Except for wheat, very large enterprise owners received the largest amount of economic rent even on a per acre basis.

Future research in this area should include estimating the second order approximation of the cost function. That is, instead of assuming a unitary elasticity of substitution function (Cobb-Douglas), we could estimate a variable elasticity of substitution function (second order translog function) as well as estimating the associated concept of factor bias. The data problems associated with yields in the Palouse by enterprise size should be addressed as a step toward estimating size economies in wheat production. The measures of intertemporal productivity and economic surplus are gross measures of benefits of new technology. However, we have not specified a measure of the costs, either private or public, of research and development to compare against these benefits. Moreover, additional effort is needed to update the supply and demand elasticities for individual commodities if the estimates of economic surplus are to have empirical credibility in more than a "relative" sense.

The analyses presented in this paper indicate that when adequate farm level cost data are available, it is now feasible to measure differentials in total factor productivity in the production of individual commodities over time, between production regions and by size of enterprise. These differentials provide important analytical insights into the distributional impacts of expenditures for research and development and the technical change that they generate. They also provide insights into the competitive position of producers by size and location. If, in addition, cost and output data can be provided for the "whole farm" units involved, alternative allocations of overhead costs among enterprises can be explored and, in addition, the economics of "farming systems" can be analyzed. We believe it is important that the national agencies involved in providing cost data for U.S. agriculture provide a continuing sample data set that permits the estimation of the economic measures referred to above.

FOOTNOTES

[1] The work in returns to research includes an extensive body of literature and includes but is not limited to that done by Ayer and Schuh (1972), Duncan and Tisdell (1971), Evenson (1968), Griliches (1958), Lindner and Jarrett (1978), Peterson (1966), Rose (1980), Schmitz and Seckler (1970) and Wise and Fell (1980).

[2] Technology bias, in the Hicksian sense refers to the phenomenon in which "the factor ratio does not stay constant at a constant factor price ratio" (Binswanger, 1974a, fn p. 377).

[3] These measures of total factor productivity are approximations only in the sense that factor bias has not been accounted for. On the other hand, these are exact Cobb-Douglas measures of productivity.

[4] Data problems regarding yield by enterprise size in the Palouse area of Washington prevented an accurate measure of size economies in wheat production. The Palouse area has a very steep increasing rainfall gradient from west to east. This is complicated by the fact that larger enterprises are situated in the western portion while smaller ones predominate in the eastern portion. This situation shows up in the data as smaller enterprises having much higher yields.

BIBLIOGRAPHY

Ayer, H.W. and G.E. Schuh. "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," American Journal of Agricultural Economics 54(4):557-569, November 1972.

Binswanger, H.P. "A Cost Function Approach to the Measurement of Factor Demand Elasticities and of Elasticities of Substitution," American Journal of Agricultural Economics 56:377-386, 1974a.

__________. "The Measurement of Technical Change Biases with Many Factors of Production," American Economic Review 64:964-976, 1974b.

Bowers, W. Machinery Management. Moline, Ill.: Deere and Company, 1981.

Brown, R.S. and L.R. Christensen. "Estimating Elasticities of Substitution in a Model of Partial Static Equilibrium: An Application of U.S. Agriculture, 1947-74," Modeling and Measuring Natural Resource Substitution. Edited by E.R. Berndt and B.C. Field, Cambridge, Mass., The MIT Press, 1981.

Chan, M.W.L. and D.C. Mountain. "Economies of Scale and the Tornquist Discrete Measure of Productivity Growth. Review of Economics and Statistics pp. 663-667, 1983.

Cochrane, W.W. "Conceptualizing the Supply Relation in Agriculture," Journal of Farm Economics 37(5):1161-1176, December 1955.

Cooke, S.C. "A Theory of Consumer Surplus and Economic Rent and an Application for Measuring the Benefits from the Mechanical Cucumber Harvester," Ph.D. dissertation, Michigan State University, 1985.

Duncan, R. and C. Tisdell. "Research and Technical Progress: The Returns to Producers," Economic Record 47:124-129, March 1971.

Evenson, R. "The Contribution of Agricultural Research and Extension to Agricultural Production," Ph.D. dissertation, University of Chicago, 1968.

Ferguson, C.E. The Neoclassical Theory of Production and Distribution, Cambridge, England: Cambridge University Press, 1975.

George, P.S. and G.A. King. "Consumer Demand for Food Commodities in the United States with Projections for 1980," Monograph No. 26, Berkeley, Cal.: Giannini Foundation, March 1971.

Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovation," Journal of Political Economy 66(5):419-431, October 1958.

Hazilla, M. and R. Kopp. "Productivity and Productive Efficiency of U.S. Agriculture." Paper presented for the Workshop on Developing a Framework for Assessing Future Changes in Agricultural Productivity, July 16-18, 1984 (Washington, DC, National Center for Food and Agricultural Policy, Resources for the Future).

Hunt, D. Farm Power and Machinery Management, Iowa State University Press, Ames, Iowa.

Jensen, H.R. "Another Look at Economies of Size Studies in Farming." Economic Report ER 82-7, University of Minnesota, Department of Agricultural and Applied Economics, St. Paul, Minnesota, August 1982.

Klitke, D. "Operation of the Enterprise Budget Generator," Research Report P-790, Stillwater: Department of Agricultural Economics, Agricultural Experiment Station, Oklahoma State University, August 1979.

Linder, R.K. and F.G. Jarrett. "Supply Shifts and the Size of Research Benefits," American Journal of Agricultural Economics 60(1):48-58, February 1978.

Peterson, W.L. "Returns to Poultry Research in the U.S.," Ph.D. dissertation, University of Chicago, 1966.

Pinstrup-Anderson, P., N.R. de Londono and E. Hoover. "The Impact of Increasing Food Supply on Human Nutrition: Implications for Commodity Priorities in Agricultural Research and Policy," American Journal of Agricultural Economics 58(2):131-142, May 1976.

Ray, S.C. "A Translog Cost Function Analysis of U.S. Agriculture, 1939-1977," American Journal of Agricultural Economics 64:490-498, 1982.

Rose, R.N. "Supply Shifts and Research Benefits: Comment," American Journal of Agricultural Economics 62(4):834-837, November 1980.

Schmitz, A. and D. Seckler. "Mechanizated Agriculture and Social Welfare: The Case of the Tomato Harvester," American Journal of Agricultural Economics 2:569-577, November 1970.

U.S. Department of Agriculture. Costs of Producing Selected Crops in the United States - 1974, 94th Congress Committee Print, Washington, DC: Government Printing Office, January 1976.

U.S. Department of Agriculture, Economic Research Service. "Corn; Soybeans; Wheat; and Cotton: Background for the 1985 Farm Legislation," Agriculture Information No. 471, 472, 467, and 476 respectively, Washington, DC, September 1984.

__________, Economic Research Service. "Firm Enterprise Data System, National Survey of Producers of Agricultural Commodities," conducted by R. Krenz and G. Garst, ERS, 1974 and 1982/83, Stillwater, Oklahoma, unpublished.

__________, Statistical Reporting Service/National Agricultural Statistical Service. "County Planted Acres, Yield and Production Data by Commodity, 1972 to 1983," Edited by J. Brueggan, Washington, DC, available on tape.

U.S. Department of Commerce. Census of Agriculture, Washington, DC: Government Printing Office, 1974 and 1982.

Wise, W.S. and E. Fell. "Supply Shifts and the Size of Research Benefits: Comment," American Journal of Agricultural Economics 62(4):838-840, November 1980.

MEASURING THE REQUIREMENTS AND BENEFITS OF PRODUCTIVITY MAINTENANCE RESEARCH

Leroy Blakeslee*

"Now here, you see, it takes all the running you can do to keep in the same place."

The Red Queen, in Lewis Carroll's
<u>Through the Looking Glass</u>.

INTRODUCTION

Lewis Carroll's Red Queen aptly describes the activities of researchers who work in support of maintaining productivity in modern agriculture. It is broadly perceived that after traditional production practices and cultivars are replaced by those producing higher output, a certain amount of research will be needed to sustain the gains that have been made. It also is argued that the higher agricultural resource productivity becomes, the greater will be the activities needed to maintain the existing productivity level.

Recognition and quantification of the relationships involved has become important for several reasons. Perhaps one of the most important is related to mechanisms for funding agriculture research. While private sector research in support of maintaining agricultural productivity is becoming even more significant, an important component of the total effort remains in the public sector. In the minds of many in the agricultural establishment, there are good reasons for continuing to support public work, but I will not go into them here. However, maintaining this support from legislative bodies dominated by non-farm interests is becoming increasingly difficult, particularly under the present conditions facing U.S. agriculture. One reason is the presumption by some that reduced support for agricultural research and extension will, at worst, merely slow agricultural productivity growth. Some see this as not at all a bad result. Current over-supply conditions in agriculture are creating a major drain on the public treasury, and further increases in productivity are seen as a stimulus to even worse problems.

Those in agriculture generally reject these arguments. The "Red Queen" argument suggests that significant reductions in research support and related extension activities would not merely halt productivity growth. Actual declines may occur. Further, the association of high productivity with oversupply problems misses the point rather badly. Price and supply management policies we have followed, together with a number of macro economic developments affecting international markets, have been the principal causes of our current dilemma.

The remedies that are being sought via the 1985 Farm Bill depend almost entirely for their success on regaining more favorable export performance. Realistically, it is not reasonable to think of the export performance of the early 1980's as a target, but some improvement can be achieved under the right conditions. While effective export marketing depends on many complex factors, there is no more fundamental imperative to an export-oriented industry than that production costs be kept lower than production costs of competing producers abroad. This is true under any circumstances, but never more so than when severe competition is being faced on international markets. Continued research in support of productivity gains here is what makes low-cost production possible. However, the U.S. has no monopoly on the option of improving productivity and lowering production costs of agricultural products through research. High payoffs to public-sector research in support of agricultural productivity are as well documented for foreign countries as they are here. Without question, the present competition we face is partly because others have cashed in on these payoffs. The U.S. can hardly afford a back off in its commitment to maintain low-cost production opportunities here under these circumstances.

---

* Leroy Blakeslee is Professor and Chairman of the Department of Agricultural Economics, Washington State University, Pullman, WA 99164.

Though the case for maintaining the even increasing agricultural resource productivity seems quite clear, the definition of maintenance research seems to be less so. I will proceed with an examination of what maintenance research is perceived to be, and how it is to be differentiated from non-maintenance research. Some evidence on the scope and nature of maintenance research activities will then be considered. Next, I will present some results from attempts to estimate structures formulated specifically to quantify the processes involved. The paper then concludes with some observations about possibilities for future work.

MAINTENANCE RESEARCH--THE BROAD DEFINITION

To many, the concept of maintenance research encompasses a very broad set of activities designed to counter a very broad set of forces that can reduce productivity, or profitability, in commercial agriculture. Somewhat surprisingly, eight different individuals who knew I was preparing this paper have independently recommended Plucknett and Smith's 1986 Bioscience article to me. Their very informative piece adopts what I consider to be a typically broad definition of maintenance research. A reasonable summary statement might be that maintenance research is any research required to maintain resource productivity, or profitability, as a result of changes in the environment surrounding production. For purposes of discussion, three dimensions of environmental change may be distinguished: physical change, economic change, and biological change.

Examples of physical change in the environment causing a need for maintenance research include soil erosion, salt accumulation under sustained irrigated agriculture, and increasing levels of air pollutants. As problems of these kinds emerge, resource productivity under existing production systems may decline unless further research programs are undertaken to develop ways of preventing or correcting emerging problems. Such research activities may represent very high payoff options even though they produce no secular improvement in resource productivity.

Sustained changes in prices of either inputs or farm products also can have the effect of making existing production practices, cropping systems, and cultivars look unattractive to profit-seeking producers. When these occur, research efforts may be needed to develop new production practices, or even entirely new crop and livestock enterprise combinations, for affected areas. Fundamentally, the arguments here rest on the same foundation as induced innovation theory. ". . . technical change is guided along an efficient path by price signals in the market" (Hayami and Ruttan, p. 57). An emerging set of prices can draw forth technology development favoring processes for using low-priced resources and saving expensive ones. But if prices then go on a new path so that even allocatively efficient use of resources with known technology becomes unprofitable, further development of yet newer technology may be called for to restore profitability of production.

Though somewhat of a side issue relative to today's discussion, the themes raised during consideration of the 1985 Farm Bill could have important implications in the future. The rhetoric emphasized a desire to legislate "market-oriented" farm programs. In the Administration's proposed bill, this meant drastically lower loan rates and target prices. The Administration had three objectives: 1) to make our program commodities price competitive, especially in international trade, and to remove the government's role as a buyer; 2) to reduce the role of government payments in farm income; and 3) to eliminate government controls on decision-making on the farm. The legislation enacted did drop loan rates, but target prices were changed little. The first objective was addressed, but the second two were not. It is unclear whether we will move to complete this agenda, or how rapidly if we do. However, in today's political environment, changes in this direction are a distinct possibility regardless of whether they occur in an abrupt fashion as suggested by the Administration, or with provisions for adjustment as, for example, in the Boschwitz-Boren proposed legislation. Resulting economic signals for farmers could well motivate demands for production technologies quite different from those presently in use. Continued, or even accelerated devaluation of land could result and grain production with lower yields per acre and a quite different input mix could be favored. It seems likely that the research establishment would need to undertake major new initiatives in response to such conditions.

The final dimension of environmental change that may trigger needs for maintenance research is biological change. Agricultural production processes are biological in character, and the focus of agricultural research is on improving productivity in biological production systems. Many research activities are directed toward developing direct suppressants of plant and animal pests via pesticides, herbicides, cultural practices, etc. Others emphasize breeding and selecting for crop and animal traits that provide resistance to the pests that are most prevalent and damaging under current field conditions. However, the composition of pest populations is neither constant nor unresponsive to the environment. Farmer adoption of direct suppressants of current pests, and adoption of crop and animals having resistance to existing dominant classes of pests alters the environment in which these pests live. Natural selection then comes into play. Those pests which were formerly prevalent recede in numbers. Successor generations will be dominated by those which can survive, or even thrive, in the new environment created by prior introduction of practices designed to control the earlier generation. The result is that the initial positive productivity effects from introducing such practices, inputs, and genetic strains, can decay over time. This produces requirements for maintenance research to compensate for the loss of productivity resulting from this biological process.

If one adopts the broad definition of maintenance research, then how are we to define non-maintenance research? It would appear that it is any research designed to improve productivity above the best previously attained level, regardless of whether the environment is changed or unchanged. While the distinction between the two is meaningful for certain purposes, it should not be over-emphasized. Plucknett and Smith have noted that "maintenance is an integral part of agricultural research, not a separate category. Upholding yield gains is the core concept of maintenance research, and it applies to all improved crops in both industrial nations and developing countries" (p. 40). The nature of the work undertaken by scientists in pursuing maintenance research is fundamentally no different from that done in non-maintenance research. Benefits from the two are also measured in identical ways. In each case it involves a comparison of results achievable from applying an extra increment of research inputs with results expected when that increment is not applied.

MAINTENANCE RESEARCH--THE NARROW DEFINITION

The narrow definition of maintenance research tends to focus on research activities designed to compensate for biological change in the environment. The origins of this form of maintenance research are not unique to agriculture, but the process whereby these needs arise is certainly more important in agriculture than in most other industries. This is because of the biological character of agricultural production processes mentioned earlier. Here, the <u>adoption</u> of many forms of productivity-increasing technology, by itself, induces biological change in the environment where production occurs. This change carries with it the seeds of subsequent decay or decline in the initial productivity gains achieved by adoption via the mechanisms described earlier. Decay is autonomous to the process.

Undoubtedly, certain forms of agricultural production technology are not subject to decay in this sense. However, it appears to be broadly applicable to many forms of agricultural technology regardless of whether it was developed to counter changes in the physical or economic dimensions of the environment, or whether it was introduced to improve productivity above the best previously attained level. The narrow definition of maintenance research associates it with research activities needed to maintain research productivity in the presence of an unchanged physical and economic environment. Within a given physical and economic environment, production techniques also may be replaced by new ones because the replacements produce better results than the best previously attained with the existing technology. Here, old production practices have become technologically obsolete. Other forms of obsolescence can be said to apply when changes in the economic or physical environment motivate development and adoption of replacement technologies.

In economics, productivity is generally taken to be a characteristic of a physical production process; i.e., a particular process for using well-defined inputs to produce one or more well-defined outputs. Productivity-oriented research is designed to increase the amount of output that can be realized from given input endowments. By extension, an economic definition of maintenance research would be research designed to maintain physical input/output ratios. Productivity obviously affects profitability, but it is not synonymous with profitability. The narrow definition excludes from maintenance research the development of new technologies designed to maintain profitability in the face of changing prices, and research to adapt to changing resource endowments.

A further comment is motivated by reflections on economists' use of the term "productivity." Discussion and illustrations of productivity change are often conducted in terms of crop yields per acre. The earlier quote from Plucknett and Smith is an example. While it may be true that, "upholding yield grains is the core concept of maintenance research," it is worth remembering that production per unit of land is merely the average physical product of the single resource (land). No economist working with a multiple input production process will want to assign overriding significance to the average physical product of a single resource as a measure of productivity for the overall process. Nor will he or she accept a comparison of average physical products of a resource in producing the same output under two processes as a basis for comparing productivity of those processes. Yields per acre, per milk cow, per hour, etc., are often useful productivity indicators, but full analysis requires more detailed consideration of input/output relationships.

Whether one works with a broad or narrow definition of maintenance research, the earlier judgement that it is an inseparable part of an overall agricultural research program still applies. Certainly, any attempt to introduce separate budgeting in support of maintenance research activities would introduce artificial distinctions that have no counterpart in the work actually done by research scientists.

Most of the discussion of work that follows will be based on the narrow definition of maintenance research. This is not to deny the importance of productivity-oriented research and extension motivated by changes in physical or economic conditions. Primarily, it is just to give a more specific focus to the paper, and to recognize the particular importance of biological adaptation as a factor causing a need for continued research to maintain productivity in agriculture.

EVIDENCE OF THE SCOPE AND NATURE OF MAINTENANCE RESEARCH ACTIVITIES

Evidence of biological adaptation among pests and pathogens is widely known. May indicates that hundreds of agricultural pest species are known to have acquired resistance to pesticides designed to control them. Plant breeding activities for many crops, particularly for small grains, concentrates heavily on improved resistance to diseases. Rapid rates of turnover in varieties grown commercially are cited as evidence of maintenance research activity. Ehrlich and Ehrlich indicate that the average life of a wheat variety in the northwestern U.S. is about 5 years. Hawaiian sugarcane varieties last about 10-12 years according to Evenson and Kislev. Others cite similar life spans for corn, cotton, soybeans, oats, and sorghum in the U.S.

Of course, evidence of varietal turnover need not, by itself, be indicative of maintenance research activity. To some degree, new varieties may be adapted because they have higher genetic potential for yields than the best achievable within existing varieties, and not because yields of existing varieties have fallen off. However, conventional wisdom on this matter is that much of the replacement occurs because yields of varieties in use begin to fall or because they are threatened.

Efforts to document specific instances of productivity declines due to biological adaptation have seldom been reported. Swallow, Norton, Brumback, and Buss reported results of two such efforts. Thirty-year trends of yields for three soybean varieties were examined to see if yield deterioration could be measured after controlling for weather and cultural practices. Yield declines were found in each case, but none were statistically significant. A further investigation was conducted to see if yield gains achieved in the Virginia soybean breeding program showed evidence of being less than those theoretically achievable in the absence of biological adaptation. Again, their empirical work did detect such a discrepancy, but statistical results were not conclusive.

Further research to identify and measure specific cases of productivity decline for individual crop and livestock enterprises under controlled conditions would be highly desirable for several reasons. One reason is that they help to provide specific content to descriptions of the biological decay process. However, evidence of this kind is not easily used in estimating aggregate maintenance research needs or payoffs from such research. Instances of biological decay are often episodic, and it is arguable that the frequency of their occurrence can only be described in terms of probabilities. Other work has been done to estimate research-productivity relationships for larger aggregates, and these often have incorporated the decay process, at least implicitly.

It is widely recognized that impacts of most research and extension expenditures on productivity occur with a distributed lag. Research activities require time for completion. Those that produce economically useful results are subject to adoption lags before they reach their maximum use level among producers. Adoption rates may be influenced by extension activities. Finally, impacts on productivity may decline as a result of obsolescence, or as a result of deterioration of the productivity-enhancing effects of new innovations.

In work relating production or productivity to research and extension expenditures, it has been common to estimate parameters of a single lag structure incorporating all of the above causes of lagged response to research and extension expenditure. Published work varies considerably in the degree to which they acknowledge that it is the stock of knowledge held by producers which can be presumed to affect output or productivity, whereas the flow of research and extension expenditure affects productivity through its effect on that stock. A very common finding is that the amount of research and/or extension expenditure in a certain year has impacts on output or productivity which initially rise with the passing of time, possibly remain constant for a time, and then fall to zero. The representation of decay or depreciation effects are, of course incorporated in the parameters of the lag structure. But under this approach, those effects are combined with knowledge generation effects, delivery service generation effects, and adoption rate effects, so that no separate estimates of the parameters of the decay or depreciation process emerge (see for example, Evenson, 1967; Havlicek and White; Lu, Cline and Quance; and White and Havlicek, among many others). Estimates of the lag at which research and/or extension effects on productivity begin to fall do indicate the lag at which negative decay or depreciation effects begin to dominate the other positive effects of research and extension expenditure. It also is possible to use results of these modeling efforts to estimate research and extension expenditures needed to sustain productivity at the observed level of any year while holding all other determinants constant at the level observed in that year. Such expenditures are legitimate estimates of maintenance research and expenditure outlays needed to maintain productivity or output at the level observed. A comparison of the estimated maintenance outlay with actual outlay for the year provides an estimate of the fraction of actual outlay devoted to maintenance.

ESTIMATING RESEARCH AND EXTENSION EFFECTS WITH AN EXPLICIT DECAY PROCESS

This section will present results of a modeling effort relating aggregate U.S. agricultural productivity to aggregate public expenditure on productivity-related research and extension activities. Decay or depreciation of research and extension effects are included explicitly.

Knowledge Creation

The modeling of knowledge creation is based on a conceptualization presented by Evenson in 1967. Let Q_t be defined as "the set of quality improvements of year t that result from research effort in year t, t-1, t-2, etc." (Evenson, p. 1419). More specifically, Q_t measures change in the stock of knowledge existing in year t. The stock of existing knowledge, K_t^*, is to be distinguished from the stock of effective productivity-sustaining knowledge that is actually in use in period t, K_t. Changes in the stock of existing knowledge are created through a "research production function" which contains research inputs R_t, R_{t-1}, R_{t-2}, etc. (measured in expenditure units) and random errors u_t, u_{t-1}, u_{t-2}, etc. By definition, the stock of existing knowledge changes by Q_t each time period. These results are reflected in equations (1) and (2). Here W(L) and C(L)

$$(1) \quad Q_t = W(L)R_t + C(L)u_t$$

$$(2) \quad K_t^* - K_{t-1}^* = Q_t$$

are polynomials in the lag operator L, and $L^s X_t = X_{t-s}$; s=0, 1, 2, . . .

An "extension production function" is introduced in which information transfer services, I_t, are related to current and lagged extension expenditures, E_t, E_{t-1}, E_{t-2}, . . ., and random errors v_t, v_{t-1}, v_{v-2}, . . .; equation (3). H(L) and D(L) are additional polynomials in the lag operator.

$$(3) \quad I_t = H(L)E_t + D(L)v_t$$

Effective knowledge actually used at one time, K_t, is determined by the stock of knowledge used previously, by biological decay or depreciation of the previously used knowledge stock, by new knowledge that is brought into use, and by extension activity. However, adoption lags are involved in bringing recently generated knowledge into actual use. These considerations are captured in equation (4). A(L) is an additional polynomial in the lag operator. It reflects adoption lags. To the extent that the adoption process can be described by a conventional "learning curve" the weights given to lag operators L^0, L^1, L^2, L^3, etc., are expected to be small for low order lags, rise to a peak for intermediate lags, and then fall to zero for high order lags. However, there appears to be no real reason to expect symmetry in this distributed lag function.

$$(4) \quad K_t = (\varphi)K_{t-1} + A(L)(K_t^* - K_{t-1}^*) + rI_t$$

For an adoption process where all newly created knowledge is adopted, and where no obsolescence occurs, the coefficients of lag operators L^0, L^1, L^2, . . . in A(L) would sum to 1.0. But as noted earlier, obsolescence affects research and extension impacts on productivity. Many newly adopted practices and inputs substitute for presently used ones because they produce better results under the same conditions. Thus it is useful to think of A(L) as reflecting adoption of new knowledge above that which is replaced in use via obsolescence. With obsolescence, future knowledge in use, K_{t+s}, never reflects the full change in existing knowledge, K_t^*. This would be associated with a set of coefficients on L^0, L^1, L^2, . . ., which sum to less than 1.0. Other factors may also account for a coefficient total less than unity. Some newly existing knowledge in K_t^* may offer technically feasible production possibilities that are unprofitable. Other knowledge may become technically or economically outmoded before it is adopted because of even newer additions to existing knowledge.

The φ parameter in equation (4) reflects biological decay. While obsolescence affects the transformation of research expenditures into effect knowledge via replacement of knowledge in use, decay occurs even in the absence of replacement. Thus, φ measures the proportion by which the productivity-sustaining capacity of K_{t-1} is reduced in time t as a result of biological adaptation.

Substituting (1) into (2), and then (2) and (3) into (4) yields equation (5). Since we may assume that $0 < \varphi < 1$, successive substitutions

$$(5) \quad K_t = (\varphi)\, K_{t-1} + A(L)\{W(L)R_t + C(L)u_t\} + r\{H(L)E_t + D(L)v_t\}$$

may be made to derive equivalent forms, equations (6) and (7). As opposed

$$(6)\quad K_t = \sum_{s=0}^{\infty} (\varphi)^s A(L)\{W(L)R_{t-s} + C(L)u_{t-s}\} + \sum_{s=0}^{\infty} (\varphi)^s\{r[H(L)E_{t-s} + D(L)v_{t-s}]\}$$

$$(7)\quad K_t = F(L)\{A(L)W(L)R_t + rH(L)E_t\} + F(L)\{A(L)C(L)u_t + rD(L)v_t\}$$

to the other distributed lag functions which are not explicit, F(L) is an explicit distributed lag function, i.e.,

$$F(L) = \sum_{s=0}^{\infty} (\varphi)^s L^s.$$

It was noted earlier that most research has estimated parameters of a single lag structure on research and/or extension expenditure in productivity modeling. Often research and extension expenditures are aggregated in some fashion because of difficulties in estimating parameters of separate lag functions for each. Referring to equation (7), this imposes restrictions linking the lag function applicable to research expenditures, F(L)A(L)W(L), and that for extension expenditures, F(L)H(L), in addition to the restriction which follows from the common factor F(L). In extreme cases, they are assumed to be identical. Because of difficulties in estimating separate effects of several serially correlated aggregates of current and lagged R and E expenditures, it is usual to impose restrictions on the set of their coefficients. Examples include requiring that they follow an "inverted V" pattern (Evenson, 1967), or that they lie on a second degree Almon polynomial with zero end-point restrictions (Lu, Cline, and Quance; Havlicek and White; White and Havlicek). With this approach, estimates are then made of the parameters of a single, overall, lag function through which output or productivity is affected by aggregates of lagged R and E expenditures. In such cases coefficients of the decay process (φ in this case) cannot be determined.

The Model

The basic productivity model appears in equation (8).

$$(8)\quad Y_t = a + b_1X_{t1} + b_2X_{t2} + cK_t + e_t$$

All variables except X_{t2} are measured in logarithms.[1] Y_t is USDA's index of aggregate resource productivity in U.S. agriculture for year t. X_{t1} is percent of the U.S. population 25 years old or more who had completed high school in year t.[2] X_{t2} is a weather index for year t. Index values estimated by Stallings and Kost were updated by regressing the U.S. crop yield index on time, calculating the ratio of actual to predicted yield for each year, and splicing this series to the Stallings-Kost index series. K_t is the stock of effective knowledge actually used in year t. The residual, e_t, is a random error such that $e_t = \rho e_{t-1} + \epsilon_t$, and the ϵ_t are assumed to be independent normally distributed random variables with mean = 0 and variance = σ^2.

The model posits that the stock of effective knowledge used in year t is determined as in equation (9). Equation (9) is based directly on equation (7). However, it is in logarithmic form. R_t and E_t are aggregate production-oriented public expenditures on research and extension, respectively, each divided by the implicit deflator for government goods and services purchases. Errors in the knowledge and extension service generating processes are ignored except that allowance is made for first-order autocorrelation in residuals to the productivity equation. The single parameter in the lag function F(L) is estimated explicitly so that a unique estimate of the depreciation effect emerges. The product of the knowledge generation and adoption lag functions applicable to research expenditures, A(L)W(L), is represented as a single lag function. A separate, simple "lag function" for extension expenditures, $H(L) = \alpha L^0$, is employed on the assumption that there is no lag between commitment of resources to extension and generation of information-delivery services.

$$(9) \quad K_t = \sum_{s=0}^{\infty} \varphi^s (\alpha E_{t-s} + \sum_{p=0}^{M} \beta_p R_{t-s-p})$$

Substituting (9) into (8) and writing γ and π_p for $c\alpha$ and $c\beta_p$, respectively, yields equation (10).

$$(10) \quad Y_t = a + b_1 X_{t1} + b_2 X_{t2} + \gamma \sum_{s=0}^{\infty} \varphi^s E_{t-s} + \sum_{p=0}^{M} \pi_p \sum_{s=0}^{\infty} \varphi^s R_{t-s-p} + e_t$$

The parameters to be estimated are a, b_1, b_2, ρ, φ, $\gamma = c\alpha$, and $\pi_p = c\beta_p$, $p = 0, 1, \ldots, M$. Parameters c, α, and β_p are not identified, but the indicated functions of them are.

The coefficients π_p are further constrained to lie on an Almon polynomial having parameters λ_d, equation (11), and

$$(11) \quad \pi_p = \lambda_0 + \lambda_1 p + \cdots + \lambda_D p^D = \sum_{d=0}^{D} \lambda_d p^d \; ; \; p = 0, 1, \ldots, M$$

restrictions may be placed on the polynomial corresponding to requirements that either $\pi_0 = 0$, $\pi_M = 0$, or $\pi_0 = \pi_M = 0$. Thus, the parameters λ_d are estimated directly, and parameters π_p are estimated indirectly in terms of λ_d and p.

Principal interest centers on estimating the rate of decay in the productivity-sustaining capacity of knowledge generated through research and extension, and the overall impacts of research and extension expenditures on productivity. Here, φ estimates the elasticity of current effective knowledge with respect to effective knowledge existing one period earlier. The extent to which φ is less than 1.0 is a measure of depreciation of the productivity-sustaining capacity of knowledge used by producers. Elasticities of productivity with respect to current and previous extension expenditures are calculated as in equation (12). Elasticities with respect to research expenditures may be

$$(12) \quad \partial Y_t / \partial E_{t-s} = \gamma \varphi^s \; ; \; s = 0, 1, 2, \ldots$$

calculated recursively as in equation (13).

$$(13) \quad \partial Y_t / \partial R_{t-s} = \begin{cases} \pi_0 & ; \; s = 0 \\ \varphi \partial Y_t / \partial R_{t-(s-1)} + \pi_s & ; \; 1 \leq s \leq M \\ \varphi \partial Y_t / \partial R_{t-(s-1)} & ; \; s > M \end{cases}$$

Estimation

The appearance of summation indices running to infinity in equation (10) is the principal factor complicating estimation. The method for handling the problem is a variant on one suggested by Just (1974, 1977) and Estes, et al. Finite approximations to the infinite sums in equation (10) are used. Estimation proceeds by using an iterative non-linear least squares approach appropriate for a first-order autoregressive error structure. The sum of squares function is concentrated on the parameter φ. Search over the range $0 < \varphi < 1$ is then employed to find the φ value within a tolerance of .0001 that minimizes the sum of ϵ_t^2 values, together with associated estimates of other parameters.

Just (1977) has shown that though such estimates are not truly maximum likelihood estimators, they asymptotically approach maximum likelihood estimators for large sample size. This motivates use of the inverse of the information matrix for calculating estimates of asymptotic standard errors of coefficients.

As with most approaches using Almon polynomials, it is necessary to search over alternative D and M values and alternative end-point restrictions. An end-point restriction corresponding to $\pi_M = 0$ was imposed in most cases and the initial search focused primarily on a D value of 2 and a substantial range of M values. Results suggested that D = 1 produced polynomial "shapes" similar to those for D = 2, and results that were otherwise superior for all M values. The criterion for selecting final results was minimum standard error of estimate (SEE) among outcomes that were economically meaningful.

Results and Analysis

Table 1 presents parameter estimates and related statistics for the equation best representing the relationship between aggregate resource productivity in U.S. agriculture and education, weather, and aggregate public R and E expenditures. The π_p values have been constrained to lie on a first degree Almon polynomial with a maximum lag of 7 years, and it is constrained so that $\pi_7 = 0$.

Table 1. Productivity Model Results Using a Linear Almon Polynomial with 7-Year Maximum Lag and Restriction $\pi_7 = 0$.

Parameter	Parameter Estimates	Asymptotic Standard Error[a]
a	1.5346	.2957
b_1	.2600	.1003
b_2	.0030	.0007
γ	.0402	.0404
λ_0[b]	.0085	.0033
φ	.7734	.0857
ρ	.1563	.1686

$F(6, 33) = 310.8$
Durbin-Watson d = 1.83[c]
$R^2 = .983$
Standard Error of Estimate = .0252[c]

[a] From the inverse of the information matrix.
[b] The estimate of λ_1 (-.0012) may be determined from the restriction $\hat{\pi}_7 = \hat{\lambda}_0 + \hat{\lambda}_1 7 = 0$.
[c] Calculated using estimates of ϵ_t.

All coefficients have the expected signs, and except for $\hat{\gamma}$ and $\hat{\rho}$, all are at least 2.5 times their standard errors. A one percent increase in the education index is estimated to produce a .26 percent increase in productivity, and a unit increase in the weather index is associated with a .3 percent increase in productivity. The estimated coefficient of the AR1 error process is only .16. This small value and associated standard error are evidence of only modest first order serial correlation in the e_t.

Research and extension effects on productivity are reflected in estimates of γ, λ_0, λ_1, and φ. The elasticity with respect to current extension expenditure is estimated to be .04, but its relatively high standard error suggests caution in accepting this value. The π_p coefficients are estimated as $\hat{\lambda}_0 + \hat{\lambda}_1 p$; $p = 0, 1, \ldots, 7$; and $\hat{\lambda}_0$ appears to be estimated with reasonable precision. The coefficient λ_1 is estimated from the restriction $\hat{\lambda}_1 = -\hat{\lambda}_0/7$, so that subject to this restriction, the ratio of this estimate to its standard error is the same as for $\hat{\lambda}_0$. Accordingly, the set of $\hat{\pi}_p$ estimates form a linearly declining sequence starting at .0085 for $p = 0$ and falling to 0 for $p = 7$. This suggests that public research expenditures have their greatest impact on undepreciated new knowledge used by farmers in the year when the expenditure is made, and that the lagged effects decline monotonically to zero after 7 years. Alternatively, this implies that for a typical mix of research expenditures in any year, the greatest share goes for activities having immediate impacts, or for activities that "pay off" in a short time, and lesser shares go for activities that will first be used by farmers after a longer delay. Most conventional descriptions of knowledge generation and adoption processes related to agriculture suggest a set of π_p coefficients that would first increase with p, and then decline to zero for larger p. The conventional expectation would also call for non-zero π_p values at lags substantially higher than 7.

The estimate of φ suggests that a one percent increase in the stock of effective knowledge used by farmers in one year, ceteris paribus, will result in only a .77 percent increase in the following year's stock. The complement, .23 percent, represents depreciation in the effective stock (its productivity-sustaining capacity) due to biological adaptation. Further, this decay process is a continuing one so that the elasticity of effective knowledge used in year t with respect to effective knowledge used in year t-s is estimated to be $.77^s$.

Productivity, as modeled here, depends on the current stock of knowledge, which, in turn, is defined in terms of present and all past research and extension expenditures. Using equations 12 and 13, together with parameter estimates in Table 1, elasticities with respect to R and E expenditures lagged any number of time periods can be estimated. Such estimates for lags of 1 through 15 years are shown graphically in Figure 1. Each set of elasticities is displayed as a continuous curve to facilitate presentation, but the actual elasticities are only defined for integer-valued lags. As Figure 1 shows, both elasticities approach 0 as the lag goes to infinity, but the research elasticities increase up to a lag of about 3 years before starting an asymptotic decline, while the extension impacts decline from the outset. Initial elasticities with respect to extension expenditures are much higher than those for research, but for lags of 4 or more, the rankings are reversed.

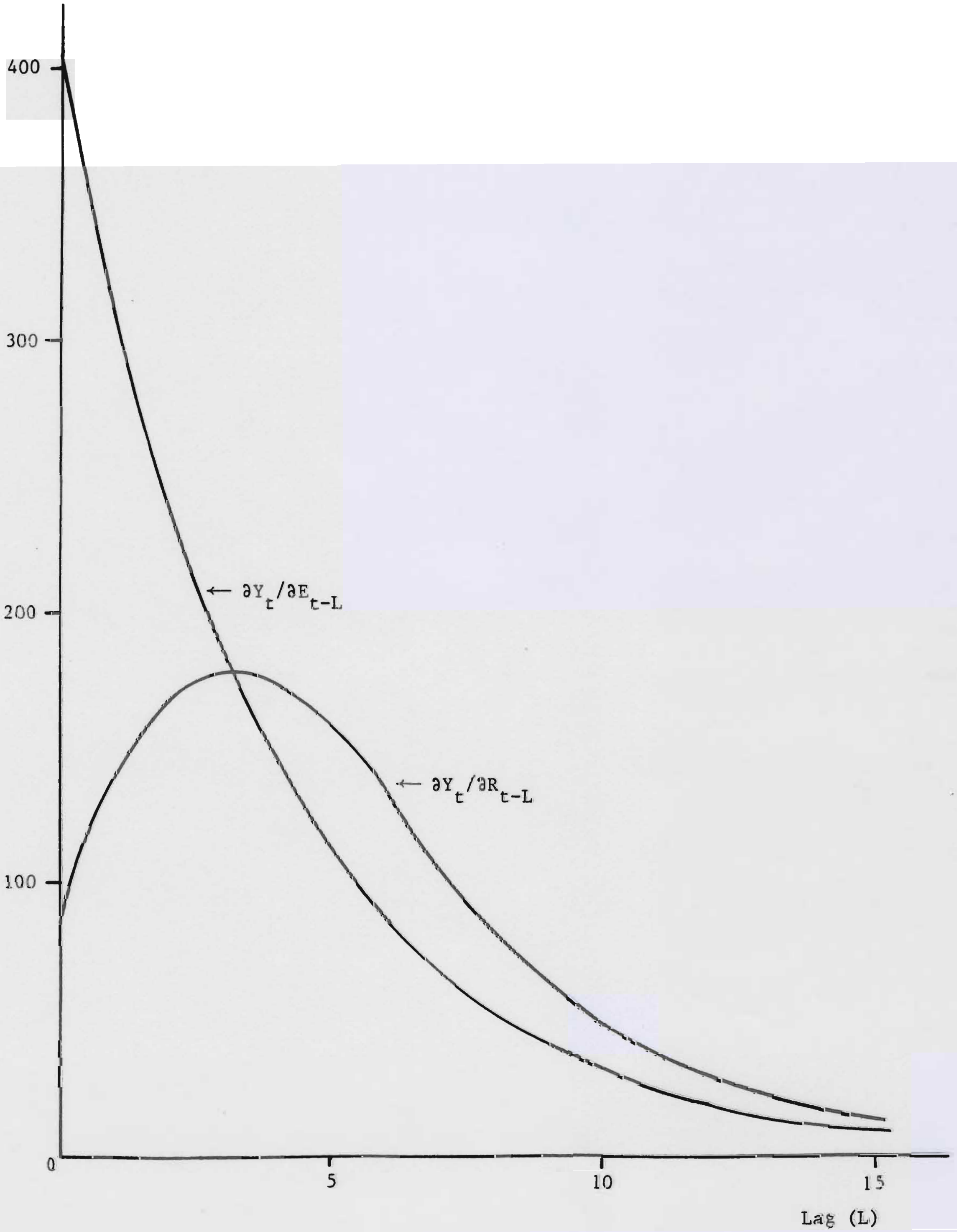
These results may also be used to estimate

$$\sum_{s=0}^{\infty} \partial Y_t / \partial R_{t-s} = .1501 \text{ and}$$

$$\sum_{s=0}^{\infty} \partial Y_t / \partial E_{t-s} = .1775,$$

so that the estimated long-run elasticity with respect to extension expenditures is found to be about 18 percent higher than that for research expenditures. Mean 1942-81 productivity, research expenditures, and extension expenditures were used to convert these long-run elasticities to long-run marginal effects of R and E expenditures on productivity. The

Figure 1. Research and Extension Expenditure Effects on Productivity ($x10^4$).



results suggest that at the margin, an additional dollar allocated to extension activities had an impact on productivity 4.57 times as large as the effect of an additional dollar spent on research.

The seemingly large effects of extension expenditures relative to research expenditure effects are, of course, subject to considerable uncertainty. The estimate of γ establishes the "height" of the $\partial Y_t/\partial E_{t-s}$ curve in Figure 1, and judging from standard errors, it is estimated with substantially less reliability than any other essential coefficient in the model. Indeed, at the outset of the study, reviews of prior research led us to expect no success in estimating separate research and extension effects because of correlation among education, research expenditures, and extension expenditures. It was only after finding promising results with structures that combined these effects that the present formulation was examined.

Results from this model were subjected to one further statistical test. The hypothesis that neither research nor extension expenditures affect productivity was examined by testing the hypothesis $\gamma = \lambda_0 = \varphi = 0$ using an asymptotic likelihood ratio test.[3] Under the null hypothesis, the test statistic is asymptotically distributed as Chi-square with 3 degrees of freedom. The calculated value, 14.9, leads to rejection of the null hypothesis at the .005 level of significance. This provides very strong evidence against the possibility that all these parameters are equal to zero.

Results Under Alternative Specifications

As noted earlier, the above results were selected after examining estimation outcomes under a variety of specifications of degree (D), maximum lag (M), and end point restrictions on the Almon polynomial. Some lack of robustness was expected and observed because of correlation among the data on explanatory variables. However, an unexpected form of non-robustness also emerged. For given D, M, and end-point restrictions, the estimation technique employs a systematic search of the sum of squares function for $\hat{\varphi}$ values in the range of .0001 $\leq \hat{\varphi} \leq$ .9999. The logic against $\hat{\varphi}$ values very close to 0 (immediate total decay) or 1 (no decay) seemed sufficiently strong that we expected the minimum sum of squares to always be associated with a $\hat{\varphi}$ value "comfortably" away from either end point. This frequently was not the case, though the reasons are not clear. When this occurred, however, the overall fit was always inferior to results with other D, M and end point restrictions where an interior optimal $\hat{\varphi}$ value was found.

The principal points that emerge from examining alternative specifications are:

1. Polynomials having an "inverted V" shape are found only when the constraint $\pi_0 = 0$ is imposed, and associated SEEs are higher than without this constraint. Even with third degree polynomials that were examined but not reported, the statistical evidence favors polynomials that initially fall with positive lags.

2. Estimates of b_1 and γ are unstable, though those associated with the equation judged to be best are centrally located within the set of estimates obtained with other specifications.

3. Long-run estimated research impacts are more robust across alternative specifications than are extension impacts. Finally, a related study of the relationship between wheat yields and wheat production oriented research expenditures in Washington was conducted using a similar model formulation (Heim and Blakeslee). Here also, the best representation of the relationship involved a declining first degree Almon polynomial with a 7-year maximum lag.

Maintenance Research and Extension Expenditures

Decay of the ability of knowledge to sustain agricultural productivity due to biological adaptation implies that some level of continuing expenditure is necessary if a productivity decline is to be avoided. The productivity model estimated here was used to estimate the fraction of actual R and E expenditure that was required for productivity maintenance in each of the 40 years from 1942 to 1981. Two sets of measures were calculated. For the first set of measures, expenditures required to generate a current year expected productivity equal to last year's level were calculated for each year. Actual expenditure in years t-1, t-2, . . ., were used in this calculation. Results were expressed as a percent of actual current year R and E expenditure and they appear in Figure 2 as the broken line.

The historical time series on real research and extension expenditure trends upward. If one simply stopped the growth of expenditure at some time and held it constant thereafter, productivity would decline asymptotically to some lower level as the decay process affected knowledge generated by more recent expenditures. For the second set of maintenance expenditure measures, the model was used to determine the level of expenditure which, if continued indefinitely, would permit maintenance of expected productivity at the level observed in each year. This "steady state" expenditure level for each year was expressed as a percent of actual expenditure, and results are plotted as the solid line in Figure 2.

In the early 1940's, the start of the period under consideration, real research and extension expenditures were well below those of the late 1930's. Existing productivity levels were reflecting these substantially higher expenditures in the immediately preceding years since not enough time has elapsed for decay to diminish their effects significantly. This is reflected in Figure 2 by estimates showing that maintenance-level expenditures were actually higher than total expenditures. Maintenance expenditure as a percent of total declined thereafter as expenditures recovered and continued to increase. Though fluctuations occurred, no apparent trend in the maintenance expenditure percents is visible from the late 1940's through the late 1960's. However, from the mid-1970's onward, both sets of percentages seem to be on a higher plateau.

The percent of actual expenditure needed to maintain previous year's expected productivity is inherently more volatile than the steady-state expenditure needed to maintain current productivity. The former is more sensitive to the pattern of expenditure in the recent past than is the latter. However, both indicators suggest that very substantial portions of current expenditures are required to maintain productivity and lesser fractions are contributing to further increases in resource productivity. Since 1973, roughly 70-80 percent of each year's research and extension expenditure was needed just to maintain the prior year's expected productivity. However, real expenditures increased in all but one of these years. If expenditure growth had stopped in any of these years, expected productivity in subsequent years would have declined. Annual expenditures necessary to sustain each year's productivity indefinitely are higher. Figure 2 shows that since 1972 such expenditures have been about 90 percent of actual expenditures in each year.

Of course, expenditures along each line in Figure 2 generally relate to maintenance of productivity at increasingly higher levels as time progresses. Estimates of expected productivity given mean weather and actual educational attainment, and lagged research and extension expenditures increase monotonically in each year since 1944. This is due not only to generally rising real expenditure but also to monotonically increasing levels of general education.

SUMMARY AND OBSERVATIONS ON FUTURE WORK

Available evidence that focuses specifically on depreciation of research and extension effects for individual crops is fragmentary and inconclusive. Further work to document and quantity specific cases should add substantially to our understanding of the processes that are at work in generating maintenance research requirements.

The exploratory work reported here in which aggregate resource productivity in U.S. agriculture is related to public expenditures on research and extension and other variables suggests that productivity-sustaining effects of public expenditures decay quite rapidly. These results further suggest that about 90 percent of recent research and extension expenditures have been required to maintain productivity.

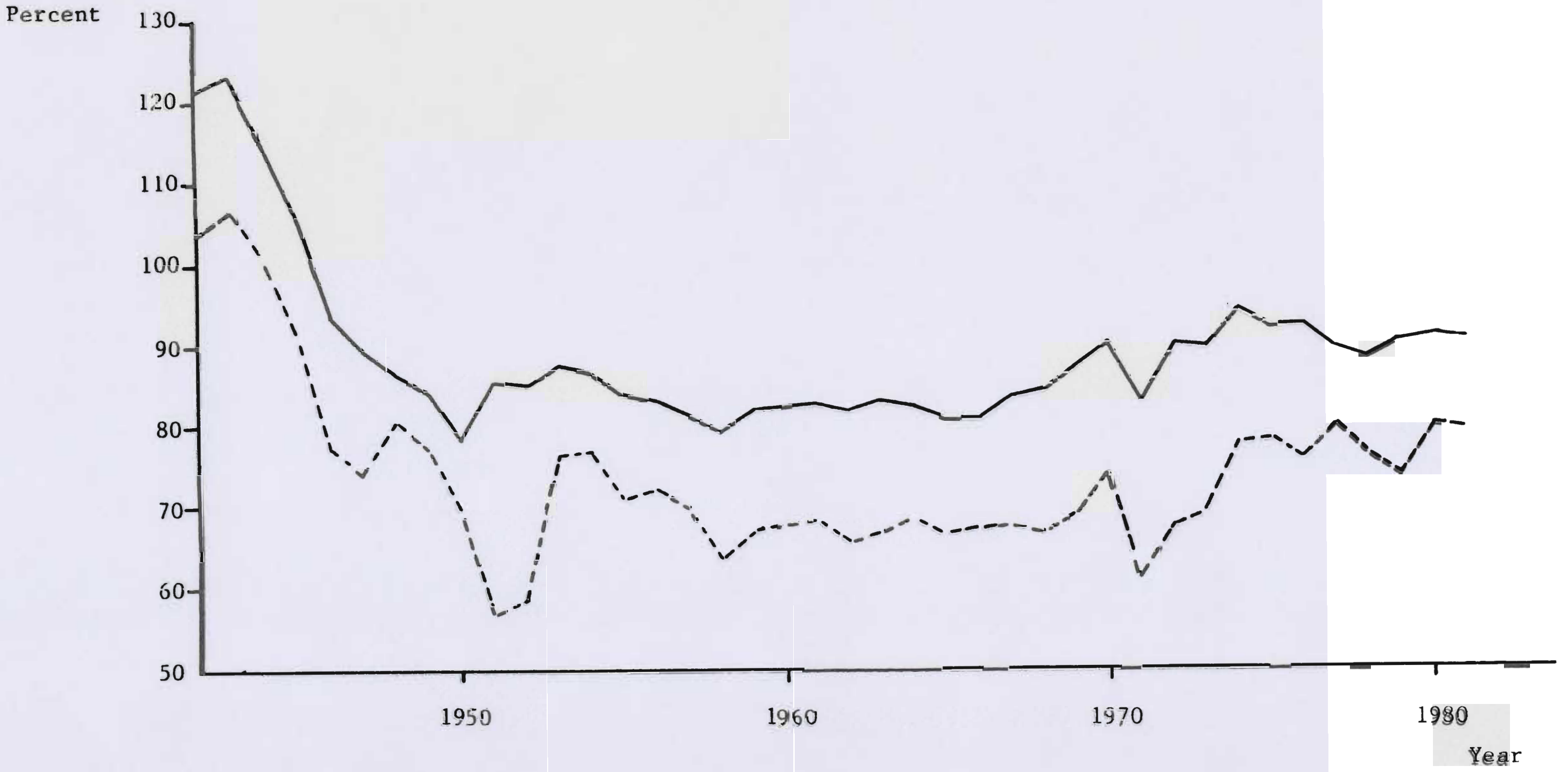


Figure 2. Percent of Actual R and E Expenditure Required to Achieve Last Year's Productivity (- - -), and to Sustain Each Year's Productivity Indefinitely (——).

An analog to Plucknett and Smith's observation that, "maintenance is an integral part of agricultural research," seems applicable to research on research productivity. That is to say, measuring depreciation of research effects, and hence maintenance research requirements, is an integral part of measuring overall agricultural research productivity. Unfortunately, the process whereby research and extension efforts are translated into productivity change is extremely complex.

Some of the complexities lie in the lag structures that are involved. To estimate depreciation rates, one must not only specify a particular depreciation process, but also separate lag structures reflecting other processes that give rise to lagged effects. For econometric applications, this requires use of considerable a priori knowledge, and it is not clear that our knowledge base is adequate for these requirements. Several examples appear in the work reported here. Depreciation effects are introduced by positing that productivity-sustaining capacity of existing knowledge declines geometrically. This may be a reasonable simplifying approximation, but it is by no means the only possibility. The best fitting weights for the process modeling combined knowledge creation and adoption were found to monotonically decline with increasing lag, and reach zero in only 7 years. Most previous work places restrictions on the weights that essentially force them to risk initially with increasing lag. Justifications typically cite long lags for knowledge creation and adoption as the reason. It is not clear that this reasoning takes proper account of the fact that some (perhaps many?) research dollars pay for "brush fire" work by research in which "off the shelf" knowledge is used to formulate remedies to newly experienced problems. In other cases, progressive farmers go directly to researchers for their results. In these instances, research dollars are paying for extension-like services having immediate payoffs that may be very high. Even for long-lived research efforts, the distribution of research expenditure over the life of the project can be skewed toward the "payoff end," and this too can affect the pattern of lagged expenditure coefficients. It also is conventional to reject negative coefficients on lagged expenditures as contradictory to a priori knowledge. Even in this case, I am not totally convinced. When "last adopters" are forced to take on new practices that they are not equipped to handle, either because of management ability or resource availability, it is not clear that the effects on aggregate productivity will be non-negative. Such issues need attention in future work.

More general problems related to functional forms for productivity models may also yield useful insights if pursued. In most empirical work, a variety of functional forms may give satisfactory results in many applications so long as little extrapolation is involved. Multiplicative Cobb-Douglass-like forms for a productivity model allow for important interactions without unduly complicating estimation. However, a model like that described earlier implies that if research or extension expenditure in any year is zero, then productivity will be zero for all years thereafter. Alternative specifications that allow for interaction, but do not force productivity to approach zero as research approaches zero, would be of interest. However, the econometric problems are likely to be formidable.

In my view, reliable quantification of the mechanisms through which maintenance research requirements arise remains to be accomplished, but the fragmentary evidence available suggests that payoffs from maintenance research are high. I believe that this subject deserves continued attention in the agenda of "research on research" as we seek continued understanding and support of efforts to maintain and improve productivity in agriculture here and abroad.

FOOTNOTES

1. With this formulation, a zero value of the educational attainment measure or for any current or lagged research or extension expenditure implies a zero current productivity index value. Clearly, this is not tenable. This formulation is used because it affords a relatively simple way to allow for falling marginal impacts of key variables and interaction between them. As with most applied work of this kind, results should be taken as reasonable appropriations only within the range of data actually observed and for modest extrapolations. Nevertheless, the limitations of the logarithmic form in this application may be more serious than in most.

2. This is not the educational attainment index used by White and Havlicek. Their's is an updated version of one constructed by Evenson, and also used by Cline and Lu, Cline and Quance. However, it is questionable whether information is available for a consistent updating. The original index was constructed so that, conceptually, its value in each year is a weighted average of factors reported by Welch which estimate relative earning capacities of workers in U.S. agriculture with different schooling in 1959. The weights applied to each of Welch's factors for any year are to measure the fraction of agricultural manpower that had the associated schooling level in that year. The implicit assumption that Welch's weights are constant and appropriate for agriculture in all years during 1939-81 is not appealing. Further, the index values for most of the first 20 years actually appear to be interpolations between the very few points where available data permitted direct calculations.

   Percent of the U.S. population completing high school is also only a proxy for the correct index, and many interpolations were again necessary for the early years. However, it is readily accessible and, on balance, may serve as well as the alternative. Empirically, both have similar properties. For the overlap years (1939-72), the simple correlation is .99. Both series contain strong trends, and the partial correlation between the 2, conditional on linear trend, is .36.

3. Note that since estimation was performed under a restriction on the Almon polynomial such that $\lambda_1 = -\lambda_0/7$, this is equivalent to the hypothesis $\gamma = \lambda_0 = \lambda_1 = \varphi = 0$.

REFERENCES

Cline, P.L. "Sources of Productivity Change in United States Agriculture." Ph.D. thesis, Oklahoma State University, 1975.

Ehrlich, P.R. and A.H. Ehrlich. Extinction. New York: Random House, 1983.

Estes, E.A., L.L. Blakeslee, and R.C. Mittelhammer. "On Variances of Conditional Least-Squares Search Parameters." Amer. J. Agr. Econ. 63(1981):141-145.

Evenson, R.E. "The Contribution of Agricultural Research to Production." J. Farm Econ., 49(1967):1415-1425.

Evenson, R.E. and Y. Kislev. "Agricultural Research and Productivity." New Haven: Yale Univ. Press, 1975.

Havlicek, J. Jr. and F.C. White. "Interregional Transfers of Agricultural Research Results: The Case of the Northeast." J. Northeastern Ag. Econ. Council, 12(Fall, 1983):19-30.

Heim, M.N. and L.L. Blakeslee. "Biological Adaptation and Research Impacts on Wheat Yields in Washington." Unpub. paper presented at annual meeting of the Amer. Agr. Econ. Assoc., Reno, NV, 1986.

Hyami, Y. and V.W. Ruttan. Agricultural Development: An International Perspective. Baltimore: Johns Hopkins Press, 1971.

Just, R.E. "An Investigation of the Importance of Risk in Farmers' Decisions." Amer. J. Agr. Econ., 56(1974):14-25.

_________. "Estimation of an Adaptive Expectations Model." Int. Econ. Rev., 18(1977): 629-644.

Kost, W.E. "Weather Index, 1950-1963." Quart. Bull., 47(1964): 38-42, Michigan State Univ. Agr. Exp. Sta.

Lu, Yao-chi, P.L. Cline and L. Quance. Prospects for Productivity Growth in U.S. Agriculture. Agr. Econ. Rept. No. 435, USDA, ESCS, Washington, D.C., 1979.

May, R.M. "Evolution of Pesticide Resistance." Nature, 315(1985):12-13.

Plucknett, D.L. and N.J.H. Smith. "Sustaining Agricultural Yields." BioScience, 36(1):40-45, 1986.

Stallings, J.L. "Indices of the Influence of Weather on Agricultural Output." Ph.D. thesis, Michigan State University, 1958.

Swallow, B.M., G.W. Norton, T.B. Brumback, Jr. and G.R. Buss. Agricultural Research Depreciation and the Importance of Maintenance Research. Dept. of Agri. Econ. A.E. 56, Virginia Polytechnic Institute and State University, 1985.

U.S. Department of Agriculture, ERS. Economic Indicators of the Farm Sector Production and Efficiency Statistics, 1983. ECIFS 3-5, Washington.

U.S. Department of Commerce, Bureau of the Census. Current Population Reports, Population Characteristics, Educational Attainment in the U.S., March 1981 and 1980. Series P-20, No. 390, Washington, D.C.

Welch, F. "Measurement of the Quality of Schooling." Amer. Ec. Rev., LVI:379-392, 1966.

White, F.C. and J. Havlicek, Jr. "Optimal Expenditures for Agricultural Research and Extension: Implications of Underfunding." Amer. J. Agr. Econ., 64(1982):47-55.

THE AGRICULTURAL KNOWLEDGE PRODUCTION FUNCTION: AN EMPIRICAL LOOK

Philip G. Pardey*

INTRODUCTION

Economic analysis of the process of technical change has often involved macro-level studies of its causes and consequences. Relatively little attention has been given to the more fundamental knowledge generation process itself. This stems in large part from the real difficulties of obtaining appropriate indicators of research output.

The view that there exists a systematic relationship between research expenditures and knowledge increments has been taken up by numerous authors including Evenson (1968), Minasian (1969), Pakes (1978), Griliches (1979), and Kamien and Schwartz (1982). It follows naturally from the perception that, in general, science progresses by a sequence of marginal improvements rather than a series of discrete and essentially sporadic breakthroughs (see Burke [1978]).

Recent studies by Pakes and Griliches (1980), Hausman et al. (1981), and Hall et al. (1984) have sought direct estimates of the research input-output relationship for research performed by private firms in the non-agricultural sector. To date there appears to be no similar analysis of the public sector agricultural research process. The study reported here represents a first step in this direction. It develops some quantifiable indicators of agricultural knowledge production by the U.S. public sector research system and will also attempt to provide some clues as to the nature of the agricultural research spending-research output relationship.

I. MODEL SPECIFICATION

A stylized model of the relationship between the research inputs and knowledge output of the State Agricultural Experiment Stations (SAES) will be presented. It draws on the approach first sketched by Pakes (1978) and later used by Pakes and Griliches (1980) to study the patent-R&D expenditure relationship in the non-agricultural sector. The exploratory nature of this study dictates a rather parsimonious approach to modelling the knowledge production process so the model developed here represents a fairly simplified version of reality. Nevertheless it purports to be a useful framework in which to study, both the 'quality' of various publication measures as indicators of gross additions to the stock of knowledge, and the nature of the lagged relationship between research expenditures and publication output.

We begin with the notion of a quite simple knowledge production function (K.P.F.) whereby gross scientific knowledge increments, $\dot{K}_t^g$, are primarily a function of current and lagged research expenditures

$$\dot{K}_t^g = g(\ c(L)R_t\ ,\ v) \tag{1}$$

where, $\dot{K}_t^g$ represents increments in the gross stock of scientific knowledge in time period t; $C(L)R_t$ a weighted sum of current and past research expenditures; and v a vector of other factors which contribute to $\dot{K}_t^g$. Cognizant of the panel nature of the data used here a more explicit version of (1) can be written as

$$\dot{K}_{it} = \tilde{\theta} + \sum_{s=0}^{S} \tilde{\beta}_s R_{i,t-s} + \tilde{\mu}_i + \tilde{\lambda}_t + \tilde{\omega}_{it} \tag{2}$$

---

* Philip Pardey is jointly a Research Associate in the Department of Agricultural and Applied Economics, University of Minnesota, St. Paul and a Research Officer, International Service for National Agricultural Research, The Hague, Netherlands. Michelle Hallaway, Denise Farnwalt and Brian Stockland shared the burden of collecting the inordinately large amount of data required for this study. Errors of fact or judgement remain the author's.

where, $\tilde{\theta}$ represents an intercept term; $\dot{K}_{it}$ the gross scientific knowledge increment for state i in time period t; $\tilde{\mu}_i$ a state specific (time invariant) variable; $\tilde{\lambda}_t$ a time specific (state invariant) variable; $R_{i,t-s}$ state level deflated research expenditures lagged s time periods; and $\tilde{\omega}_{it}$ residual influences on $\dot{K}_{it}$ which are assumed to vary over both state and time periods.[1]

The $\tilde{\mu}_i$ variable represents state-specific differences in research efficiency which are assumed to be uncorrelated with time. This interpretation is analogous to similar variables purporting to measure managerial efficiency in more traditional production function studies. At a more fundamental level, the variable reflects differences in either the particular research agenda faced by each experiment station (i.e. their technological opportunities) and/or institutional factors which are conducive to a more-or-less productive research effort. While states clearly share a number of common agricultural production and distribution problems, there is certainly a significant class of problems which is state specific in nature given the varying requirements placed on agricultural production processes by location, specific economic, political and geo-climatic influences.

The $\tilde{\lambda}_t$ variable represents time specific shifts in the productivity of the research process. With much agricultural inquiry being of a downstream nature, discoveries in the complementary 'core' sciences at the upstream end of the spectrum, along with non-quantified improvements in scientific instrumentation and research hardware will act, inter-alia, to enhance the research productivity of the agricultural sciences over time. It is expected that this time specific variable would, in general, be positively related to $\dot{K}$.

Lastly, the $\tilde{\omega}_{it}$ term is taken to reflect the inherently stochastic nature of the research process or, alternatively, captures the combined influences of omitted time-varying factors specific to the i^{th} state. These three terms, $\tilde{\mu}_i$, $\tilde{\lambda}_t$ and $\tilde{\omega}_{it}$ jointly represent the variables captured by the v term in equation (1).

Given the unobservable nature of $\dot{K}$, we require a suitable indicator in order to make the model operational. State specific increments to the gross stock of scientific knowledge may be directly embodied in a variety of observable outputs. These include publications in scientific journals, patented and non-patented output such as new mechanical innovations and processes or new biological material and finally, other publications such as books, station bulletins, newsletters and the like. Of course not all new knowledge is embodied in these indicators. A certain number of findings are extended beyond the laboratory bench via direct contact with potential users either through telephone contact, public media releases or on-farm visits.

Here aggregate publication performance is used to directly proxy the quantity of agricultural knowledge produced by each of the experiment stations. Given the institutional and incentive structure under which SAES researchers operate it seems reasonable that publications more completely capture the knowledge output of the stations than alternative output proxies such as patents[2]. Publications afford researchers a means of establishing intellectual property rights over their work which will ultimately affect their salary scale, promotion rate, and tenure status. The ability to make some adjustments for variations in scientific quality also add substantially to its appeal as a direct measure of scientific output. This represents a significant advantage over studies of the patent-R&D expenditure relationship where the ability to make plausible adjustments for quality variations is not as readily available.

The quality adjustment made in this study give rise to two alternative measures of research output, namely

(1) raw publication counts, and
(2) constant quality publication counts.

The indicator function in which P_{it} represents the (constant quality) publication output of state i in period t is given by

$$(3) \qquad P_{it} = \tilde{\tilde{\theta}} + \alpha \dot{K}_{it} + \tilde{\tilde{\varepsilon}}_{it}$$

where the error term is decomposed into three components such that

$$\tilde{\tilde{\epsilon}}_{it} = \tilde{\tilde{\mu}}_i + \tilde{\tilde{\lambda}}_t + \tilde{\tilde{\omega}}_{it} \tag{4}$$

The $\tilde{\tilde{\mu}}_i$ variable represents state specific differences in the average propensity to publish. The number of publications realized from a particular level of research activity represents the joint influence of the institutional environment, as it influences the rewards accruing to those who publish, the (aggregated) utility functions of those who do the research, and the publishing traditions of the particular scientific disciplines represented at each experiment station.

For instance, SAES may vary in the emphasis they place on (non-refereed) publication mechanisms for extending the results of their research projects, depending in part on the demands of their clientele groups. This reflects the derived demand aspects of publication output. Furthermore, SAES administrators may vary in the emphasis they place on publication output as an indicator of the research productivity of their research staff. To the degree this affects their reward structure it acts as an incentive or disincentive to generate publications and thereby affects the supply of publication output (see Hansen et al. [1978])^3. As a qualification to these influences it is likely that researchers effectively operate in a national market so that state level differences in publication incentives may not have a strong or measurable impact on the propensity to publish.

The $\tilde{\tilde{\lambda}}_t$ variable captures influences on the propensity to publish which change over time. Finally the $\tilde{\tilde{\omega}}_{it}$ variable reflects variation in the propensity to publish not accounted for by the time or state specific effects. In this study the total publication output for each state is derived from the publication performance of a stratified random sample of researchers. Consequently $\tilde{\tilde{\omega}}_{it}$ also captures sampling errors in the measurement of P_{it}.

Imposing orthogonality on the $\dot{K}$ and $\tilde{\tilde{\epsilon}}_{it}$ variables we will assume that the $\tilde{\tilde{\mu}}_i$, $\tilde{\tilde{\lambda}}_t$ and $\tilde{\tilde{\omega}}_{it}$ components of $\tilde{\tilde{\epsilon}}_{it}$ are also uncorrelated with the determinants of $\dot{K}$ given by (2). Substituting equations (2) and (4) into (3) gives the reduced form equation relating lagged research expenditures to publication output such that

$$P_{it} = \theta + \sum_{s=0}^{S} \beta_s R_{i,t-s} + \mu_i + \lambda_t + \omega_{it} \tag{5}$$

where

$$\theta = (\tilde{\tilde{\theta}} + \alpha\tilde{\theta})$$

$$\mu_i = (\tilde{\tilde{\mu}}_i + \alpha\tilde{\mu}_i)$$

$$\lambda_t = (\tilde{\tilde{\lambda}}_t + \alpha\tilde{\lambda}_t)$$

$$\beta_s = \alpha\tilde{\beta}_s$$

$$\omega_{it} = (\tilde{\tilde{\omega}}_{it} + \alpha\tilde{\omega}_{it})$$

$$i=1,2,\ldots\ldots N \; ; \; t=1,2,\ldots\ldots T$$

The state specific term μ_i represents the weighted sum of both knowledge production and subsequent publication performance influences which are specific to the various states. Likewise the λ_t variable represents the weighted sum of these same influences which are of a time specific nature. When estimating equation (5) it is clear that the response of $\dot{K}$ to a unit change in research expenditure, R, cannot be identified given the information contained in this model. Nevertheless, the form of the distributed lag linking $\dot{K}$ to R can be investigated by normalizing the estimated lag coefficients to obtain $\tilde{\beta}_s/\Sigma\tilde{\beta}_s = \beta_s/\Sigma\beta_s$ for all s.

The research production process, represented by equation (5) or variants thereof constitutes the primary focus of the subsequent empirics.

II. DATA AND ESTIMATION ISSUES

We begin with a look at the publication-based proxy of SAES knowledge output and its associated quality adjusters. Given the paucity of previous work in this area, some attention will be given to the conceptual issues involved along with the mechanics of variable construction.

A. The Quantity Dimension of Research Output

The aggregate publication performance of each station was estimated on the basis of the average research performance of a random sub-sample of station researchers. First the researcher population of each experiment station, for the two fiscal years 1970/71 and 1974/75, was established by reference to the appropriate Cooperative State Research Service (CSRS) listing of Professional Workers in State Agricultural Experiment Stations and Other Cooperating State Institutions. All individuals who, on the basis of their location (i.e. branch versus main station), degree, appointment and/or professional status, could be reasonably classified as support or auxiliary staff were excluded. A population of around 10,000 researchers was identified, from which a stratified random sample consisting of around twenty percent of the population was chosen[4].

Table (1) indicates that overall the samples closely conform to the research disciplines represented in the SAES. Just over 50 percent of these researchers are associated with one of the plant science disciplines while 30 percent are spread amongst the animal sciences. Given the constant turnover of research personnel at any particular SAES, the 1970 to 1973 publication performance of each station was estimated using the 1970/71 sample of researchers (i.e. Sample I) whilst the 1974 and 1975 publication record used the 1974/75 researcher sample (i.e. Sample II). Both these samples constitute independent draws from the population of SAES researchers and represent 23.2 and 22.2 percent of the 1970/71 and 1974/75 population respectively.

The scientific publication output of each sample researcher for the appropriate years was obtained by a manual search of the respective Source Indexes of the Science Citation Index (SCI) compiled by the Institute for Scientific Information[5]. The overall data set involved separate records for 16,050 publications. This data was then integrated with biographical information concerning source authors (i.e. station and discipline affiliation, degree, appointment and professional status, etc.).

Some summary publication statistics are presented in Tables I.1 and I.2, Appendix I. Nearly two-thirds of the publications are full-length articles. Most of the remaining publications are abstracts of papers presented at professional meetings or shorter notes. From Table I.2 we observe that around 88 percent of the publications are jointly authored with the majority having one or two co-authors. Given this high percentage of co-authored articles we proceeded to calculate both the average number of articles and average number of prorated articles per sample researcher per year for each station. The raw and prorated averages were scaled by the appropriate population number of researchers per station to yield estimates of the total publication output for each station for the 6 years 1970-1975[6].

B. The Quality Dimension of Research Output

One of the most frequently encountered criticisms of direct indexes of scientific output is that the unit of measurement does not adequately account for likely quality differences. Two notions of quality are possible. In an economic context quality can be taken to mean the relationship between research benefits and the measured level of resources committed to that research. Hence, higher quality research generates a larger present value benefit stream for a given level of measured research inputs. Scientific quality according to Evenson and Wright (1982) is measured by conformity to standards established by scientific work at the frontier of the discipline. More generally the scientific quality of a researcher (or a body of research) is assessed with respect to the relative significance of the individual's

Table (1) Researcher Statistics - Number of Researchers per Discipline; Sample and Population Averages (1)

Discipline (2)	Average Number of Researchers			
	1970-73	1974-75	1970-75	
	Sample I	Sample II	Sample	Popln.
Agronomy	539	553	546	2012
	(24.1)	(24.4)	(24.2)	(20.2)
Entomology	172	195	184	880
	(7.7)	(8.6)	(8.2)	(8.8)
Forestry	184	177	181	919
	(8.2)	(7.8)	(8.0)	(9.2)
Horticulture	138	146	142	663
	(6.2)	(6.4)	(6.3)	(6.7)
Plant Diseases	158	152	155	725
	(7.1)	(6.7)	(6.9)	(7.3)
TOTAL PLANT SCIENCE	1191	1223	1207	5199
	(53.2)	(53.9)	(53.6)	(52.3)
Animal Science	286	257	272	1019
	(12.8)	(11.3)	(12.1)	(10.2)
Dairy	55	47	51	226
	(2.5)	(2.1)	(2.3)	(2.3)
Fisheries	25	29	27	213
	(1.1)	(1.3)	(1.2)	(2.1)
Poultry	43	42	43	197
	(1.9)	(1.9)	(1.9)	(2.0)
Vet. Medicine	260	236	248	1325
	(11.6)	(10.4)	(11.0)	(13.3)
TOTAL ANIMAL SCIENCE	669	611	640	2980
	(29.9)	(27.0)	(28.4)	(30.0)
Agric. and Envir. Science	44	64	54	219
	(2.0)	(2.8)	(2.4)	(2.2)
Core Sciences and Statistics	225	250	238	896
	(10.0)	(11.0)	(10.6)	(9.0)
Genetics and Plant Breeding	34	13	24	118
	(1.5)	(0.6)	(1.1)	(1.2)
Nutrition and Food Science	73	102	88	524
	(3.3)	(4.5)	(3.9)	(5.3)
Other	3	4	4	13
	(0.2)	(0.2)	(0.2)	(0.1)
TOTAL	2239	2267	2253	9949(3)

(1) Figures in parentheses are percentages of the respective SAES totals.

(2) Agronomy includes plant science, soil science and water and range science. Forestry includes wildlife. Horticulture includes pomology, vegetable crops, viticulture and oenology. Plant diseases include nematology and plant pathology. Animal science includes animal husbandry. Fisheries includes aquaculture. Vet. Medicine includes animal diseases and microbiology. Environmental science includes landscape architecture. Core sciences includes biochemistry, biophysics, biology, botany, chemistry and zoology.

Scientists were generally allocated to research disciplines on the basis of the discipline classification reported in the listing of "Professional Workers in SAES and other Cooperating Institutions". Over time and between station inconsistencies were resolved by reference to the research specialization which was also recorded for each researcher. Multiple counts (i.e. where the same researcher is listed more than once per state, say, at the main as well as sub-station[s]) were eliminated by cross-matching the discipline listing with an alphabetical listing also recorded in the "Professional Workers" publication.

(3) This figure excludes 424 researchers who were also listed at various substations but could not be allocated to a specific discipline. Also excluded are social science and agricultural engineering researchers. Adding all these researchers to this figure would increase the overall population size to 12,270.

Table (1) Researcher Statistics - Number of Researchers per Discipline; Sample and Population Averages [(1)]

	Average Number of Researchers			
	1970-73	1974-75	1970-75	
Discipline [(2)]	Sample I	Sample II	Sample	Popln.
Agronomy	539	553	546	2012
	(24.1)	(24.4)	(24.2)	(20.2)
Entomology	172	195	184	880
	(7.7)	(8.6)	(8.2)	(8.8)
Forestry	184	177	181	919
	(8.2)	(7.8)	(8.0)	(9.2)
Horticulture	138	146	142	663
	(6.2)	(6.4)	(6.3)	(6.7)
Plant Diseases	158	152	155	725
	(7.1)	(6.7)	(6.9)	(7.3)
TOTAL PLANT SCIENCE	1191	1223	1207	5199
	(53.2)	(53.9)	(53.6)	(52.3)
Animal Science	286	257	272	1019
	(12.8)	(11.3)	(12.1)	(10.2)
Dairy	55	47	51	226
	(2.5)	(2.1)	(2.3)	(2.3)
Fisheries	25	29	27	213
	(1.1)	(1.3)	(1.2)	(2.1)
Poultry	43	42	43	197
	(1.9)	(1.9)	(1.9)	(2.0)
Vet. Medicine	260	236	248	1325
	(11.6)	(10.4)	(11.0)	(13.3)
TOTAL ANIMAL SCIENCE	669	611	640	2980
	(29.9)	(27.0)	(28.4)	(30.0)
Agric. and Envir. Science	44	64	54	219
	(2.0)	(2.8)	(2.4)	(2.2)
Core Sciences and Statistics	225	250	238	896
	(10.0)	(11.0)	(10.6)	(9.0)
Genetics and Plant Breeding	34	13	24	118
	(1.5)	(0.6)	(1.1)	(1.2)
Nutrition and Food Science	73	102	88	524
	(3.3)	(4.5)	(3.9)	(5.3)
Other	3	4	4	13
	(0.2)	(0.2)	(0.2)	(0.1)
TOTAL	2239	2267	2253	9949[(3)]

(1) Figures in parentheses are percentages of the respective SAES totals.

(2) Agronomy includes plant science, soil science and water and range science. Forestry includes wildlife. Horticulture includes pomology, vegetable crops, viticulture and oenology. Plant diseases include nematology and plant pathology. Animal science includes animal husbandry. Fisheries includes aquaculture. Vet. Medicine includes animal diseases and microbiology. Environmental science includes landscape architecture. Core sciences includes biochemistry, biophysics, biology, botany, chemistry and zoology.

Scientists were generally allocated to research disciplines on the basis of the discipline classification reported in the listing of "Professional Workers in SAES and other Cooperating Institutions". Over time and between station inconsistencies were resolved by reference to the research specialization which was also recorded for each researcher. Multiple counts (i.e. where the same researcher is listed more than once per state, say, at the main as well as sub-station[s]) were eliminated by cross-matching the discipline listing with an alphabetical listing also recorded in the "Professional Workers" publication.

(3) This figure excludes 424 researchers who were also listed at various substations but could not be allocated to a specific discipline. Also excluded are social science and agricultural engineering researchers. Adding all these researchers to this figure would increase the overall population size to 12,270.

contribution to their field. One method commonly used to establish significance entails a peer group review procedure (see Shaw [1967]). This subjective evaluation technique is limited by the problems of standardization of evaluation criteria and the individual biases and information base of the evaluators. Furthermore such exercises are essentially nonreplicable.

An alternative procedure is to measure the subsequent citation performance of a piece of research. The maintained hypothesis is that on-average the cited work is a useful input in the production of current research. Thus citation performance is a quantifiable measure of the impact of published work on the future knowledge (publication) output of the profession. This line of argument has been used in the recent economics literature by McDowell (1982) and Davis and Papanek (1984).

One of the major advantages of a citation based measure of scientific quality is its ability to capture not only the spatial impact of a piece of research (i.e. across disciplines) but also the temporal dimension of its influence. It seems reasonable to suggest that, ceteris paribus, articles which are cited more recently have a greater impact on the research process than those which are cited at a later point in time. The earlier an article is cited the greater its indirect impact on future research if the citing article is in turn cited by other researchers. Thus, in a present value context the citation profile and not simply the cumulative citation performance of a body of research is the important determinant of its overall impact on subsequent research.

As the present study involved observations on 16,050 publications it was well beyond our resources to map the citation performance of each article over a number of years. Rather than simply measure the cumulative citation rate of each article, and so miss the temporal dimension of its citation performance, it was decided to standardize the citation performance of each article on a particular year - in this case two - following its publication date.[7].

C. Research Inputs

To estimate equation (5) requires an accurate measure of the resources used by the SAES for research endeavors. Many previous augmented production function studies have used a fairly restricted set of research expenditure estimates. However, given the variety of construction and mismeasurment errors which were identified in the sources commonly used to date (for instance Latimer [1964], Cline [1975], and Davis [1979]) in this study we opted to construct a research input estimate based entirely on original sources[8].

Research expenditures for each SAES were split to factor level. Capital investments were further subdivided into plant and equipment plus land and building purchases, while 'labor', or more specifically non-capital expenditures included salaries, fringe benefits, and operating expenses. While all 'labor' related costs are appropriately expensed in the year of purchase, this is not so for capital. Capital purchases or investments represent gross additions to the capital stock at any point in time and what is required (see Griliches [1960], and Yotopolous [1967]) is a measure of the current productive service flow of the capital assets, which is viewed as an estimate of the capital resources used in the current period.

Non-capital expenditures were deflated using an index of average university salaries, since this component was primarily salaries of research and support staff. Land and building expenditures were deflated using the Handy-Whitman index of public construction prices. The implicit price deflator for State and Local Government Purchases of Goods and Services was used to deflate plant and equipment expenditures[9]. After deflating, the total real service flows derived from plant and equipment, and land and buildings were calculated. Land and buildings were assumed to have a 25 year service life, and plant and equipment a 10 year service life. Additionally, both service flow profiles were proxied by a One-Hoss Shay assumption with zero salvage value. These two series were summed to get a measure of the total service flows arising from capital investments. Together with the deflated non-capital expenditures they provide a reasonably accurate measure of the real resources committed by the SAES to the knowledge production process over the 1963 to 1975 period.

Table (5) Regression of Citation Adjusted Publication Output (PRONET) on Agricultural Research Expenditure[a].

Variable	OLS	WITHIN	BETWEEN	EGLS[b]
R_0	0.3367 (0.8707)[c]	0.4875 (0.5724)	-6.9013 (10.961)	0.3042 (0.6123)
R_{-1}	-0.7926 (1.1479)	-0.6302 (0.6566)	-1.8776 (23.569)	-0.6316) (0.7096)
R_{-2}	0.2694 (1.1465)	-0.1402 (0.6558)	15.791 (19.031)	-0.0894 (0.7124)
R_{-3}	0.9849 (1.1819)	1.0121 (0.6733)	1.9235 (16.713)	1.0693 (0.7330)
R_{-4}	0.5729 (1.1248)	0.5282 (0.6249)	11.091 (21.574)	0.5689 (0.6929)
R_{-5}	-0.6560 (1.140)	-0.8193 (0.6388)	13.839 (18.441)	-0.7484 (0.7044)
R_{-6}	0.0359 (1.170)	0.5086 (0.6562)	-29.706 (17.344)	0.5151 (0.7263)
R_{-7}	1.2883 (0.8727)	0.1079 (0.5453	19.401 (9.4456)	0.3270 (0.5913)
ΣR_{-i}	1.3623 (0.0809)	1.0548 (0.5923)	1.3784 (0.0474)	1.315 (0.1498)
R^2	.5320	.0352	.6877	.2421
NT	264	264	44	264
'Mean' Lag	3.87	3.30	4.64	3.62

(a) Four outlier states (Delaware, Maine, Nevada and New Mexico) and trend variable omitted. All variables measured in natural logs.

(b) See note (b) Table (4.4). Here $\hat{\sigma}_1^2 = 3.0410$, $\hat{\sigma}_\omega^2 = 0.2640$ and $\hat{\sigma}_\mu^2 = 0.4628$.

(c) Standard errors in parentheses.

D. Estimation Issues

When pooling time-series, cross-section data the most contentious issues concern the nature of the state and time specific variables and the related, but separate issue concerning the relationship between these effects variables and the other regressors (Hsiao [1986]). Treating μ_i and λ_t as fixed variables, the resulting covariance or fixed effects model can be estimated by including these variables as separate time and state specific dummy variables and applying OLS. This least squares dummy variable (LSDV) estimation technique not only gives unbiased and efficient estimates of β_k but also gives direct estimates of each time and state specific effect which are unique up to a normalization. Thus, under a fixed effects regime we can obtain BLU estimates of the slope coefficients by applying OLS to the transformed equation[10],

$$(6) \qquad (P_{it} - \bar{P}_{i.}) = \sum_{k=1}^{S} \beta_k (R_{kit} - \bar{R}_{ki.}) + \omega_{it} - 1/T\sum_{t=1}^{T} \omega_{it}$$

It is clear from this equation that we utilize only the variation within each state (i.e. the over-time variation about state means) to derive what is called the within estimates. By completely ignoring the between state variation we consequently eliminate a major portion of the variation among both the explained and explanatory variables if the between effects variation is large.

To incorparate the between effects information into the estimation procedure we can treat the time and state specific effects as random variables, giving rise to the variance components or random effects model. This generates an error structure which is no longer independent and identically distributed so that a generalized least squares (GLS) procedure is required in order to obtain unbiased and efficient estimates of the β's[11]. Using the method suggested by Fuller and Battese (1969) we can obtain GLS estimates by applying OLS to the transformed equation,

$$(7) \qquad P_{it} - \gamma\bar{P}_{i.} = (1 - \gamma)\,\bar{\theta} + \sum_{k=1}^{K} \beta_k (R_{kit} - \gamma\bar{R}_{ki.}) + \omega_{it} - \gamma\bar{\omega}_{i.}$$

where $\gamma = 1 - \sigma_{\omega}/\sigma_1$ and $v_{it} = \omega_{it} - \gamma\bar{\omega}_{i.}$ is i.i.d.

As Mundlak (1978) observed, this GLS procedure ignores the consequences of the correlation which may exist between the effects and the explanatory variables. In the context of our model, this is equivalent to assuming that differences in research efficiencies are correlated (on average) with interstate differences in research expenditures. Pakes and Griliches (1980) argue that in general, at the firm level, differences in $\tilde{\mu}_i$ are transmitted to differences in average research expenditures, $\bar{R}_{i.}$, with more efficient research departments being allocated more research funds. This being the case we could then form the auxiliary regression

$$(8) \qquad \tilde{\mu}_i = \sum_{s=0}^{S} \phi_s \bar{R}_{i.,-s} + \tilde{\mu}_i^*$$

where

$$\bar{R}_{i.,0} = T^{-1}\sum_{t=1}^{T} R_{i,t}, \qquad \bar{R}_{i.,-1} = T^{-1}\sum_{t=0}^{T-1} R_{i,t-1} \qquad \text{etc.}$$

substituting equation (8) into (2), (3), and (4) we can rewrite (5) as

$$(9) \qquad P_{it} = \theta + \sum_{s=0}^{S} + \beta_s R_{i,t-s} + \sum_{s=0}^{S} \phi_s \bar{R}_{i.,-s} + \mu_i + \lambda_t + \omega_{it}$$

where $\tilde{\mu}_i = (\bar{\mu}_i + \alpha\tilde{\mu}_i^*)$, $\phi_s = \alpha\tilde{\phi}_s$

and all other variables are defined as before.

In contrast to the private sector research process it is not clear, a priori, that the research efficiency-research expenditure relationship described by equation (8) holds in the case of public sector agricultural research. This ambiguity arises in part from the mechanisms whereby the benefits from public sector agricultural research are appropriated. In the Pakes-Griliches case, private firms directly capture (part of) the returns from research activity presumably via patents, new product or process developments or licensing agreements. Assuming profit maximizing behavior, Mundlak and Hoch (1965) have shown that the unobservable part of the K.P.F. is transmitted to a research input demand equation given by the first order profit maximizing conditions.

However, in the case of publicly funded agricultural research much of the benefit is not directly appropriated by those institutions and/or individuals undertaking research, but instead is filtered through a political mechanism. Several authors (Guttman [1978], Rose-Ackerman and Evenson [1982], and Hadwiger [1982]) have suggested, that in the case of publicly funded agricultural research, political rather than just economic efficiency criteria influence the allocation of research resources. Within this context they identified a variety of factors correlated with increased appropriations to the SAES. Whether or not these factors are systematically related to the relative research efficiency of the SAES is not readily apparent so that the feedback mechanism described in the profit maximizing case above may not be operative here.

One approach which can resolve the issue, for the purposes of estimation, is simply to proceed with the LSDV approach and make inferential statements concerning the estimated β's conditional on the realized values of μ_i and λ_t in the sample. These LSDV estimators are, conditional on the μ_i and λ_t in the sample, best, linear, and unbiased. Because this approach makes no specific assumptions about the distribution of μ_i and λ_t it can be used for a wider range of problems. Nevertheless, if the restrictive distributional assumption of the variance component model is correct, then using this additional information will result in a more efficient estimator. As the superiority of the variance component over the covariance model is jeopardized in the presence of correlation between the effects and explanatory variables, this issue will also be explored in the empirical work to follow.

An unbiased estimate of σ_1, and σ_w can be derived from

$$\hat{\theta}_1^2/T = \hat{\nu}'\hat{\nu}/N\text{-}K$$

where $\hat{\nu}'\hat{\nu}$ is the sum of squared residuals from applying OLS to the between equation (i.e. where all variables enter as only state, over-time means) and

$$\hat{\sigma}_\omega^2 = \hat{\omega}'\hat{\omega} \,/\, N(T-1) - K'$$

$$\text{with } K' = K-1$$

where $\hat{\omega}$ is the estimated residuals from applying OLS to equation (6).

Finally, an estimator for $\hat{\sigma}_\mu^2$ can be obtained from

$$\hat{\sigma}_\mu^2 = (\hat{\sigma}_1^2 - \hat{\sigma}_\omega^2)/T$$

Notice there is no guarantee that $\hat{\sigma}_{\mu}^{2}$ is positive. A negative value may well be an indication that the random effects model is misspecified. For instance the maintained hypothesis of constant β over time and/or states may be in error or it could well be that the independence assumption $E(\mu_i | X) = 0$ is violated.

III. RESULTS

The average publication performance per researcher (per station) per year is given by the PUB and PROPUB variables in Table (2). Averaging across all disciplines and SAES gives a yearly publication output measure (PUB) of around 1.2 which is approximately halved to 0.53 if publications are prorated (PROPUB) according to the number of coauthors per publication[12]. Given the relatively small proportion of sole authored publications (averaging only 12.4 percent over the sample) this is to be expected.

The two research quality weights used in this study are the TOTCIT and NETCIT variables respectively. Both measure the average yearly citation performance of publications two years following their publication date. The TOTCIT variable captures the total number of citations for this period and the NETCIT variable nets out self-citations by both source and coauthors. Despite the large range in both these figures, their relatively low coefficient of variation suggests that the average citation performance of quite a few stations is at the lower end of the data range. Both measures show that for at least one of the sample years, 1970-75, none of the publications from Delaware were cited whilst Wisconsin achieved the highest total and net citation rate of 3.84 and 3.29 respectively.

It was argued earlier that prorated publication output, weighted by net citations, is an appropriate indicator of the overall performance of the SAES. Nevertheless an analysis of the relationship between these various measures, afforded by the correlation matrix in Table I.3, Appendix I, is instructive. A $\rho = 0.947$ indicates a strong positive relationship between the two quantity measures PUB and PROPUB with an even stronger relationship, $\rho = 0.984$, holding between the quality measures TOTCIT and NETCIT. In contrast, the relationship between the various quantity and quality measures is far less definitive. These results show that the systematic variance ratio from a regression of either quantity measure on either quality measure ranges from 0.126 to 0.140. Thus, at the station level, there is a positive but reasonably loose association between research quality and quantity.

The simple correlation coefficients in Table (I.3) also suggest the results from estimating equation (5) will be sensitive to the form of the dependent variable. Nevertheless on statistical grounds, the four quality adjusted research output indicators appear to be good proxies for each other. On conceptual grounds, the PRONET variable is the most appealing and will form the benchmark in the regression analysis to follow.

Prior information concerning the appropriate form of the relationship between publication output and research expenditures described by equation (5) is sparse. To keep a specification search within manageable proportions, we restricted our choice to linear, log linear, semi log and double log forms. The regressors were log and linear current expenditures on labor and estimated capital service flow, additive time and state dummies and multiplicative size dummies. Taking medium sized stations as the reference group, the size dummies allowed the expenditure coefficients potentially to vary for small (<100 researchers), medium and large (>500 researchers) stations. The specification with log P was preferred over the linear P model[13]. By applying a series of standard Fisher F-tests the data also suggests that a double log model is preferred over a log linear specification, size effects (at least as they impact the slope coefficients) are degenerate, and significant trend and state effects are present.

One of the stated goals of this study is to inquire into the strength of the systematic relationship between SAES research expenditures and publication based indices of research output. Various measures of research input and output were presented earlier and, given the panel nature of the data set, it is possible to partition their variance into several dimensions. This is done in Table 3.

Table (2). Descriptive Statistics for Selected Publication Based Agricultural Research Output Measures.[a]

Variable	Mean	Standard Deviation	Minimum	Maximum
Population	255.4	162.96	44.0	727.0
Per Researcher:				
Pub	1.159	0.471	0.160	3.019
Propub	0.527	0.211	0.093	1.242
Totcit	0.960	0.570	0	3.835
Netcit	0.790	0.580	0	3.288
Per Station:[b]				
Pub	330.08	238.37	8.80	1501.7
Propub	151.24	134.25	5.312	698.4
Pub x Net[c]	321.24	452.31	0.0009	3004.4
Pro x Net[c]	145.96	204.29	0.0005	1244.1

(a) These figures are derived from a panel set consisting of observations on 48 states (Alaska and Hawaii omitted) for the period 1970-75 inclusive.

(b) Per station figures are simply the per researcher figures weighted by the appropriate researcher population figure.

(c) When used as a quality weight, the zero citation count was arbitrarily set at 0.0001. This allowed logarithmic values to be calculated.

In all cases the between (states) dominates the within (states) variance with the various output measures showing relatively more variation in the within or over time dimension than the expenditure figures. Given the relatively large spread of station sizes and the short nature of the panel (8 years), this is not unexpected. Weighting the raw publication count measures (PUB and PROPUB) by the net citation count increases the variation proportionately more in the within than the between dimension.

Given the earlier assertion that the error term, $\tilde{\omega}_{it}$, in the knowledge production function (equation [2]) is orthogonal to $\tilde{\tilde{\omega}}_{it}$, the error term from the indicator function (equation [3]), we can write

$$R^2_{P.\dot{K}} = 1 - \operatorname{var}(\tilde{\tilde{\omega}}) / \operatorname{var}(P)$$

and

$$R^2_{P.\Sigma R} = 1 - (\alpha^2 \operatorname{var}(\tilde{\omega}) + \operatorname{var}(\tilde{\tilde{\omega}})) / \operatorname{var}(P)$$

It follows that the coefficient of determination from a regression of P on current and lagged R gives the lower bound of the systematic-to-total variance ratio of P as a measure of knowledge increments $\dot{K}$. In this sense, the $R^2_{P.\Sigma R}$ statistic gives the 'proxy error' which follows from using (weighted) publications as an indicator of gross additions to the stock of knowledge.

From the results presented in Table (4), we observe that, in the total or OLS relationship of quality adjusted publication counts on summed research capital and labor expenditures, no more than 47 percent of the variation in P can be attributed to its 'error' as a measure of knowledge stock increments. Of course the actual 'proxy error' may be far less than this figure if the noise in the knowledge production function were known to dominate the overall error term ω_{it} in equation (5).

Partitioning the total relationship into its between and within components we observe, using the complete sample, that the 'proxy error' drops to a maximum of 25 percent in the between dimension. Thus, the on-average knowledge increment-lagged expenditure pattern for each experiment station appears to be captured fairly completely using quality adjusted publications as a proxy for knowledge increments. However, for the publication-expenditure relationship in the within dimension R^2's of the order of 0.07 were recorded. From the data available to us, we cannot identify the source of this large random component in yearly deviations of each SAES from its average level of operations. It would arise if the publication process were subject to a great deal of instability over time. Alternatively it may be that the knowledge production process is such that, within the range of our data at least, small fluctuations over time in the research expenditures of a particular station are not systematically translated to changes in research output ($\dot{K}$) for particular years.

Qualitatively these results are surprisingly similar to those obtained by Pakes and Griliches in their 1980 study of the firm level patent-R&D expenditure relationship. Using raw patent data over an eight year period from 1969-1975, and research expenditure data over the 1963-75 period for 121 medium and large U.S. corporations, they estimated the double log relationship between patents and current and (five years) lagged R&D expenditures. They obtained R^2's for the total regressions ranging from 0.74 to 0.95, for the between dimension ranging from 0.77 to 0.97, and for the within dimension ranging from 0.11 to 0.49[14].

In all dimensions their R^2's were somewhat higher than those obtained from this study. This may simply result from the bigger data set used in their investigation. However, it may also arise in part from the use of raw patent counts to proxy research output. In our study using the raw publication count (PROPUB) rather than the citation adjusted measure (PRONET) in general caused the R^2's to increase. It may also be that the biologically orientated research of the SAES is inherently more noisy than the research and development projects undertaken by the corporations in the Pakes-Griliches sample[15]. (i.e. the var (ω) term is relatively larger for biological as opposed to industrial research). Alternatively patenting activity, being

Table (3) Partitioning of Sample Moments for Various Agricultural Research Output and Expenditure Measures (N = 48, T = 6)(a)

	Between Variance(b)	Within Variance(c)	Ratio of Within to 'Total' Variance
Pub	5.479	0.050	0.009
Propub	5.465	0.061	0.011
Pubnet	11.097	0.650	0.055
Pronet	11.100	0.630	0.054
Labor	3.102	0.007	0.002
Capital	3.594	0.017	0.005
Labor + Capital	3.342	0.006	0.002

(a) All (state-level) research output and expenditure variables are measured in their natural log form.

(b) Given by $\frac{T\Sigma(X_{i.} - X_{..})}{N-1}$

(c) Given by $\frac{T\Sigma(X_{it} - X_{i.})}{N(T-1)}$

Table (4) Regression of Citation Adjusted Publication Output (PRONET) on Agricultural Research Expenditure[a].

Variable	OLS	WITHIN	BETWEEN	EGLS[b]
R_0	-0.5994 (1.0050)[c]	0.0252 (0.8050)	-5.4798 (10.735)	0.0204 (0.8473)
R_{-1}	-0.0075 (1.2889)	0.0789 (0.8986)	-5.4824 (21.584)	0.3080 (0.9920)
R_{-2}	-0.1180 (1.2709)	-0.9056 (0.8992)	8.3317 (16.079)	-0.3187 (0.9835)
R_{-3}	1.0557 (1.2559)	-0.1406 0.8817	24.977 (14.755)	0.6920 (0.9640)
R_{-4}	0.2871 (1.2745)	-0.4862 (0.8931)	-28.982 (19.648)	0.3462 (0.9754)
R_{-5}	-0.0557 (1.2994)	-0.3574 (0.8868)	20.689 (18.662)	-0.0226 (0.9938)
R_{-6}	-0.0823 (1.3153)	-0.1552 (0.9166)	-33.306 (17.776)	0.3767 (1.0132)
R_{-7}	0.9123 (1.0260)	-1.5631 (0.8741)	20.828 (9.4215)	0.0902 (0.8635)
Trend	0.0377 (0.0384)	177.37 (43.095)	-	0.0473 (0.0301)
ΣR_{-i}	1.5567 (0.0896)	-3.5041 (1.3761)	1.5740 (0.2005)	1.4922 (0.1546)
R^2	.5315	.0660	.7521	.2737
NT	288	288	48	288
'Mean' Lag	3.76	4.83	4.47	3.41
χ^2				16.395

(a) All variables measured in natural logs.

(b) For the estimated GLS procedure, all variables, Z_{it}, are transformed as $Z_{it} - \gamma Z_{i.}$ where

$\hat{\gamma} = 1 - \hat{\sigma}_\omega/\hat{\sigma}_1$. Here $\hat{\sigma}_1^2 = 3.3162$, $\hat{\sigma}_\omega^2 = 0.6611$ and $\hat{\sigma}_\mu^2 = 0.4509$.

(c) Standard errors in parentheses.

the outcome of a corporate decision making process, may be less sporadic in nature (particularly in the over time or within dimension) than the publishing process, which represents in part the aggregate publishing propensities of individual researchers within each of the SAES.

A primary objective of this study is to gain some insight into the nature of the lagged relationship between research inputs and outputs. Following the procedure suggested by Hatanaka and Wallace (1980), we estimated the distributed lag relationship between research inputs and research outputs in a form-free manner. This is an appropriate approach to take if we are interested in capturing certain features of a lag distribution, such as the long run lag (i.e. the sum of the lag coefficients), the mean lag, and the variance of the lag, with few ad hoc constraints being imposed on the lag distribution.

The results in Tables (4) and (I.4) in Appendix I, indicate that the individual lag coefficients are estimated with a low degree of precision. However, the sum of the lag coefficients, measuring the long run expenditure response of (quality adjusted) publication output, is estimated quite precisely. As expected, the OLS and between estimates are very close. They show that a 1 percent once and for all increase in real research expenditures leads to around 1.6 percent increase in constant quality research (publication) output. The output response for unadjusted research output is somewhat lower at around 1.2. Thus the use of quality unadjusted publication counts underestimates the research output response resulting from increased research expenditures by approximately 25 percent. This result holds across most of the specifications reported here.

The EGLS long run elasticity estimate appears to be dominated by the between variation and is at odds with the within estimate. Given the truncated nature of the panel, this is not surprising but it was decided to investigate several reasons which could account for this discrepancy. The first concerns misspecification of the random effects model. A violation of the orthogonality assumption concerning the state effects variable μ_i and the X_{it}'s (i.e. $E(\mu_i | X_{it}) \neq 0$) causes the random effects estimator to be biased and inconsistent, while having no impact on the fixed effect estimator. Hausman (1978) suggests a natural test of the null hypothesis of independent μ_i's is to consider the difference between the two estimators, $\hat{q} = \hat{\beta}_{FE} - \hat{\beta}_{RE}$. If no misspecification is present then $\hat{q}$ should statistically be near zero[16].

The relevant χ^2 statistics for a Hausman test presented in Tables (4) and (I.4) suggest there is no significant misspecification in the random effects model for either the PRONET or PROPUB case. The maintained hypothesis that the X_{it}'s and the μ_i variable are orthogonal is not rejected. This contrasts with the Pakes-Griliches study of the private sector patent production process where firm specific effects were correlated with research expenditures. The funding mechanism regarding public sector agricultural research is such that the direct or indirect link between these state specific effects and the level of research expenditures appears more tenuous than in the case of private sector funding.

For an alternative explanation we observe that the within estimate of the expenditure coefficients for the PRONET model is extremely sensitive to the inclusion or omission of a trend variable. The deviation of slowly changing research expenditures around an over time mean is not only small but appears to be highly collinear with a simple trend variable. The spread between the within and EGLS estimates drops sharply when the trend variable is omitted[17]. In contrast, the OLS and EGLS estimates of the long run response of research output are relatively insensitive to changes in the trend variable specification.

Table (5) shows the difference between the EGLS and within result for the PRONET model is further reduced by the omission of four outlier states - Delaware, Maine, Nevada and New Mexico. For at least one of the six years in the sample, these states exhibit a calculated error $|P_{it} - \hat{P}_{it}|$ greater than twice the standard deviation of the estimate. Omitting them from the sample causes the sum of squares residuals to drop by approximately 62 percent. The precise cause of this 'deviant' research performance is not clear but could be related to the relatively small size of these stations. In particular, there may exist an aggregation effect whereby the summed research output of a small number of researchers is more volatile than for a somewhat larger research organization. Unfortunately, corroborative evidence on such a size effect is difficult to come by.

Using the absolute value of the estimated lag coefficients we can construct point estimates of the 'mean' of the normalized lag distributions, m_i , such that,

$$\hat{m}_i = \hat{\mu}_i \; / \hat{\mu}_o$$

$$\text{where } \hat{\mu}_i = \sum_{s=0}^{K} s^i \; |\beta_i| \qquad\qquad i = 0,1,.....,k.$$

Various estimates of the 'mean' lag were given in the preceding tables and are averaged in Table (6) along with comparative figures from some other studies. The gestation lag represents the average lag between project inception and completion, while the time from project completion to commercial application is given by the application lag.

Averaging the Rapoport (1971) and Wagner (1968) figures gives a mean gestation lag of around 1.34 years which is close to the Pakes-Griliches (1980) estimate of 1.6 years. The quality unadjusted estimate from this study, which is closest to the output measures used by these comparative studies, suggests that the mean gestation lag for public sector biologically orientated research is around 0.7 to 1.0 years longer than the private sector manufacturing oriented research. The different nature of both the research problems and the institutional environment could account for this difference.

Moreover, the mean gestation lag between research expenditures and quality adjusted research output is consistently longer than the quality unadjusted output measures. The summary figures in Table (6) show that for the case of public sector agricultural research, the quality adjusted 'mean' lag is approximately six months (19 percent) longer than the quality unadjusted figure. These results suggest that in failing to standardize the units by which research output has been quantified, previous studies (such as the Pakes Griliches [1980] study which simply used raw patent counts) have significantly underestimated the mean lag between project inception and project completion.

IV. SUMMARY

These initial results on the agricultural research expenditure-research output relationship are quite encouraging. Although they convey relatively little information about the precise shape of the lag distribution, we have been able to obtain a significant relationship between lagged research expenditures and (weighted) publication output, even after controlling for unspecified state specific effects. Summary measures such as the 'mean' gestation lag and long run expenditure response were used to characterize this relationship. These measures were informative and plausible in the light of comparative studies in the private, non-agricultural research sector. The empirical implications of using raw versus quality adjusted publication output variables were also explored and found to be of significance.

For our data at least, the relationship between research expenditures and research output within states over time appeared quite tenuous. Short term fluctuations in research expenditures showed little systematic influence on research output. The on-average or longer run differences in research expenditures between the states does appear to influence research performance in a fairly systematic manner.

The summary measures do suggest that a significant lag between research inputs and outputs exist although Hall et al. (1984), summarizing extensive empirical work on the patent-R&D relationship for the private sector, highlight the substantial difficulties in trying to pin down this relationship. Key issues involve possible simultaneity between patent output and R&D expenditures, lag truncation biases due to the relationship between pre and in-sample R&D expenditures, and a lack of independence between unspecified state-specific effects and in-sample R&D expenditures. In the present study we tested formally for the failure of this independence assumption and got results which suggest that unspecified state effects were not correlated with in-sample research expenditures. Nevertheless, in both the PROPUB and PRONET models these unspecified state effects appeared to account for significant differences in the research performance of the SAES, even after controlling for differences in research spending.

Table (6) Estimates of the 'Mean' R&D Lag (in years).

	R&D Gestation	Application	Total
Rapoport[a]			
Chemicals	1.48	0.24	1.72
Machinery	2.09	0.31	2.40
Electronics	0.82	0.35	1.17
Wagner[a]			
Durables	1.15	1.47	2.62
Nondurables	1.14	1.03	2.17
Pakes-Griliches[a]			
All Manufacturing	1.16	n.a.	n.a.
Pardey[b]			
Agriculture			
(i) Quality Adjusted	3.36	n.a.	n.a.
(ii) Quality Unadjusted	2.83	n.a.	n.a.

(a) From Pakes and Schankerman (1978) calculated from data contained in Rapoport (1971) and Wagner (1968).

(b) Represents an average of the 'mean' lags from the specifications presented in Table (5) and an equivalent set of PROPUB regressions minus 6 months, an approximation of the average publication lag from project completion to publication.

FOOTNOTES

1. For notational simplicity the gross superscript, g, will be suppressed forthwith.

2. Evenson and Wright (1982) express similar sentiments.

3. They show that research output as proxied by publications significantly enhances the earnings of academic economists. See also Wright (1983) and Pakes and Nitzan (1983) for discussions on the economics of invention incentives in the private sector.

4. The goal is to estimate the total (i.e. population) number of publications per station, $\hat{P}_i = N_i \hat{p}_i$ where n_i and N_i represent the sample and population size for state i respectively and $\hat{p}_i$ is an estimate of the average number of publications per researcher in state i. However, the variance of $\hat{P}_i$ is estimated by $V(\hat{P}_i) = N_i^2 s_i^2 / n_i [(N_i - n_i)/N_i]$ after applying the finite sample correction factor to the estimate of p_i. (Here $s_i^2 = \Sigma(x_{ij} - \bar{x}_i)^2 / n_i - 1$, x_{ij} being the observed number of publications for researcher j in state i, and $\bar{x}_i = \hat{p}_i$, s_i^2 is assumed to be relatively constant across different i's.) Thus, in order to transmit homoskedastic sampling error to the error term in a regression of $\hat{P}_i$, we need to determine n_i by selecting a constant, k, defined as: $k = N_i^2 / n_i (1 - n_i / N_i)$ such that $\Sigma n_i / \Sigma N_i = 0.20$. However, choice of k such that Σn_i approximately equals twenty percent of ΣN_i implied unrealistically small sample sizes ($n_i < 1$) for the smaller stations. A practical alternative was to (iteratively) choose k^* such that $k^* = 1/n_i (1 - n_i / N_i)$. If the underlying population variance was in fact constant across all stations, then this procedure would introduce heteroskedastic sampling error into a regression with total publications per station as the dependent variable. We will return to this issue in Section III.

5. There are alternative sources - the annual Cooperative State Research Service (CSRS) Funds for Research at State Agricultural Experiment Stations reports, and listings from the United States Department of Agriculture's Current Research Information System (CRIS) - but they were both deemed too incomplete and unreliable for our purposes. Moreover, it was not possible to develop a quality index for the CSRS listing, while the fixed length format of the CRIS records means that it under-reports the publication output of highly productive or large projects. Limiting the coverage to scientific publications also eliminates a potentially serious upward bias which may result from using a broader class of publications. For example, many station bulletins etc. simply 'repackage' the knowledge produced by the station (and already reported in scientific articles) for a non-scientific audience.

6. The pro-rated measure is empirically more appealing a priori because it removes the implicit double counting which is likely when scaling the unadjusted per researcher figure to a station level figure. The population figure used here for scaling was inclusive of social science and agricultural engineering researchers.

7. The proportion of articles published by a sub-sample of 150 researchers, receiving either one or two citations, peaks in year t-2. This year also records the second lowest proportion of non-cited articles and the highest number of total citations.

8. See Pardey (1986) chapter 4 for more details.

9. See Pardey, Craig and Hallaway (1987) for more deflator details. Here non-capital expenditures were calculated as Total Expenses - .8 (Fees, Sales and Miscellaneous)- Equipment - (Land and Buildings).

10. For the moment we assume the time effect is being proxied by a simple linear trend variable. This is tested in Section III. Indirect least squares intercept estimates can be recovered by substitution.

11. With this approach we estimate, instead of the (N-1) μ's and (T-1)λ's of the covariance model, only two parameters for each effect, namely their mean and variance.

12. These averages are in line with those obtained for other studies. Shaw (1967) recorded a mean publication per year count of 1.68 based on the complete publication records of approximately 3,000 scientists in ARS-USDA through to January 1965. Limiting the count to peer reviewed articles (as does this study) Salisbury (1980, Table 9) obtained an annual publication output, averaged across all Illinois SAES scientists for the 1948-78 period, of 1.08.

13. A Box-Cox procedure (where all variables, z, are transformed $(z^\lambda - 1)/\lambda$) which artificially nested the linear and log P models was tried, with $\lambda = 0.270$ maximizing the value of the resultant likelihood function. We have no rationale for accepting this value other than its statistical difference from $\lambda = 1$ or 0. However, application of a Glejser (1969) test suggested that the linear P model suffered from heteroskedasticity in the error term ω, possibly induced by our sampling procedure as discussed earlier. Logging the dependent variable appears to remove the problem.

14. These figures dropped even further to range from 0.06 to 0.47 after partialling out time.

15. Their sample included 38 firms in the chemical drugs and medicine industry, 13 in machinery, 10 in office computing and accounting machinery, 8 in electronics components and communication, 11 in professional and scientific instruments and 41 in other manufacturing.

16. From results presented in Hausman, we can write $V(\hat{q}) = V(\hat{\beta}_{FE}) - V(\hat{\beta}_{RE})$ and form the specification test statistic $m = \hat{q}'M(\hat{q})^{-1}\hat{q} \overset{A}{\sim} \chi^2_K$ where $\hat{M}(\hat{q}) = (X'Q_1X)^{-1} - (X'\hat{\Omega}^{-1}X)^{-1}$, K = the number of unknown parameters in β when no misspecification is present, Q_1 the matrix such that $Q_1X = X - X_{i..}$, and $\hat{\Omega}$ the estimated covariance matrix from a random state specific effects specification of equation (5). (In fact $M(\hat{q}) = 1/T[V(\hat{q})]$.) The equivalent test in a regression format is to perform OLS on the augmented equation $Y_{GLS} = \beta X_{GLS} + \alpha X_{FE} + v$ where Y_{GLS}, X_{GLS}, and X_{FE} are the appropriately transformed variables, and test whether $\alpha = 0$ by comparing the estimated variance from the random effects specification to the estimated variance from the augmented specification.

17. In an extended discussion on the veracity of within estimates Mairesse (1978) cites this collinearity problem, along with the fact that within deviations are not generally large and may be severely affected by measurement error, as good reasons for resorting to the between estimates.

REFERENCES

Burke, J., *Connections*, Little, Brown and Co., Boston, 1978.

Cline, P.L., "*Sources of Productivity Change in United States Agriculture*," Unpublished Ph.D. Thesis, Oklahoma State University, Stillwater, 1975.

Davis, P. and G.F. Papenek, "Faculty Ratings of Major Economics Departments by Citations," *American Economic Review*, Vol. 74, 1984, pp. 225-230.

Davis, J.S., "*Stability of the Research Production Function Coefficient for U.S. Agriculture*," Unpublished Ph.D. Thesis, University of Minnesota, St. Paul, Minnesota, 1979.

Evenson, R.E., "*The Contribution of Agricultural Research and Extension to Agricultural Production*," Unpublished Ph.D. Thesis, University of Chicago, Illinois, 1968.

Evenson, R.E. and B. Wright, "An Evaluation of Methods for Examining the Quality of Agricultural Research," in *An Assessment of the United States Food and Agricultural Research System*, Office of Technology Assessment, Vol. II, Part C, April 1982.

Fuller, W.A. and G.E. Battese, "Estimation of Linear Models with Crossed-Error Structure," *Journal of Econometrics*, Vol. 2, 1974, pp. 67-78.

Glejser, H., "A New Test for Heteroscedasticity," *Journal of the American Statistical Association*, Vol. 64, 1969, pp. 316-323.

Griliches, Z., "Measuring Inputs in Agriculture: A Critical Survey," *Journal of Farm Economics*, Vol. 42, 1960, pp. 1411-1433.

Griliches, Z., "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *Bell Journal of Economics*, Vol. 10, 1979, pp. 92-116.

Guttman, J., "Interest Groups and the Demand for Agricultural Research," *Journal of Political Economy*, Vol. 86, 1978, pp. 467-484.

Hadwiger, D.F., *The Politics of Agricultural Research*, University of Nebraska Press, Lincoln, 1982.

Hall, B.H., Z. Griliches and J.A. Hausman, "Patents and R and D: Is There a Lag?," Working Paper No. 1454, National Bureau of Economic Research, September 1984.

Hansen, W.L., B.A. Weisbrod and R.P. Strauss, "Modeling the Earnings and Research Productivity of Academic Economists," *Journal of Political Economy*, Vol. 86, 1978, pp. 729-741.

Hatanaka, M. and T.D. Wallace, "Multicollinearity and the Estimation of Low-Order Moments in Stable Lag Distributions," in J. Kmenta and J. Ramsay, eds., *Evaluation of Econometric Models*, Academic Press, New York, 1980.

Hausman, J.A., "Specification Tests in Econometrics," *Econometrica*, Vol. 46, 1978, pp. 1251-1272.

Hausman, J.A., B. Hall and Z. Griliches, "Econometric Models for Count Data with an Application to the Patents-R&D Relationship," Technical Paper No. 17, National Bureau of Economics Research, August 1981.

Hsiao, C. *Analysis of Panel Data*. Cambridge University Press, Cambridge, 1986.

Institute for Scientific Information, *Science Citation Index*, Philadelphia, yearly volumes, 1970-1975.

Kamien, M.I. and N.L. Schwartz, *Market Structure and Innovation*, Cambridge University Press, Cambridge, 1982.

Latimer, R.G., "*Some Economic Aspects of Agricultural Research and Education in the United States*," Unpublished Ph.D. Thesis, Purdue University, West Lafayette, Indiana, 1964.

Mairesse, J., "New Estimates of Embodied and Disembodied Technical Progress," *Annales de l'INSEE*, No.30-31, 1978, pp.681-720.

McDowell, J.M., "Obsolescence of Knowledge and Career Publication Profiles: Some Evidence of Differences Among Fields in Costs of Interrupted Careers," *American Economic Review*, Vol. 72, 1982, pp. 752-768.

Mundlak, Y., "On the Pooling of Time Series and Cross Section Data," *Econometrica*, Vol. 46, 1978, pp. 69-85.

Mundlak, Y. and I. Hoch, "Consequence of Alternative Specifications in Estimation of Cobb-Douglas Production Functions," *Econometrica*, Vol. 33, 1965, pp. 814-828.

Pakes, A.S., "*Economic Incentives in the Production and Transmission of Knowledge: An Empirical Analysis*," Unpublished Ph.D. Thesis, Harvard University, Cambridge, 1978.

Pakes, A. and M Schankerman, "The Rate of Obsolescence of Knowledge, Research Gestation Lags, and the Private Rate of Return to Research Resources," Discussion Paper No. 659, Harvard Institute of Economic Research, Harvard University, Cambridge, October 1978.

Pakes, A. and Z. Griliches, "Patents and R&D at the Firm Level: A First Report," *Economic Letters*, Vol. 5, 1980, pp. 377-381.

Pakes, A. and S. Nitzan, "Optimum Contracts for Research Personnel, Research Employment, and the Establishment of "Rival" Enterprises," *Journal of Labor Economics*, Vol. 1, 1983, pp. 345-365.

Pardey, P.G., "*Public Sector Production of Agricultural Knowledge*," Unpublished Ph.D. Thesis, University of Minnesota, St. Paul, Minnesota, 1986.

Pardey, P.G., B. Craig and M. Hallaway, "U.S. Public Sector Agricultural Research Deflators: 1890-1985," Department of Agricultural and Applied Economics Staff Paper P87-25. St. Paul: University of Minnesota, August 1987.

Rapoport, J., "The Anatomy of the Product-Innovation Process: Cost and Time", in E. Mansfield et.al., *Research and Innovation in the Modern Corporation*, Norton, New York, 1971, pp. 110-135.

Rose-Akerman, S. and R.E. Evenson, "The Political Economy of Agricultural Research and Extension: Grants, Votes and Reapportionment," *American Journal of Agricultural Economics*, Vol. 67, No. 1, February 1985, pp. 1-14.

Rosenberg, N., *Perspectives on Technology*, Cambridge University Press, Cambridge, 1976.

Salisbury, G.W., "Research Productivity of the State Agricultural Experiment Station System: Measured by Scientific Publication Output," Agricultural Experiment Station Bulletin No. 762, University of Illinois, Urbana-Champaign, July 1980.

Shaw, B.T., "The Use of Quality and Quantity of Publication as Criteria for Evaluating Scientists," Miscellaneous Publication No. 1041, United States Department of Agriculture, Washington D.C., 1967.

U.S. Department of Agriculture, Agricultural Research Service, *Report on the State Agricultural Experiment Stations*, Washington D.C., yearly issues, 1955-1959.

U.S. Department of Agriculture, Cooperative State Research Service, Professional Workers in State Agricultural Experiment Stations and Other Cooperating Institutions, Agricultural Handbook No. 305, Washington, D.C., various years.

U.S. Department of Agriculture, Cooperative State Research Service, Funds for Research at State Agricultural Experiment Stations and Other Cooperative State Institutions, Washington, D.C., yearly issues, 1960-1975.

U.S. Department of Agriculture, Office of Experiment Stations, Report on the State Agricultural Experiment Stations, Washington, D.C., yearly issues, 1938-1954.

Wagner, L.U., "Problems in Estimating Research and Development Investment and Stock," American Statistical Association, Proceedings of the Business and Economics Statistical Section, 1968, pp. 189-198.

Wright, B.D., "The Economics of Invention Incentives: Patents, Prizes, and Research Contracts," American Economic Review, Vol. 83, 1983, pp. 691-707.

Yotopoulos, P.A., "From Stock to Flow Capital Inputs for Agricultural Production Functions: A Microanalytic Approach," Journal of Farm Economics, Vol. 49, 1967, pp. 476-491.

Appendix I

Table (I.1) Publication Statistics - Type of Publication, Period Averages.[a]

	Publications per Year		
Publication Type[b]	1970-73 average	1974-75 average	1970-75 average
Article	1807 (64.9)	1709 (66.6)	1758 (65.7)
Biographical	0	1	1
Correction	7 (0.3)	7 (0.3)	7 (0.3)
Discussion	3 (0.1)	2 (0.1)	3 (0.1)
Editorial	12 (0.4)	9 (0.4)	11 (0.4)
Letter	18 (0.6)	14 (0.5)	16 (0.6)
Meeting	679 (24.4)	600 (23.4)	640 (23.9)
Note	244 (8.8)	206 (8.0)	225 (8.4)
Review	14 (0.5)	21 (0.8)	18 (0.7)
TOTAL	2783	2567	2675

(a) Figures in parentheses are percentages.

(b) The publication type categories are self explanatory. They are the same categories as used by ISI. (See ISI, 1982, p. 14).

Table (I.2) Publication Statistics - Coauthor Frequency per Publication, Period Averages.[a]

Number of Coauthors	Publications per Year		
	1970-73 average	1974-75 average	1970-75 average
0	386 (13.9)	275 (10.7)	331 (12.4)
1	1036 (37.2)	910 (35.4)	973 (36.4)
2	759 (27.3)	749 (29.2)	754 (28.2)
3	400 (14.4)	393 (15.3)	397 (14.8)
4	140 (5.0)	156 (6.1)	148 (5.5)
5	44 (1.6)	52 (2.0)	48 (1.8)
6	20 (0.7)	35 (1.4)	28 (1.0)

(a) Figures in parentheses are percentages.

Table (I.3) Simple Correlation Matrix for Various Agricultural Research Output and Quality Indicators.[a]

1.	Pub	1.000							
2	Propub	0.947	1.000						
3	Totcit	0.370	0.349	1.000					
4	Netcit	0.374	0.355	0.984	1.000				
5	Pub x Tot	0.705	0.662	0.849	0.846	1.000			
6	Pub x Net	0.689	0.647	0.847	0.860	0.994	1.000		
7	Pro x Tot	0.697	0.696	0.854	0.853	0.989	0.985	1.000	
8	Pro x Net	0.679	0.678	0.851	0.867	0.982	0.989	0.994	1.000
		1	2	3	4	5	6	7	8

(a) All variables are measured on an average researcher per state basis.

Table (I.4) Regression of Raw Publication Output (PROPUB) on Agricultural Research Expenditure[(a)].

Variable	OLS	WITHIN	BETWEEN	EGLS[(b)]
R_0	-0.1718	0.1103	-2.8121	0.0345
	(0.4682)[(c)]	(0.2527)	(6.4844)	(0.2770)
R_{-1}	-0.4966	0.3850	1.1064	0.5597
	(0.6004)	(0.2821)	(13.038)	(0.3143)
R_{-2}	-0.1319	-0.4261	-1.3339	-0.1623
	(0.5921)	(0.2823)	(9.7122)	(0.3115)
R_{-3}	0.5089	-0.1050	15.544	0.2178
	(0.5851)	(0.2768)	(8.9129)	(0.3039)
R_{-4}	0.2160	0.0125	-15.974	0.3138
	(0.5937)	(0.2804)	(11.868)	(0.3079)
R_{-5}	0.0058	-0.0784	8.5244	0.0429
	(0.6053)	(0.2784)	(11.273)	(0.3131)
R_{-6}	-0.1290	-0.2141	-10.703	0.0321
	(0.6127)	(0.2878)	(10.738)	(0.3211)
R_{-7}	0.3713	-0.3965	6.8120	0.1114
	(0.4779)	(0.2745)	(5.6910)	(0.2829)
Trend	-0.0432	10.066	-	-0.0397
		(13.531)		(0.0098)
ΣR_{-i}	1.1659	-0.9329	1.1638	1.0900
R^2	.7480	.0466	.8163	.3529
NT	288	288	48	288
'Mean' Lag	3.23	3.50	4.28	2.69
χ^2				16.621

(a) All variables measured in natural logs.

(b) See note (b) Table (4). Here $\hat{\sigma}_1^2 = 1.2102$, $\hat{\sigma}_\omega^2 = 0.0602$ and $\hat{\sigma}_\mu^2 = 0.1917$.

(c) Standard errors in parentheses.

DISTRIBUTION OF AGRICULTURAL RESEARCH IMPACTS

Fred C. White*

INTRODUCTION

When there is a correspondence between two logical systems, duality can be used to derive a correspondence between results in one system and results in another system (Russell and Wilkinson, 1978). Under appropriate regularity conditions, dual functions such as normalized profit functions in production economics embody the same information on technology as the more familiar primal production functions. The technology can be examined directly using the primal approach or indirectly using the dual approach. It is often easier to estimate product supply and input demand relationships using a dual approach, because only endogenous variables appear on the left-hand side of equations and only exogenous variables appear on the right-hand side of equations (Shumway, 1983).

Duality concepts allow the estimation of output supply and input demand functions that are consistent with underlying economic theory (Shumway, 1986). Estimation generally requires that the equations be estimated as a system in order to account for relevant cross-equation restrictions. Regularity conditions related to homogeneity, symmetry, and curvature properties required to ensure that a profit-maximizing solution exists can be maintained through appropriate restrictions or tested.

Considering the versatility and power of the duality approach, one would conclude that empirical estimates using this approach might be better in some sense than estimates from other models that were not consistent with economic theory. The purpose of this paper is to review empirical estimates related to technological change in U.S. agriculture that have been obtained using the duality approach. Both static and dynamic duality models will be considered, although there is only limited empirical evidence on technological change using the dynamic duality approach.

DISTRIBUTION EFFECTS CONCEPTUALIZED

Agricultural research has important distributional effects within farming and within rural areas in general. Research affects the relative productivity of land, labor, and capital, which in turn affects the efficient mix of inputs and the share of income attributable to each of these inputs. These changes in productivity can be viewed as shifts in factor demand curves. The interaction of supply and demand will determine levels of factor use and factor returns. Hence factor supply elasticities are important in determining the income effects due to shifts in factor demands, resulting from agricultural research. Land services are quite inelastic in supply, which means that land rental rates and land prices are sensitive to shifts in demand for land services. In contrast, most other farm inputs have more elastic price elasticities of supply, indicating shifts in factor demand might change input usage with little or no impact on factor prices.

Farm Operators

Results from agricultural research may have varying effects on producers by size categories, by geographical region, and by commodities being produced. Some mechanical innovations have favored large-scale farms on the basis of economic efficiency rather than some physical limitation. A technology which is adopted only in a limited geographical area, particularly biological innovations such as the development of improved crop varieties, can alter comparative advantages among regions. Using new technologies in the production of one commodity may impact on the production and/or utilization of other commodities. For example, an improvement in beef production resulting in lower beef prices might affect pork and poultry consumption and the demand for feed grains.

---

* Fred C. White is Professor, Department of Agricultural Economics, University of Georgia, Athens, GA 30602

Whenever economies of size are present there are economic pressures to expand farm size, because larger farms would have lower costs per unit of output than smaller farms. There is considerable controversy over the magnitude of cost savings associated with increasing farm size. Distinguishing between technical economies and pecuniary economies sheds some light on the controversy. There appears to be a significant technical basis for economies of size, i.e. technology has lowered per unit costs by a greater degree on large farms than on small farms (Hall and LeVeen, Jensen). When only technical economies are considered, it appears that relatively modest sized farms can achieve a major portion of the possible cost savings associated with size. Costs in highly mechanized crops generally continue to decrease slowly throughout the entire range of surveyed farm sizes; but in vegetable and fruit crops, costs do not appear to decease substantially after an initial phase of rapid decline (Hall and LeVeen). Miller, Rodewald, and McElroy in a study of economies of size of U.S. field crop farming found that as farm size increases in most field crop regions, per unit costs decline at first, and then are relatively constant. There is some evidence that when pecuniary economies are considered, the unit cost curve does not flatten out but continues to decline with larger farm sizes (Knutson, Penn and Boehm).

Technology affects farmers according to the speed with which new innovations are adopted. Progressive farmers can benefit from a new technology through early adoption. Adoption lags, which systematically favor the larger farmers, occur because it is more profitable for large farms than small to invest in acquiring information. There is a concern that in the case of integrated agriculture, certain types of information may be only available to those that are a part of the system. In a study of adoption of new crop varieties, Perrin and Winkelman noted that new seed varieties and fertilizer which should help both large and small farms, favored larger farms because the small farms lagged behind in the early stage of adoption.

Farmland Owners

Technological change affects the productivity of land and hence impacts on the demand for farmland and its price. Farmers would therefore be affected according to the amount of farmland owned. An increase in the value marginal product of land will favor owners relative to renters. The distinction between farmland owners and renters is becoming more important because an increasing proportion of farmland is rented and a larger proportion of farmers rent part of the land they operate (U.S. Department of Agriculture, Agricultural Statistics). Herdt and Cochrane (1966) reported that technological advance with stable or rising prices has benefited farmland owners, not necessarily farm operators. They said that farmers view technological change as reducing the cost of production and hence are able to bid up the price of farmland accordingly. Heady (1971) argued that rapid increases in agricultural productivity would lower the value productivity of farmland in the case of low price elasticities of demand for farm products, reducing farm revenue. While the net effect of technological change would be to lower the share of total income attributable to farmland, farmland prices increased during periods in which the government supported prices because of compensatory government programs. With price supports, increased productivity resulted in sizable capital gains to farmland owners (Cochrane, 1965). However, these capital gains must be evaluated in terms of the government programs in effect to support farm prices and not be considered as the sole responsibility of technological change.

Farm Workers

Changes in the proportion of farm income attributable to labor depends on the type of technology. Labor-saving technology reduces the demand for labor. Mechanical technology, which has been developed almost entirely by private sector research, generally can be characterized as labor-saving (Evenson, 1980). Estimated income effects indicate that technological changes have increased the marginal physical productivity of labor used in farming (Wallace and Hoover, 1966). The result is an increase in the demand for labor if farm product prices are unaffected. However, as farm prices adjust downward to expanded output resulting from technological change, the demand for labor declines because the demand for agricultural products is inelastic (Bauer, 1969).

The differential impact of technological change on certain groups of labor is evident. Workers whose skills complement agricultural innovations have experienced an increase in their marginal productivity and in their real income. However, unskilled workers who do the same work that can be done by mechanical innovations have experienced a decline in the demand for their efforts. Those workers remaining in agriculture have faced prospects of declining real incomes.

The substitution of capital for farm labor can have adverse effects on workers not suited for nonfarm employment because of age, lack of skills or inadequate employment opportunities. This problem has associated with it social costs that include unemployed resources and increased social services for displaced farm workers.

STATIC DUALITY

Theory

The roots of duality traced primarily to two pioneering works by Hotelling and Shephard. Hotelling first introduced the application of duality to economics in 1932. Then Shephard presented a comprehensive treatment of duality in production economics, including derivation of fundamental theories and lemmas in 1953. Theoretical developments by Berndt and Christensen, Diewert, Lau, and McFadden in the 1970's formed the basis for numerous empirical applications.

The static dual profit function is

$$(1) \quad \pi^{*} = F\ (P,\ W,\ Z)$$

where π^{*} is the maximum level of profit associated with the exogenous competitive prices, G is a convex function of prices, P is a vector of normalized output prices, W is a vector of normalized input prices, and Z is a vector of exogenous variables. Technical change can be considered in this model by including either a time variable or a research expenditure variable among the exogenous variables.

Maximum profit in the model can be determined by specifying the functional form and deriving the first-order conditions. The Cobb-Douglas functional form was initially used in duality but more recently more flexible functional forms such as the generalized Leontief, translog, or quadratic forms have been used. These latter functional forms can be interpreted as a second-order Taylor series approximation of the unknown underlying technology. Simultaneous solution of the first-order conditions for a maximum obtained using Hotelling's lemma yields factor demand and output supply equations.

$$(2) \quad X_i{*} = -X_i{*}(P,\ W,\ Z) \qquad i = 1,\ \ldots,m$$

$$Y_j{*} = Y_j{*}\ (P,\ W,\ Z) \qquad i = 1,\ \ldots,n$$

The actual form of these equations is dependent on the functional form.

Empirical Applications

The first application of duality in agriculture was reported by Lau and Yotopoulos (1972). They derived supply and factor demand functions from a Cobb-Douglas profit function. The profit function and the labor demand function were estimated jointly. The estimated model did not account for technological change. Subsequent studies used more flexible functional forms and accounted for technological change.

Binswanger estimated an aggregate dual translog cost function for U.S. agriculture, explicitly considering technical change. The Cobb-Douglas form of cost and production functions was rejected. The coefficient of the time variable was significant in the labor and machinery equations. These findings imply non-neutral technical change during the period 1949-1964. Technical change was labor saving and machinery using.

A surge of empirical applications using dual approaches appeared in the agricultural economics literature in the 1980's. Babin, Willis, and Allen (1982) examined industrial demand for production inputs. Chambers (1982) examined the meat products industry. Heien (1982) examined food demand. Lopez (1980) analyzed the structure of Canadian agricultural production. Using a generalized Leontief model, he estimated derived demand equations for four inputs for the 1946-1977 period. The hypothesis of no factor augmenting technical progress could not be rejected for Canadian agriculture. Hence the observed decrease in farm labor demand and increased capitalization in Canadian agriculture reflected changes in relative prices rather than technological change. In addition to these studies on duality there have been a number of studies in U.S. agricultural production which will be reviewed below.

Ray (1982) estimated a translog cost function for U.S. agriculture for 1939-1977. The rate of technical change in U.S. agriculture as measured by the Hicks-neutral technical change coefficient on the time variable indicated a 1.8% growth rate in productivity. The measure of technological change estimated from the regression approach is the net of factor substitution, which should make it a more precise measure of productivity growth than a simple trend in aggregate productivity data.

Weaver estimated the translog form of the profit function to characterize agricultural production in North and South Dakota from 1950-1970. Three output categories and five input categories were modeled. Technical change was found to be labor saving relative to all other input categories. Furthermore, technical change was capital saving relative to fertilizer, petroleum, and materials.

Antle utilized a single product translog profit function to measure the structure of U.S. agricultural technology over the 1910-1978 period. During the 1910-1946 period the hypothesis of neutral technical change was rejected with the bias primarily towards machinery and against land. However, the biases were not large. The 1947-1978 estimates showed a dramatic change in the magnitude and direction of biased technical change. For the postwar period the technology was labor saving and capital and chemical using. Technical change was biased most toward chemical inputs and against labor.

Shumway (1983) examined the structure of agricultural production for Texas field crops. He estimated interrelated supply functions for six commodities and input demand functions for fertilizer and hired labor for the 1957-1979 period. The statistically significant coefficients related to technological change indicated a positive shift in the supply curve for cotton, negative shifts in the supply of wheat and corn, and a positive shift in the demand for fertilizer. No statistically significant technological change was evidenced in the supply for rice and hay and the demand for hired labor.

Shumway and Alexander (1986) estimated supply for five output groups and demand for four inputs groups for ten U.S. production regions, 1951-1982. Homogeneity, symmetry, and convexity were maintained in each of the models. Coefficients for the trend variable in the demand and supply equations are reported by regions in table 1. In 74 out of 90 cases the trend coefficient was positive in the demand and supply equations. The largest technical shifts by region were as follows: materials - Southern Plains, hired labor - Northeast, machinery - Corn Belt, energy - Corn Belt, feed grains - Corn Belt, food grains - Northern Plains, oil crops - Corn Belt, other crops - Pacific, and livestock - Southern Plains. Since the endogenous quantities were obtained by dividing input expenditures or value of production by a Divisia price index equal to one in the base period, the magnitude of these coefficients is directly comparable. The aggregate technical shifts were greater for machinery and energy than for hired labor and materials. The greatest technical shift in the supply functions was in oil crops, followed by livestock and feed grains. The technical shifts in the supply functions were generally greater than the technical shifts in the input demand functions.

In a study of multiple-input multiple-output technology, I analyzed the supply functions for three output groups and four input groups for U.S. agriculture, 1948-1979. The normalized profit function was conceptualized in a quadratic form. Data for the analysis were from Ball (1985). Results from the model are reported in Table 2. The input were considered negative outputs, so the sign on the trend variable (8) has to be reversed for the input demand equations. The demand for labor exhibited a large technical reduction (-0.69). The demand for materials had the largest technical increase (0.34), followed by land (0.04) and capital

Table 1. Temporal Parameters From Input Demand and Output Supply Equations for U.S. Production Regions, 1951-1982

	Demand Equations				Supply Equations				
	Materials	Hired Labor	Machinery	Energy	Feed Grains	Food Grains	Oil Crops	Other Crops	Livestock
Northeast	0.0016	0.0300*	0.0319*	0.0150*	0.0234*	-0.0002	0.0072	-0.0165	0.0514*
Lake States	0.0331*	0.0186*	0.0413*	0.0237	0.0575*	0.0195*	0.0300	0.0173	0.0669*
Corn Belt	-0.0620	0.0160	0.0985*	0.0858*	0.1737*	0.0228	0.2845*	-0.0045	-0.0309
Northern Plains	0.0337*	0.0160*	0.0261*	0.0412*	0.1079*	0.0426*	0.0499*	0.0168*	0.0312*
Appalachia	-0.0244*	0.0181*	0.0228	0.0182*	0.0368*	0.0112*	0.0625*	0.0740*	0.0398*
Southeast	-0.0031	0.0131*	0.0144*	0.0241*	0.0021	0.0121*	0.0681*	0.0538*	0.0642*
Delta States	-0.0082	-0.0134	-0.0023	0.0314*	-0.0041	0.0225*	0.0679*	-0.0295*	0.0423*
Southern Plains	0.0417*	0.0090*	0.0190*	0.0326*	0.0155*	0.0196*	0.0055	0.0176*	0.0791*
Mountains	0.0182*	-0.0047	0.0208*	0.0331*	0.0222*	0.0182*	-0.0021	0.0400*	0.0432*
Pacific	0.0186*	0.0206*	0.0154*	0.0484*	0.0138*	0.0286*	0.0071	0.1876*	0.0662*
Sum	0.0492	0.1053	0.2879	0.3535	0.4488	0.1969	0.5806	0.3566	0.4534

Source: C. Richard Shumway and William P. Alexander. "Agricultural Product Supplies and Input Demands: Regional Comparisons." Texas Agricultural Experiment Station Technical Article, Texas A&M University, College Station, Texas.

*Statistically significant at 5% level.

(0.03). The supply of field crops has a larger technical shift (0.48) than livestock and dairy (0.24) and fruits, nuts, and vegetables (-0.08).

DYNAMIC DUALITY

Theory

The dynamic duality theory developed by Epstein assumes that the objective of a price-taking firm is to maximize the discounted value of the firm. If the firm's profit function meets certain regularity conditions, including convexity in output prices, input prices, and gross investment and twice differentiable, then optimal input demand and output supply equations can be derived by applying Hotelling's lemma.

The dynamic duality theory of Epstein assumed that technology is stationary, i.e., technology in the next period will be the same as technology in this period. If producers are aware of the technological change, the stationary assumption may not be appropriate. Karp, Fawson, and Shumway modified Epstein's theory by including a technology function R(t) in the

Table 2. Parameter Estimates of Output Supply and Input Demand Relationships With Technological Change

Parameter[a]	Estimate	Standard Error	Parameter[a]	Estimate	Standard Error
B0	-2.0019	7.1157	D39	0.6841	0.9057
C2	-83.6009*	3.7979	D44	0.6677*	0.2479
C3	-17.2224*	1.4204	D45	-0.6034	0.4548
C4	-7.8073*	0.5123	D46	1.4131	0.3741
C5	-6.7082*	3.1304	D47	-1.5289*	0.1939
C6	36.1738*	3.5026	D48	-0.0431*	0.0048
C7	13.8332*	1.4738	D49	-0.2603	0.3058
C8	0.4751	0.2746	D55	9.6619*	4.2493
C9	25.2323	13.0602	D56	-3.8515	2.8435
D22	-3.6776	9.2774	D57	-1.8518	1.2035
D23	-5.1727*	1.6854	D58	-0.3424*	0.0342
D24	-0.2469	0.7175	D59	-4.4922	2.3882
D25	-1.2064	4.4098	D66	-10.2710	4.2190
D26	-0.9569	4.5452	D67	-1.4076	0.9206
D27	11.7862*	1.3166	D68	0.2429*	0.0420
D28	0.6915*	0.0615	D69	9.3952*	3.8136
D29	9.3310*	4.1406	D77	-8.2659*	0.6066
D33	-0.7177	1.1465	D78	-0.0820*	0.0123
D34	-0.0759	0.2275	D79	0.1457	0.6877
D35	-2.3675	1.5757	D88	0.0026	0.0049
D36	2.2856	1.2598	D89	-0.3373*	0.1518
D37	3.3208*	0.5502	D99	-42.3281	44.6353
D38	-0.0299	0.0166			

[a] Variable numbers: 1 - field crops, 2 - labor, 3 - capital, 4 - land, 5 - materials, 6 - livestock and dairy, 7 - fruits, nuts and vegetables, 8 - research expenditures, and 9 - diversion payments.

*Statistically significant at 5% level.

production function and derived the set of factor demands and output supply functions as follows:

$$(3)\quad I^* - \delta K = J_{Kp}^{-1}(rJ_p + \dot{K} - J_{Rp}\dot{R})$$

$$(4)\quad L^* = rJ_w + J_{Kw}(J_{Kp})^{-1}(rJ_p + \dot{K} - J_{Rp}\dot{R}) + J_{Rw}\dot{R}$$

$$(5)\quad y^* = r(J - J_w w - J_p P) - (J_K - w'J_{wK} - p'K)\ (I^* - \delta K) + J_R\dot{R}$$

where J = value function of the firm, K = vector of quasi-fixed inputs, L = vector of variable inputs, I = vector of gross investment on quasi-fixed inputs, w = price vector of L, p = price vector of K, F = production function using L and K, $\dot{R} = \partial R/\partial t$, r = the discount rate, δ = depreciation rate of quasi-fixed inputs, and t = time. If producers expect technology to be stationary ($\dot{R} = 0$), then these equations would reduce to those initially derived by Epstein.

Empirical Application

Lyu and White applied dynamic duality theory for ten production regions in the United States, 1949-1979. The technology variable was based on an index of production-oriented research and extension expenditures, assuming a 13-year lag. Parameter estimates of equations (3), (4), and (5) are presented in Table 3. The hypotheses that farm real estate is variable and machinery is variable are tested. Note that equation (3) can be rewritten to have the form of a multivariate flexible accelerator with a constant adjustment coefficient as

$$(6)\ I^* - \delta K = M(K - \overline{K})$$

where $M = rU + D$

$\overline{K} = -(rU + D)^{-1}(D[ra_2 + rBp + rGw + rNR - N\dot{R}])$, and

U is the identity matrix.

M is the constant adjustment matrix and $\overline{K}$ is the vector of steady state stocks. If a factor of production is perfectly variable then Mii = -1 and Mij = 0. These hypotheses were both rejected at the 1% significance level for farm real estate and machinery, indicating that farm real estate machinery can be specified as quasi-fixed inputs. The rejection of these hypotheses indicates the relevance of dynamic models.

The main concern of this study is to examine how technological change in U.S. agriculture affects factor demands and output supply. The technology elasticities of farm real estate, machinery, labor, intermediate input, and output were calculated by taking the derivatives of equations (3), (4), and (5) with respect to R and evaluating the variables at the sample means. The technology elasticities are .009, .0088, -.0065, -.0542, and 1.553 for farm real estate, machinery, labor, intermediate input, and output respectively. The positive sign of the technology elasticity for farm real estate indicates that the value marginal product of real estate increased as a result of agricultural research. This result coupled with the inelastic supply of farmland indicates that agricultural research contributed to rising farmland prices over the 1949-1979 period.

It is arguable whether the technology variable should have negative impacts on the demand for intermediate inputs, although the general perception is that advances in technology in U.S. agriculture have resulted in the increased use of intermediate inputs. The relationships between the technology variable and demand for machinery and labor and supply of output are as expected. Advances in technology have increased the demand for machinery and reduced the demand for farm labor. The largest effects of the technology variable are on output--a one percent increase in technology increased the total agricultural output by 1.553 percent. Since the technology index is composed of R & E expenditures, there is also a positive relationship between agricultural R & E and agricultural production.

Table 3. Parameter Estimates of Dynamic Factor Demands with Technological Change

Variables	Estimate	Standard Error
Intercept	-1934.40	4545.16
Real estate	-14.36	7.43
Machinery	-.23	4.46
Machinery price	-414.86	75.44
Wage	-2589.74	157.87
Materials price	8.72	74.83
R&E	47.25	93.38
Real estate squared	.06	.02
Real estate machinery	-.01	.01
Machinery squared	-.01	.01
Real estate price squared	-.01	.01
Real estate price, machinery price	.02	.01
Machinery price squared	-.04	.02
Wage squared	-.03	.01
Wage, materials price	.005	.005
Materials price squared	.005	.003
Real estate price, real estate	-.074	.009
Real estate price, machinery	-.13	.015
Machinery price, real estate	-.07	.011
Machinery price, machinery	-.13	.019
Wage, real estate	-3.27	.86
Wage, machinery	4.53	.71
Materials price real estate	-.65	.38
Materials price, machinery	-1.15	.31
R&E squared	-.36	.96
wage, real estate price	-2.77	1.02
Wage, machinery price	13.70	1.85
Materials price, real estate price	.49	.55
Materials price, machinery price	-7.86	.97
R&E, real estate	.10	.07
R&E, machinery	.03	.05
R&E, real estate price	.12	.13
R&E, machinery price	-.80	.41
R&E, wage	.09	.34
R&E, materials price	.38	.23

CONCLUSIONS

Duality provides a framework to estimate output supply and input demand relationships that are consistent with economic theory. Hence it is not surprising that the application of duality to production economics has received considerable attention in the economic literature over the past 15 years. This paper has reviewed the empirical evidence on technical change that has been forthcoming from these studies. The results across studies have been highly consistent, indicating significant technical change in the post war period. The results indicate that the technology has been labor saving and capital and chemical using. These results in themselves are not unlike results from other studies, but they do lend credibility to the general approach to duality.

In addition, there are some unique results available from these duality studies. In particular, the technical shifts in inputs versus outputs are interesting. There appeared to be greater shifts in the supply of such output categories as feed grains, oil crops, and livestock than the shifts in demand for any of the input categories. Also, the geographical distribution of where technical change has occurred is interesting. The Corn Belt experienced the greatest technical changes of all regions in the areas of demand for energy and machinery and supply of feed grains and oil crops. However, the Southern Plains experienced the greatest increase in the demand for materials and supply of livestock. The Northeast and Pacific regions experienced a significant increase in the demand for hired labor.

While the studies of static duality have generally focused on variable inputs, the concept of dynamic duality offers the opportunity to examine all inputs. However, this area of research has not yet attracted as much attention as the area of static duality. Available results from dynamic duality indicate a positive shift from technology in the demand for farmland, capital and output. The elasticity of output with respect to technology is several times greater than any elasticity of demand for inputs. The area of dynamic duality appears to be particularly fruitful for further research.

REFERENCES

Antle, J.M. "The Structure of U.S. Agricultural Technology, 1910-78." American Journal of Agricultural Economics 66(1984):414-421.

Babin, Frederick G., Cleve E. Willis and P. Geoffrey Allen. "Estimation of Substitution Possibilities Between Water and Other Production Inputs." American Journal of Agricultural Economics 64(1982): 149-152.

Ball, V. Eldon. "Output, Input, and Productivity Measurement in U.S. Agriculture, 1948-79." American Journal of Agricultural Economics 67(1985):475-486.

Bauer, L.L "The Effect of Technology on the Farm Labor Market." American Journal of Agricultural Economics 51(1969):605-618.

Berndt, E.R. and L.R. Christensen. "The Internal Structure of Functional Relationships: Separability, Substitution, and Aggregation." Rev. Economic Studies 40(1973):403-410.

Binswanger, H. "A Cost Function Approach to the Measurement of Elasticities of Substitution." American Journal of Agricultural Economics 56(1974):377-386.

Chambers, Robert G. "Duality, the Output Effect, and Applied Comparative Statics." American Journal of Agricultural Economics 64(1982):152-156.

Cochrane, Willard W. The City Man's Guide to the Farm Problem. University of Minnesota Press, Minneapolis, 1965.

Diewert, W.E. "An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function." Journal of Political Economy 79(1971):481-507.

Epstein, Larry G. "Duality Theory and Functional Forms for Dynamic Factor Demand." Rev. Economic Studies 48(1981):81-95.

Evenson, Robert E. "Research Evaluation: Policy Interests and the State of the Art." Presented at Symposium on Methodology for Evaluation of Agricultural Research, Minneapolis, Minnesota, May 1980.

Hall, Bruce F. and E. Phillip LeVeen. "Farm Size and Economic Efficiency: The Case of California." American Journal of Agricultural Economics 60(1978):589-600.

Heady, Earl O. "Welfare Implications of Agricultural Research." Resource Allocation in Agricultural Research. Walter L. Fishel, ed. University of Minnesota Press, Minneapolis, 1971, pp.121-136.

Heien, Dale. "The Structure of Food Demand: Interrelatedness and Duality." American Journal of Agricultural Economics 64(1982)213-221.

Herdt, R.W. and W.W. Cochrane. "Farm Land Prices and Farm Technological Advance." Journal of Farm Econ. 48(1966):243-263.

Hotelling, H. "Edgeworth's Taxation Paradox and the Nature of Demand and Supply Functions." Journal of Political Economy 40(1932):577-616.

Jensen, Harald R. "Farm Management and Production Economics, 1946-70." A Survey of Agricultural Economics Literature. Lee R. Martin, ed. University of Minnesota Press, Minneapolis, 1977. pp.3-89.

Karp, Larry S., Chris Fawson and C. Richard Shumway. Impact of Expectation Formation on Dynamic Investment Decisions: An Application to U.S. Agriculture. Working Paper No. 343. California Agricultural Experiment Station, Giannini Foundation of Agricultural Economics, March 1985.

Knutson, Ronald D., J.B. Penn, and William T. Boehm. Agricultural and Food Policy. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1983.

Lau, L.J. A Characterization of the Normalized Restricted Profit Function. Technical Report No. 134, Stanford University, June 1974.

Lau, L.J. and P.A. Yotopoulos. "Profit, Supply and Factor Demand Functions." American Journal of Agricultural Economics 54(1972):11-18.

Lopez, R.E. "The Structure of Production and the Derived Demand for Inputs in Canadian Agriculture." American Journal of Agricultural Economics 62(1980):38-45.

Lyu, Syu-Jyun Larry and Fred C. White. "Dynamic Factor Demands with Technological Change." Proceedings of the American Statistical Association. 1985.

McFadden, D.L. Cost, Revenue, and Profit Functions. North-Holland Publishing Company, Amsterdam, 1972.

Miller, Thomas A., Gordon E. Rodewald and Robert G. McElroy. Economies of Size in U.S. Field Crop Farming. National Economics Division, ESCS, USDA, Agricultural Economic Report 472, 1981.

Perrin, Richard and Don Winkelman. "Impediments to Technical Progress on Small vs Large Farms." American Journal of Agricultural Economics 58(1976):888-894.

Ray, S. "Translog Cost Analysis of U.S. Agriculture." American Journal of Agricultural Economics 64(1982):490-498.

Russell, R. Robert and Maurice Wilkinson. Microeconomics - A Synthesis of Modern and Neoclassical Theory. John Wiley & Sons, New York, 1979.

Shephard, R.W. Cost and Production Functions. Princeton University Press, Princeton, 1953.

Shumway, C.R. "Supply, Demand, and Technology in a Multiproduct Industry: Texas Field Crops." American Journal of Agricultural Economics 65(1983):748-60.

Shumway, C. Richard. "Supply Relationships in the South - What Have We Learned?" Southern Journal of Agricultural Economics 18(1986):11-19.

Shumway, C. Richard and William P. Alexander. Agricultural Product Supplies and Input Demands: Regional Comparisons. Texas Agricultural Experiment Station Technical Article, Texas A&M University, College Station, TX 1986.

U.S. Department of Agriculture. Agricultural Statistics. U.S. Government Printing Office, Washington, D.C., 1985

Wallace, T.D. and D.M. Hoover. "Income Effects of Innovation: The Case of Labor in Agriculture." Journal of Farm Economics. 48(1966):325-338.

Weaver, Robert D. "Multiple Input, Multiple Output Production Choices and Technology in the U.S. Wheat Region." American Journal of Agricultural Economics 65 (1983):45-56.

RESEARCH BIAS EFFECTS FOR INPUT AND OUTPUT DECISIONS: AN APPLICATION TO U.S. CASH-GRAIN FARMS

Wallace E. Huffman*

INTRODUCTION

Duality theory and static multi-product technology have been applied to analyze aggregate agricultural data by Shumway; Weaver; and McKay, Lawrence and Vlastuin. Several studies (e.g., Antle; Binswanger; and Lopez, 1985a) have indexed technology with a time trend, but no study has attempted to investigate the effects of agricultural research, extension, and education in the multiple-output dual static framework.

The objectives of this paper are (i) to assess the bias effects in cash-grain farmers' production decisions caused by public agricultural research, public extension, and farmers' schooling and (ii) to present new estimates of the shadow values of agricultural research, extension, and schooling obtained from the static dual model of agricultural production. The model is fitted to data for 42 states, pooled over Agricultural Census years 1949-74, containing the cash-grain farm type.

The organization is as follows: The econometric model of production is first presented. Second, the empirical analyses, which contain a discussion of the data and empirical results, are presented. Conclusions and implications are in the final section.

THE ECONOMETRIC MODEL

The objective of cash-grain farmers is assumed to be best represented by maximizing expected profit. Thus, farmers are assumed on average to be risk neutral, farm production decisions are assumed separable from farm household consumption decisions, and production is assumed static rather than dynamic. There is mixed evidence in the literature on each of these issues.

Consider the production decisions of a multi-product firm making choices on n+m+1 net outputs y_i (Lau 1976). They supply n+1 outputs ($y_i > 0$, $i=0,\ldots,n$) and employ m variable inputs ($y_i < 0$, $i = n+1, \ldots, n+m$). There are q fixed or environmental factors, including governmental policies, that are denoted by $z_\ell \geq 0$, $\ell=1, \ldots, q$. Denote P_0 as the numeraire price, which could be set equal to 1, and define the normalized expected price of outputs and inputs as $p_i = P_i/P_0$, $i=1, \ldots, n+m$. All p_i are positive.

With competitive behavior and regular technology, a one-to-one relationship exists between the technology and its dual transformation, the normalized restricted profit-function (Nadiri; Diewert 1973; Lau 1976). Although the characteristics of the technology can be examined directly through the primal approach or indirectly by the dual formulation, the dual approach is computationally easier to manipulate; it yields a set of choice functions that are determined by variables that are exogenous to individual firms, and it permits a wider range of hypotheses to be tested. The normalized restricted profit-function, hereafter called the profit-function, is

$$(1)\ \pi = G(p,z)$$

where π is a firm's normalized variable profit (i.e., nominal profit deflated by P_0), G is the profit-function, and p and z are vectors of the n+m normalized prices and q fixed and environmental factors, respectively. The profit-function is assumed to be twice continuously differentiable, convex, and monotonic in p and z.[1] Applying Hotelling's lemma, the system of (profit maximizing) output supply and input demand functions are directly obtained by differentiating the profit-function with respect to p:

---

* Wallace Huffman is Professor, Department of Economics, Iowa State University, Ames Iowa.

$$(2)\quad \frac{\partial G}{\partial p_i} = y_i^* (p,z),\ i=1,\ \ldots,\ n+m$$

The shadow-value equations for the q fixed and environmental factors (z_k) can be obtained. The shadow value of z_k, or λ_k, is obtained by differentiating the profit-function with respect to z_k (Nadiri, p. 452; Diewert 1974, p. 140):

$$(3)\quad \lambda_k = \frac{\partial G}{\partial z_k} = \lambda_k (p,z),\ k=1,\ \ldots,q.$$

Derivatives of the profit-function and transformation function with respect to z_k are equivalent. The optimal choice and the shadow-price equations are functions of the normalized prices associated with current choices and the fixed and environmental factors, including governmental policies (Lau 1976).

From the available flexible forms, the normalized quadratic profit-function is chosen for this study because it has some net advantages over other flexible forms. It imposes homogeneity in prices and is self-dual. It has a Hessian matrix of constants, which means that local convexity in prices implies global convexity. Additional implications for the production technology are weak separability between inputs and outputs and quasi-homotheticity (Lopez 1985b). The latter conditions imply linear expansion paths in input and output space, but they need not start at the origin.

The normalized quadratic profit-function is:

$$(4)\quad \pi = \alpha_0 + \sum_{i=1}^{n*} \alpha_i p_i + \sum_{k=1}^{q} \delta_k z_k$$

$$+ \frac{1}{2} \sum_{i=1}^{n*} \sum_{j=1}^{n*} \beta_{ij} p_i p_j + \frac{1}{2} \sum_{k=1}^{q} \sum_{\ell=1}^{q} \phi_{k\ell} z_k z_\ell$$

$$+ \sum_{i=1}^{n*} \sum_{k=1}^{q} \gamma_{ik} p_i z_k,$$

where $n* = n+m$, and αs, βs, γs, and δs are the unknown parameters of the profit-function. The net-output equations, with random disturbance terms added, for the n+m current choices are:

$$(5)\quad y_i^* = \alpha_i + \sum_{j=1}^{n*} \beta_{ij} p_j + \sum_{k=1}^{q} \gamma_{ik} z_k + \mu_i,\ i=1,\ \ldots,\ n*.$$

These n* optimal choice equations are each linear in the variables - net output, normalized prices, and fixed and environmental factors - and in the unknown parameters and disturbances. The equation for optimal numeraire output can, in principle, be obtained residually. Recall that $y_0^* = \pi - \sum_{i=1}^{n*} p_i y_i^*$, and substituting equation system (5) for y_i^*, the optimal quantity of y_0 is:

$$(6)\quad y_0^* = \alpha_0 + \sum_{k=1}^{q} \delta_k z_k - \frac{1}{2} \sum_{i=1}^{n*} \sum_{j=1}^{n*} \beta_{ij} p_i p_j + \frac{1}{2} \sum_{k=1}^{q} \sum_{\ell=1}^{q} \phi_{k\ell} z_k z_\ell.$$

Because the profit-function is assumed to be twice continuously differentiable, its partial derivatives are invariant to the order of differentiation. Given that the net supply equations are first derivatives of the profit-function, the slopes of the net supply equations are the second partial derivatives. The cross-equation symmetry conditions (i.e. $\beta_{ij} = \beta_{ji}$, $i \neq j$, i, j=1, ..., n+m) are imposed to reduce the number of unknown parameters to be estimated and to ease the burden imposed on the data.

The responsiveness of net outputs to prices is summarized in elasticities:

$$\eta_{ij} = \frac{\partial \ln y_i^*}{\partial \ln p_j} = \beta_{ij} p_j / y_i^*, \quad i, j=1, \ldots, n+m;$$

$$\eta_{i0} = \frac{\partial \ln y_i^*}{\partial \ln p_0} = - \frac{1}{y_i^*} \sum_{j=1}^{n^*} \beta_{ij} p_j, \quad i=1, \ldots, n+m;$$

$$\eta_{0j} = \frac{\partial \ln y_0^*}{\partial \ln p_j} = - (p_j / y_0^*) \sum_{i=1}^{n^*} \beta_{ij} p_i, \quad j=1, \ldots, n+m_j;$$

$$\eta_{00} = \frac{\partial \ln y_0^*}{\partial \ln p_0} = \frac{1}{y_0^*} \sum_{i=1}^{n^*} \sum_{j=1}^{n^*} \beta_{ij} p_i p_j .$$

Convexity of the profit-function implies that the own-price elasticity of output supply is expected to be positive and of input demand is expected to be negative. Cross-price elasticities can be positive, negative, or zero. If y_i^* and y_j^* are inputs (outputs), i and j are designated "substitutes" when $\eta_{ij} > 0$ and "complements" when $\eta_{ij} < 0$.

The shadow-value equations for the fixed and environmental factors associated with the normalized-quadratic profit-function are as follows:

$$(7) \quad \lambda_k = \frac{\partial \pi}{\partial z_k} = \delta_k + \sum_{\ell=1}^{q} \phi_{k\ell} z_\ell + \sum_{i=1}^{n^*} \gamma_{ik} p_i, \quad k = 1, \ldots, q$$

(Nadiri). These equations give the marginal change in normalized profit for an increment in z_k. Given estimates for δ_k, $\phi_{k\ell}$, and γ_{ik}, the shadow-value equations can be evaluated at the sample mean of p and z.

Several measures of bias effects induced by technical change or other nonprice factors, for example z_k, have been used in the literature. A Hicksian measure, based upon marginal rates of technical substitution (transformation), has the disadvantage that bias effects must be measured between every pair of net outputs. When there are a large number of outputs and inputs, this set of calculations is difficult to summarize. Antle proposes a single measure of the bias effect on each optimal choice caused by a change in technology or z_k. Although he employs a translog profit-function and single-output technology, his methodology can be adapted to multiple-output technology to obtain a net summary measure of the bias effect induced in optimal choice y_i^* relative to all optimal choices due to change in z_k.

To facilitate the presentation, consider the dual implicit transformation function $F(y_0, \ldots, y_{n+m}, z_1, \ldots, z_k) = 0$, which can be represented in unsymmetric form as $y_0 = f(y_1, \ldots, y_{n+m}, z_1, \ldots, z_k)$, $y_0 > 0$ (Diewert 1973, pp. 286-87). The unsymmetric form gives maximum output of y_0 as a function of the other n+m outputs and the k fixed or environmental factors. Define the i-th elasticity of transformation as $\epsilon_i = \frac{y_i}{y_0} \frac{\partial f}{\partial y_i}$ where $\frac{\partial f}{\partial y_i} < 0$, i = 1, ..., n+m, $\epsilon_i < 0$ for $y_i > 0$, $\epsilon_i > 0$ for $y_i < 0$, and define $\epsilon = \sum_{i=1}^{n^*} \frac{y_i}{y_0} \frac{\partial f}{\partial y_i}$.

Furthermore, for a profit maximizing competitive equilibrium, $\epsilon_i = - p_i\, y_i^*/y_0^*$, and $\epsilon = -\pi^*/y_0^*$ where $\pi^* = \sum_{i=1}^{n^*} p_i\, y_i^* < 0$.[2] The <u>change in the transformation elasticity share or profit share</u> $\epsilon_i/\epsilon = p_i y_i^*/\pi^*$ can be employed to define the relative bias in y_i^* caused by a change in z_k. The profit share approach is consistent with the netput framework where the same item can be an input or output, depending on whether it is sold or purchased. Furthermore, if only one output (y_0) is produced, then ϵ_i/ϵ is the factor cost share for y_i^*.

The bias effect is measured here as:

$$\Gamma_{ik} = \left\{ \frac{z_k}{\epsilon_i/\epsilon} \right\} \frac{\partial(\epsilon_i/\epsilon)}{\partial z_k}, \quad i = 1, \ldots, n{+}m, \; k = 1, \ldots, q.$$

For outputs and inputs, the bias effect is said to be toward (against) y_i^* if $\Gamma_{ik} > 0$ ($\Gamma_{ik} < 0$). Thus, when z_k increases, a favorable bias effect on y_i^* means that its profit share (using $\pi^* = \pi - y_0^*$) has increased. The bias effect is neutral if $\Gamma_{ik} = 0$. Furthermore, a weighted average of the Γ_{ik}s equals zero where the weights are optimal profit shares, $\sum_{i=1}^{n^*} (p_i y_i^*/\pi^*)\, \Gamma_{ik} = 0$.

Equivalent bias effects can be derived directly from the normalized profit-function. Using $\epsilon_i = - p_i y_i^*/y_0^*$ and equation (1), then

$$\epsilon_i = - \frac{\pi}{y_0^*} \frac{\partial G}{\partial p_i} \frac{p_i}{\pi}, \quad \epsilon = - \frac{\pi}{y_0^*} \sum_{i=1}^{n^*} \frac{\partial G}{\partial p_i} \frac{p_i}{\pi}, \text{ and } \epsilon_i/\epsilon = \frac{\partial G}{\partial p_i} \frac{p_i}{\pi} \Big/ \sum_{i=1}^{n^*} \frac{\partial G}{\partial p_i} \frac{p_i}{\pi}.$$

For the normalized quadratic profit-function, the bias effect is obtained by exploiting the profit-share statement of Γ_{ik} and equation system (5):

$$(8)\quad \Gamma_{ik} = \left\{ \frac{\partial\left(p_i y_i^* \Big/ \sum_{i=1}^{n^*} p_i y_i^*\right)}{\partial z_k} \right\} \frac{z_k}{p_i y_i^* \Big/ \sum_{i=1}^{n^*} p_i y_i^*} = \gamma_{ik} \frac{z_k}{y_i^*} - \frac{z_k}{\pi^*} \sum_{i=1}^{n^*} \gamma_{ik} p_i,$$

$$i = 1, \ldots, n{+}m, \; k = 1. \ldots, q.$$

Because the normalized-quadratic profit-function has a dual technology with input-output separability, these bias effects are due to shifts of "expansion paths."[3]

The random disturbance terms (μ_is) that enter the net output equations arise from weather conditions and agricultural pest problems deviating from normal. They are assumed to be homoscedastic, uncorrelated, and normally distributed. Because these production decisions are affected by similar shocks, contemporaneous cross-equation correlation of the disturbances in the n+m equations is likely and is permitted.

THE EMPIRICAL ANALYSES

A set of six equations for output supply and input demand functions are to be jointly fitted to data for 42 U.S. states pooled over the six census years 1949-1974.[4] The parameter estimates of these equations are used to derive the estimates of own-price elasticities of supply and demand, estimates of bias effects of U.S. public policy on farmers' production decisions, and shadow values of the public policy variables.

The Data

The data are for cash-grain farms in 42 U.S. states derived from the six Agricultural Censuses between 1949 and 1974.[5] Farms in the past have been classified into 6-8 major types based upon the primary sources(s) of farm sales, e.g. cash-grain, general livestock, dairy, cotton. Farms in any one of these type classes can be expected to have more similar technology than all farms. Cash-grain farms--farms having ≥ 50 percent of their sales from grain and beans--represent a large and increasing share of U.S. farm types, except for the New England region. Thus, the New England states are excluded from our analysis, and the remaining 42 states in the contiguous 48 states are included.

The current production decisions of cash-grain farmers are condensed into seven major aggregate (per farm) quantity indexes. There are four variable inputs: fertilizer (commercial), fuel, machinery services, and labor (farmer and hired) and three outputs: wheat, soybeans, and feed grains (corn, grain, sorghum, oats, barely). These are the major outputs of cash-grain farms, and we have chosen to ignore a large number of outputs (e.g., livestock, cotton, tobacco, vegetables, fruits) that are of secondary importance on these farms. The independent variables for explaining these choices are the expected product prices, current variable input prices, and fixed and environmental factors, including research, extension, education, and farm-commodity policies.

The variables entering the supply and demand functions are summarized in Table 1. The quantity of fertilizer was derived by dividing expenditures on fertilizer (U.S. Dept. Comm.) by a state level weighted price index. The state price index was obtained by applying state quantity weights to national average prices for the primary nutrients N, P, and K.[6] Prices for separate components were weighted by expenditure shares. The price of fertilizer, the independent variable, is the one-year lagged state-level price of the composite fertilizer quantity. The quantity of fuel for agricultural use was derived by dividing expenditures on gasoline, diesel fuel, LP gas, and oil and grease (U.S. Dept. Comm.) by a state-level weighted fuel price. Regional expenditure shares for 1964 were applied in earlier years. The petroleum price, the independent variable, is the one year lagged state price of the composite fuel quantity.

The quantity of machinery services was derived by dividing an estimate of rental expenditures for owned and hired machinery services by a state price index for machinery services. Expenditures on machine hire were taken directly from the Census of Agriculture. The implicit rental expenditures for owned machinery in year t is computed as $\sum_{i=1}^{n} p_{it}$ $(r_t+d_{it}) K_{it}$, where p_{it} is the "new price" of the i-th type of machine in year t, k_{it} is the number of machines of type i in year t, r_t is the PCAs annual average interest rate on loans outstanding (Agricultural Statistics), and d_i is the straight-line depreciation rate on the i-th type of machine (Am. Society of Agr. Engineers). The types of farm machinery were limited to ones reported in the Census of Agriculture; i.e., farm trucks, wheel and crawler tractors, balers, combines, corn pickers, and forage harvesters. The "new prices" of machines were derived from prices of machines reported in the Official Tractor and Farm Equipment Guides. The state rental price index of machine services is W_{pt} $(r_{t-1}+\bar{d}_t)$ where W_{pt} is the wholesale price index for agricultural machinery and equipment at the beginning of t (U.S. Dept. Labor), and $\bar{d}_t$ is the weighted average depreciation rate for the set of machines on farms.

The farm labor input is measured as the annual hours of farm operator and hired labor employed on farms. Farm operators were assumed to work an average of 300 days per year at on-farm and off-farm work combined and to work an average of 8 hours per day at farm and off-farm work, and their farm hours were derived by subtracting an estimate of their annual hours of off-farm work. Annual hours of hired labor are derived as annual expenditures on hired labor plus expenditures on contract labor (U.S. Dept. Comm.) divided by the state average annual hourly farm wage (Farm Labor). The wage rate for hired farm labor is arbitrarily assumed to be the marginal cost of operator employed farm labor. The wage rate for farm labor, the independent variable, is the state average wage rate for hired labor lagged one year.

The bushels of grain harvested were used to construct measures of the outputs of wheat, soybeans, and feed grains. The feed grain quantity index is a Fisher-quantity index constructed by using the quantities of corn, oats, barley, and grain sorghum harvested (U.S. Dept. Comm.) and state average prices received for the commodities (Agr. Prices). The expected output prices, the independent variable, are the average closing futures market prices in the planting month for harvest month contracts, adjusted for state differences in average transportation costs.[7] The planting months are March or April, except for winter wheat for which it is September. The (expected) feed grains price is the numeraire price in the empirical analysis, and the other output and input prices are divided by it.

Fixed factors that affect output-input choices are the land stock, pre-season precipitation, and time trend. The land stock is measured in constant quality units as a price weighted quantity index of five land-use types on cash-grain farms (Hoover). The weights are fixed for all years. Relative weights were taken from Hoover and expressed at the 1949 average land-price levels (U.S. Dept. Comm.). Preseason precipitation is known at planting time, and it is measured as the total of the state average precipitation received during the months of October through March before planting. The trend and trend squared are included to remove the effects of unmeasured variables that are correlated with time and that otherwise might cause spurious estimates of coefficients of included variables.

The policy variables are (public) agricultural research, extension, farmers' education, and feed grain and wheat program variables. The agricultural research variable is constructed as the real stock of public agricultural research per-commodity-subregion. Research expenditures in year t are assumed to have trapezoidal shaped weights--first linearly increasing, constant, and then linearly decreasing and to sum to unity (Evenson 1978, pp. 202-205).[8] For each state, these variables represent both indigenous research and borrowable research from other states located in similar geoclimatic regions. The agricultural extension variable is the stock of extension per-commodity-subregion. The stock of extension is obtained using geometrically declining weights. (.5, .25, .125, etc.) of current and past expenditures on extension and on farm management and agricultural engineering research (Evenson 1978, p.204).

Schooling of farmers may have allocative as well as general efficiency effects on production (Welch 1970; Huffman 1977). The schooling level of cash-grain farmers is proxied by a Welch-type weighted (Welch 1966, 1970) average number of years of schooling completed by all farmers in a state (Census of Population).

The government program variables are rather crude. They concentrate on the loan rate but ignore acreage restrictions. They are derived as $(p_i/P_{Li})\ D_i$, where p_i is the normalized price of the i-th output, i=5 (wheat), 7 (feed grains); P_{Li} is the national average loan rate (Cochrane and Ryan) for wheat (i=5) and for corn (i=7); D_i is a dummy variable taking the value of 1 if output i is produced, and 0 otherwise. To the extent that these programs have resource allocation effects, the coefficient of the wheat program variable is expected to be negative in the wheat supply equation, and the coefficient of the feed grain program variable is expected to be negative in the feed grains supply equation.

Several other variables are included in the output supply and input demand equations. First, the share of the farm operators that are 65 years of age or older is included to represent the effects of partial retirement and possible short-term planning horizon of older farmers on production decisions. Second, the three outputs are not always produced by cash-grain farmers in all 42 states. In particular, the number of states in which soybeans are produced (by cash-grain farms) is rather small in 1949, and the number of states in which farmers produce soybeans increases over time. For the whole sample, sixty-five percent of the states have cash-grain farms reporting positive quantities of soybeans harvested. In all supply-demand equations, variables are added to permit the intercept and coefficients of the normalized soybean and wheat prices to differ because of the practical problem of truncation at zero for soybean and wheat supply decisions. This is a crude attempt to incorporate structural change.

Econometric Estimation

The estimation proceeds in steps. The set of supply and input demand equations are estimated by 3-stage least squares subject to within- and cross-equation restrictions and to the predicted value of a farm-type selectivity variable. The cross-equation restrictions are the symmetry condition, $\beta_{ij} = \beta_{ji}$. The within-equation restrictions arise from restricting the coefficient of the normalized price of soybeans (wheat) to being zero in all supply and input demand equations when soybeans (wheat) are not produced. The restricted 3-stage least-squares estimator is consistent and efficient, conditional on the farm type selectivity variable.[9] This step provides the estimates α_i, β_{ji}, and γ_{ik}. Estimates of δ_k and $\phi_{k\ell}$ are obtained by fitting the following equation:

$$(9) \quad \pi^r = \alpha_0 + \sum_{k=1}^{q} \delta_k z_k + \frac{1}{2} \sum_{k=1}^{q} \sum_{\ell=1}^{q} \phi_{k\ell} z_k z_\ell + v$$

where the dependent variable is derived as $\pi^r = \pi - \sum_{i=1}^{n^*} \hat{\alpha}_i p_i - \frac{1}{2} \sum_{i=1}^{n^*} \sum_{j=1}^{n^*} \hat{\beta}_{ij} p_i p_j - \sum_{i=1}^{n^*} \sum_{j=1}^{q} \hat{\gamma}_{ik} p_i z_R$ and where v is a random disturbance term that is assumed to have a zero mean in large samples, except for farm-type selectivity.

Observed farm output or sales is the result of production decisions and random shocks to technology and prices. Thus, the probability that a farm is classified as a cash-grain farm depends on p and z (Huffman 1987). Thus, E(ϵ/the farm type classification), $\epsilon = \mu_i$, v, are unlikely to be zero. This condition could bias all the estimated coefficients (Heckman). To ameliorate selectivity biases, a new variable which is the predicted relative frequency of (not) observing cash-grain farms to each aggregate supply and input demand equation and to equation (9).[10]

Estimates of the Product Supply and Input Demand Equations

Estimates of the parameters of the six equations, derived from the normalized quadratic profit-function and fitted to the 296 pooled observations for U.S. cash-grain farms, are reported in Table 2. All own-price coefficients have the expected sign, and all are significantly different from zero at the 5 percent level, except for the coefficient of the soybean price. The coefficients of the fixed factors are plausible. Increasing the average land input per farm causes the quantity of all variable inputs demanded and all outputs supplied to increase, except for soybeans. Greater preseason precipitation decreases the demand for all variable inputs, except fertilizer, and increases the quantity supplied of all outputs. As the share of older farmers (≥ age 65) increases, the demand for all inputs and supply of outputs are reduced. The soybean supply equation has a statistically significant cash-grain farm-type selectivity effect.[11]

Only estimates of the own-price input demand and output supply elasticities, evaluated at the sample means, are presented. All demand elasticities are negative as expected and less than one in absolute value. The demand elasticities are -0.73 for fertilizer, -0.74 for fuel, -0.60 for machinery, and -0.44 for labor. The own-price supply elasticities are 2.64 for wheat, 0.80 for soybeans, and 1.49 for feed grains.

It is useful to compare these estimates of demand and supply elasticities to ones obtained by others that employ a similar methodology, although they used different data. Shumway (1983) and Weaver (1983) have the similarities of applying a profit-function framework, disaggregating output, treating land as fixed, and time period analyzed. Weaver's model for the Dakotas produced larger demand elasticities for fertilizer, machinery services, and labor. His estimates for these inputs exceeded one in absolute value. Our estimate of the demand for fuel is, however, sizably larger than his. On the other hand, Shumway's model for Texas field crops produced almost exactly the same estimates of demand elasticities for fertilizer and labor. Our estimate of the demand elasticity for machinery services is sizably larger in absolute value than his estimate for machinery input. Weaver's and Shumway's estimates of the supply elasticities for feed grains and wheat (foodgrains) are roughly one-half as large as our estimates. Neither includes soybeans as an output.

Estimates of the bias effects in cash-grain farmers' production decisions attributed to a change in an increment to agricultural research, extension and farmers' schooling are presented in Table 3. These estimates are obtained by evaluating equation (8) at the sample mean for z_k, y_i^*, p_i and π^*. The estimates of γ_{ik} are taken from Table 2. These results show, other things equal, that additional agricultural research has a bias effect in favor of all inputs and all outputs in the sense that their profit shares are increased. Although it may seem unusual that all six of these measures of bias can be positive, this can occur when an increase in agricultural research increases the size of π^*, which is negative (-2.482 at the mean of the sample). This makes π^* smaller in absolute value, and each of the p_iq_i/π^* can (but need not) increase. Except for wheat, for which agricultural research has an approximately neutral effect, the favorable bias effects of agricultural research are relatively large in the sense that the elasticities of the profit shares range between 0.64 and 1.4. (Recall that for a neutral effect, $\Gamma_{ik} = 0$.) The most favorable bias, however, is toward fertilizer and soybeans.

Agricultural extension has bias effects that are generally smaller than those of agricultural research, and additional extension is biased against some choices. An increase of agricultural extension reduces the profit shares of fertilizer, wheat, and fuel, although the bias of the latter is not economically different from zero. Additional extension has bias effects in favor of machinery, labor, and soybeans. Farmers' schooling, like agricultural research, is the source of favorable bias toward all six choices. The magnitudes of the bias effects are very large for the inputs, ranging between 3.1 and 3.7. The favorable bias effect is even larger for wheat (7.9) but only 0.8 for soybeans. Thus, additional farmers' schooling is a source of extremely large "favorable" bias effects.

Although alternative estimates of the bias effects could be computed, the estimates just reported suggest that public agricultural research, public extension, and farmers' schooling have non-neutral effects on production decisions of cash-grain farmers. Furthermore, the sizes of these effects are not directly comparable to earlier measures reported by Antle (1984) and by Binswanger (1974) because they used single output technology and by Weaver because of different definitions of bias effects and because they index technology with time.

Estimates of shadow values of agricultural research, extension, and schooling are obtained by evaluating equation (7) at sample mean values of the zs and ps. Estimates of γ_{ik}s are taken from Table 2 and estimates of δ_k and $\phi_{k\ell}$ are obtained by fitting equation (9) with a sample selectivity term added by ordinary least squares. The fitted equation is not reported here.[12] The benefit-cost comparison is performed by using a mean number of commodities per state of 7.24 and a zero real discount rate. Likely choices of the discount rate are small (0-2 percent), and the choice of a zero rate makes the computation much easier.

The shadow values of agricultural research, extension, and farmers' schooling are all positive. An increase of research expenditures by $1,000 in a state allocated across 7.24 commodities has benefits in that state and in other states because of spillover effects into similar regions and subregions. The within-state shadow value is an increment to profits of $0.0157 per cash-grain farm. An approximately equal value of benefits comes from the spillover effects on cash-grain farms of other states. Thus, with an average of 9,320 cash-grain farms per state, the total benefits to cash-grain farms from a $1,000 increase in agricultural research stock of one state is $292. An increase of expenditures on extension by $1,000 (allocated across 7.24 commodities) has a shadow value of $0.023 per cash-grain farm. There is no spillover effect into other states, but with an average of 9,320 cash-grain farms per state, the increment in profits of cash-grain farms is $217 per state. Although benefits to cash-grain farms are less than the cost for both research and extension, farms of other types, which are an average of 81.7 percent of all commercial farms, are expected to obtain positive benefits too. Thus, the total benefits to farms of all types may be positive.

The shadow value of one year of schooling (a .14 increase of the education index) for cash-grain farmers is $1,074. When this real return is projected over a 45-year horizon, the return to one year of schooling of cash-grain farmers compares favorably with the cost.

These computations of shadow values should be viewed with some caution. They are computed assuming that output and input prices remain unchanged in the face of adjustments caused by an increment to one of these variables. Also, we have assumed that market prices of outputs and inputs reflect marginal social value.

CONCLUSIONS

A conceptual model of production decisions on cash-grain farms has been developed in this paper based upon competitive farm output and input markets and a normalized quadratic profit-function. The empirical analysis focuses upon four variable inputs and three outputs. The model is fitted to data for 42 U.S. states pooled over census years 1949-1974.

Some of the results are:

(1) Input demand functions are own-price inelastic, but supply functions for two of three outputs are own-price elastic.

(2) Additional agricultural research and farmers' schooling have had relatively large bias effects--measured by change in profit share--in favor of all inputs and outputs of cash-grain farms. Additional extension has caused biases in favor of machinery demand, labor demand, and soybean supply but against wheat supply and fertilizer demand. Extension has had an essential neutral effect on fuel demand.

(3) Agricultural research, extension, and farmers' schooling have positive shadow values (marginal effects on farm profits). The marginal benefits seem to compare favorably with the marginal costs.

FOOTNOTES

*The author is Professor of Economics, Iowa State University. Helpful suggestions were obtained from the discussions at the Symposium. This study is part of a much larger project that Robert E. Evenson and I have under way to analyze the development and performance of U.S. agricultural research and education. Financial assistance from USDA-CSRS and the Iowa Agriculture and Home Economics Experiment Station is acknowledged. Journal Paper No. 12642 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project 2516.

[1] The profit-function is convex if its matrix of cross-partial derivatives $[\pi_{ij}]$ is positive semi-definite or if all its characteristic roots are positive or zero.

[2] In the discussion that follows, $\pi^* \; (= \pi - y_0^*) \neq 0$.

[3] Antle and Capalbo show that the interpretation of bias effects are simplified when the technology in input-output separable.

[4] We have proposed a theoretical model of farm-level behavior and are planning to fit this model to aggregate average data. Linear aggregation of variables over farms is appropriate when the individual profit-functions are normalized quadratic. Output and input prices may, however, not be exogenous at the state level of aggregation.

[5] The five-year interval between successive Censuses of Agriculture reduces the number of observations available on each state from what annual data would provide. Annual data are not available for farms by type, only for all farms.

[6] See Huffman and Evenson for more details on the derivation of variables.

[7] Although there is not uniform agreement about the appropriate output prices to use, the futures' markets efficiently incorporate information. Gardner (1976) has shown that own-price elasticities of supply are much larger when futures prices are used rather than one-year lagged actual prices.

[8] The research variable for each state is the summation of an applied research stock and a basic research stock. The total stock of each type of research for a state in a year t is constructed as:

$$S(a,b,c)_t + \alpha \; SSR(a,b,c)_t + \beta \; SR(a,b,c,)_t$$

where $S(\ )_t$ = within-state stock of research in $_t$, and $SSR(\ )_t$ = research stock of other states in a similar geoclimatic region in t, and $SR(\ )_t$ = research stock of other states in the same geoclimatic region in t. The parameters a,b, and c refer to the length (years) of segments in the trapazoidal weight pattern; a is the number of years of rising linear weights, starting at zero for the year of investment; b is the number of years of constant (peak) weight; and c is the number of years of declining linear weights, ending with zero weight. These weights sum to one and differ by major census region (Northern, Southern, Western). The parameters α and β are borrowability parameters, taking values of 0, .25, or .5.

[9] The estimated coefficients of the demand and supply equation may be affected by the choice of the equation to delete.

[10] The equation fitted to explain the cash-grain proportion of all farms contained all the variables included in the output supply and input demand equations (see Table 2), except for feed-grain program and wheat program variables. However, the land and share of farm operators ≥ age 65 variables are defined for all farms, not just cash-grain farms.

[11] The Hessian matrix fails the test for convexity. One of the eigen values was negative, and the other five were positive.

[12] The set of zs included in this regression are land, preseason precipitation agricultural research, extension, education, feed grain program, wheat program, share of farmers ≥ 65, and time. The equation also includes the selectivity variable. Symmetry of the $\phi_{k\ell}$s is imposed (i.e., $\phi_{k\ell} = \phi_{\ell k}$, in the estimation) and a total of 56 coefficients are estimated. The R^2 for the fitted equation is 0.70.

Table 1. Sample Mean Value of Quantities, Prices, and Other Variables: U.S. Cash Grain Farms, 42 States, 1949-1974

Variables	Unit	Mean
Normalized profit (π)	$1,000/farm	2.178
Quantities		
Fertilizer	1,000 weighted lbs/yr.	-1.571
Fuel	1,000 weighted gal/yr.	-0.918
Machinery	1,000 weighted machine yrs/yr.	-1.338
Labor	1,000 hrs/yr.	-2.532
Wheat	1,000 bu/yr.	3.462
Soybeans	1,000 bu/yr.	1.487
Food grains	1,000 weighted bu/yr.	4.660
Normalized prices		
Fertilizer	$/weighted lb.	0.764
Fuel	$/weighted gal.	0.906
Machinery	$/weighted machine yr.	1.505
Labor	$/hr.	1.016
Wheat	Expected $/bu.	0.843
Soybeans	Expected $/bu.	1.947
Feed grains[a]	Expected $/weighted bu.	1.362[b]
Other		
Land	$/farm	40,075.0
Preseason precipitation	Inches/season	15.6
Agricultural research	$1,000/per commodity	16,814.9
Extension	$1,000/per commodity	4,826.9
Education	Weighted yrs/farm opr.	1.390
Feed grain program	$/bu.	0.352
Wheat program	$/bu.	0.629
Share farm opr ≥ age 65	Unit free	0.117
Selectivity	Unit free	0.834
D_1 (1 = no wheat)	-	0.060
D_2 (1 = no soybeans	-	0.345

[a] Numeraire price, not normalized.

Table 2. Three-Stage Least Squares Estimate of System of Aggregate Product Supply and Input Demand Functions: U.S. Cash Grain Farms, 42 States, 1949-1974[a/]

	Demand Equations ($y_i<0$)				Supply Equations ($y_i>0$)	
Variable	Fertilizer	Fuel	Machinery	Labor	Wheat	Soybean
Normalized Prices:						
Fertilizer	1.610 (2.87)	-0.510 (2.71)	-0.204 (1.41)	-0.235 (1.15)	1.701 (2.45)	0.229 (0.39)
Fuel	-0.510 (2.71)	0.780 (2.87)	-0.467 (4.15)	0.323 (2.32)	0.284 (0.99)	0.571 (2.27)
Machinery	-0.204 (1.41)	-0.467 (4.15)	0.539 (5.76)	-0.676 (7.09)	-0.097 (0.40)	0.798 (3.89)
Labor	-0.235 (1.15)	0.323 (2.32)	-0.676 (7.09)	1.124 (6.96)	0.942 (2.63)	0.417 (1.33)
Wheat	1.701 (2.45)	0.284 (0.99)	-0.097 (0.40)	0.942 (2.63)	10.253 (3.84)	-6.775 (5.15)
Soybean	0.229 (0.39)	0.571 (2.27)	0.798 (3.89)	0.417 (1.33)	-6.775 (5.15)	1.260 (0.87)
Wheat x D_1	-1.701 (2.45)	-0.284 (0.99)	0.097 (0.40)	-0.942 (-2.63)	-10.253 (3.84)	6.775 (5.15)
Soybean x D_2	-0.229 (0.39)	-0.571 (2.27)	-0.798 (3.89)	-0.417 (1.33)	6.775 (5.15)	-1.260 (0.87)
Fixed Factors:						
Land	-1.58×10^{-5} (9.69)	-1.02×10^{5} (15.08)	-1.30×10^{-5} (22.09)	-1.96×10^{-5} (21.80)	8.79×10^{-6} (1.40)	-6.25×10^{-7} (0.18)
Preseason precipitation	-0.001 (0.18)	0.019 (5.99)	0.007 (2.38)	0.013 (2.97)	0.124 (4.17)	0.069 (4.12)
Time	0.633 (1.94)	0.047 (0.35)	0.066 (0.56)	0.169 (0.94)	-0.423 (0.34)	0.494 (0.71)
Time^2	-0.202 (3.05)	-0.039 (1.44)	-0.068 (2.86)	-0.026 (0.71)	0.307 (1.19)	-0.038 (0.27)
Policy:						
Agr. research	-1.69×10^{-5} (2.82)	-1.79×10^{-6} (0.73)	3.30×10^{-6} (1.55)	1.32×10^{-7} (0.40)	1.29×10^{-4} (5.76)	1.82×10^{-5} (1.44)
Extension	1.66×10^{-5} (0.88)	1.79×10^{-6} (0.47)	-1.12×10^{-6} (0.17)	-7.81×10^{-6} (0.75)	-1.29×10^{-4} (0.48)	3.27×10^{-5} (0.81)
Education	0.750 (2.10)	0.308 (2.07)	-0.031 (0.24)	0.602 (3.04)	9.685 (7.08)	-3.122 (4.17)
Feed grain program	0.051 (0.24)	-0.104 (1.17)	-0.162 (2.09)	-0.004 (0.03)	1.234 (1.57)	-1.006 (2.32)
Wheat program	-0.228 (0.58)	0.161 (0.98)	-0.190 (1.34)	0.233 (1.07)	0.937 (0.62)	-0.842 (1.01)

[a/] Asymptotic t-statistics, conditioned on the selectivity variable, are in parentheses under the estimate of the coefficients.

Table 2. Three-Stage Least Squares Estimate of System of Aggregate Product Supply and Input Demand Functions: U.S. Cash Grain Farms, 42 States, 1949-1974[a]
-Continued-

	Demand Equations ($y_i<0$)				Supply Equations ($y_i>0$)	
Variable	Fertilizer	Fuel	Machinery	Labor	Wheat	Soybean
Other:						
Share f.o. ≥ age 65	2.051 (1.32)	3.932 (6.11)	1.820 (3.27)	5.430 (6.30)	-17.408 (2.87)	-10.441 (3.12)
Selectivity	-0.331 (0.33)	0.595 (1.40)	0.354 (0.99)	0.369 (0.67)	2.792 (0.78)	-4.209 (2.10)
D_1	1.549 (2.09)	0.353 (1.15)	-0.352 (1.36)	0.500 (1.29)	9.699 (3.41)	-7.803 (5.47)
D_2	0.564 (1.00)	0.389 (1.63)	0.564 (2.89)	0.265 (0.89)	-2.904 (2.15)	0.514 (0.38)
Intercept	-3.321 (1.93)	-2.682 (3.74)	-0.949 (1.56)	-5.385 (5.89)	-18.781 (3.16)	11.572 (3.38)

[a] Asymptotic t-statistics, conditioned on the selectivity variable, are in parentheses under the estimate of the coefficients.

Table 3. Bias in Choices Induced by Changes in Fixed Factors and Government Policy Variables: U.S. Cash-grain Farms, 1949-1974

Fixed factors and government policy z_k	Current Choices[a/]					
	Inputs				Outputs	
	Fertilizer	Fuel	Machinery	Labor Γ_{ik}	Wheat	Soybeans
Agricultural research	0.860	0.716	0.641	0.683	0.012	0.887
Extension	-0.035	-0.004	0.019	0.030	-0.037	0.105
Education	3.062	3.245	3.734	3.383	7.876	0.828
Profit share						
$p_i y_i^* / \pi^*$	0.495	0.336	0.796	1.047	-1.097	-0.575

[a/] A positive (negative) sign indicates a bias effect in favor of (against) an output or an input.

REFERENCES

American Society of Agricultural Engineers. Agricultural Engineers Yearbook, 17th ed., 1970.

Antle, John. "The Structure of U.S. Agricultural Technology, 1910-78," Amer. J. Agr. Econ. 66 (1984):414-421.

Antle, John M. and Susan M. Capalbo. "An Introduction of Recent Developments in Production Theory and Productivity Measurement," in Agricultural Productivity: Measurement and Explanation, Capalbo, S.M. and J.M Antle (eds.), Washington, D.C.: Resources for the Future, Inc., (forthcoming), 1987.

Binswanger, Hans P. "The Measurement of Technical Change Biases with Many Factors of Production." Amer. Econ. Rev. 64 (1974):964-76.

Cochrane, Willard W. and Mary E. Ryan. American Farm Policy, 1948-1973. Minneapolis, MN: University of Minnesota Press, 1976.

Diewert, W.E. "Functional Forms for Profit and Transformation Functions," J. Econ. Theory 6 (1973):284-316.

Diewert, W.E. "Functional Forms for Revenue and Factor Requirements Functions," Int. Econ. Rev. 15 (Feb. 1974):119-130.

Evenson, Robert E. "Research, Invention, Extension and Productivity Change in U.S. Agriculture: A Historical Decomposition Analysis." Proceedings of Symposium on Research and Extension Evaluation, Moscow, Idaho: University of Idaho, 1978.

Gardner, Bruce. "Futures Prices in Supply Analysis," Amer. J. Agr. Econ. 58 (1976):81-84.

Heckman, James J. "Sample Selection Bias as a Specification Error." Econometrica 47 (1979):153-162.

Hoover, Dale A. "A Study of Agricultural Land Prices in the United States, 1911-1958," Ph.D. Dissertation, University of Chicago, 1961.

Huffman, Wallace E. "Allocative Efficiency: The Role of Human Capital," Quart. J. Econ. 91 (1977):59-80.

Huffman, Wallace E. and Robert E. Evenson. "Supply and Demand Functions for Multi-Product U.S. Cash-grain Farms: Biases Caused by Research and Other Policies, 1949-1974." Iowa State University, Department of Economics, Staff Paper Series No. 155, April 1986.

Huffman, Wallace E. "An Econometric Methodology for Multiple-Output Agricultural Technology: An Application of Endogenous Switching Models," in Agricultural Productivity: Measurement and Explanation, Capalbo, S.M. and J.M. Antle (eds.), Washington, D.C.: Resources for the Future, Inc., (forthcoming), 1987.

Lau, L.J. "A Characterization of the Normalized Restricted Profit Function," J. Econ. Theory 12 (1976):131-163.

Lopez, Ramon. "Supply Response and Investment in the Canadian Food Processing Industry," Amer. J. Agr. Econ. 67 (1985a):40-48.

Lopez, Ramon. "Structural Implications of a Class of Flexible Functional Forms for Profit Functions." Int. Econ. Rev. 26 (1985b):593-601.

McKay, Lloyd, Denis Lawrence and Chris Vlastuin. "Profit, Output Supply, and Input Demand Functions for Multiproduct Firms: The Case of Australian Agriculture," Int. Econ. Rev. 24 (1983):323-339.

Nadiri, M. Ishaq. "Producers Theory," in Handbook of Mathematical Economics Vol. II, ed. K. J. Arrow and M. D. Intriligator, New York: North-Holland Publ. Co., 1982.

National Farm and Power Equipment Dealers Association. Official Tractor and Farm Equipment Guide. St. Louis, MO, various years.

Shumway, C. Richard. "Supply, Demand, and Technology in a Multiproduct Industry: Texas Field Crops," Amer. J. Agr. Econ. 65 (1983):748-760.

U.S. Department of Agriculture, Agricultural Prices. Washington, D.C.: U.S. Government Printing Office, various issues.

U.S. Department of Agriculture, Agricultural Statistics. Washington: U.S. Government Printing Office, various issues.

U.S. Department of Agriculture. Farm Labor, various issues.

U.S. Department of Commerce. Census of Agriculture, 1949, (1954, 1959, 1964, 1969, 1974). Washington, D.C.: Government Printing Office.

U.S. Department of Commerce. Census of Population 1950, (1960, 1970). Washington, D.C.: Government Printing Office.

U.S. Department of Labor, Bureau of Labor Statistics. Handbook of Labor Statistics. Washington, D.C.: Government Printing Office, various years.

Weaver, Robert D. "Multiple Input, Multiple Output Production Choices and Technology in the U.S. Wheat Region," Amer. J. Agr. Econ. 65 (1983):45-56.

Welch, Finis. "Education in Production," J. Polit. Econ. 78 (1970):35-59.

Welch, Finis. "The Determinants of the Returns to Schooling in Rural Areas, 1959." Ph.D. Dissertation, University of Chicago, 1966.

EVALUATING THE RESEARCH BENEFITS FOR TRADED COMMODITIES

Geoff Edwards*

INTRODUCTION

A great deal of attention has been devoted in the last two decades to assessing the economic consequences of agricultural research. The biotechnology revolution (see, for example, Hueth and Just, 1986; Kalter and Tauer, 1986) may provide a further stimulus to study of the size and distribution of the benefits and costs of research.

The present paper is in two parts. The first part outlines the approach used by Edwards and Freebairn [1981, 1984] to study the benefits from cost-reducing research. The approach is a simple, partial equilibrium one, but it incorporates the tradeability of commodities and the fact that research may reduce costs in the country of primary concern and/or in the rest of the world. Some results obtained with this approach are summarized, and an illustration gives estimates of the benefits to Australia and the rest of the world from research-induced cost reductions in the wheat industry. The second part of the paper contains observations on some additional issues that are relevant in assessing the economics of research for tradeable commodities. The issues are: choice of objective function in cost-benefit analysis of agricultural research; disaggregation into more than two sectors; effect of market distortions on benefits from research; property rights and trade in inputs; equity in distribution of the benefits and costs of research; and demand-shifting research and promotion. Most of these appear to be issues on which further research is appropriate.

MEASURING THE GAINS FROM COST-REDUCING RESEARCH FOR TRADED COMMODITIES

In the relatively small number of studies that allow for international trade, some assume that the country in which research reduces costs can export or import any quantity of the commodity without affecting world price (e.g. Akino and Hayami 1975; Ramalho de Castro and Schuh 1977). Other research allows for impacts on world prices through an excess demand curve (e.g. Martin and Havlicek 1977; Sarris and Schmitz 1981). As far as I know, Edwards and Freebairn [1981, 1984] were the first to allow research to shift the supply curve down in the rest of the world as well as in the country of primary interest. This approach reflected the obvious point that country A's gain from cost-reducing research for an export commodity would be less, ceteris paribus, if the research reduced costs for other countries producing the commodity than if the productivity gain was confined to country A. Use of a disaggregated model with a rest of the world (ROW) sector as well as a country A sector also allowed social benefits from research to be calculated from the perspective of country A, ROW or the world as a whole.

The Model

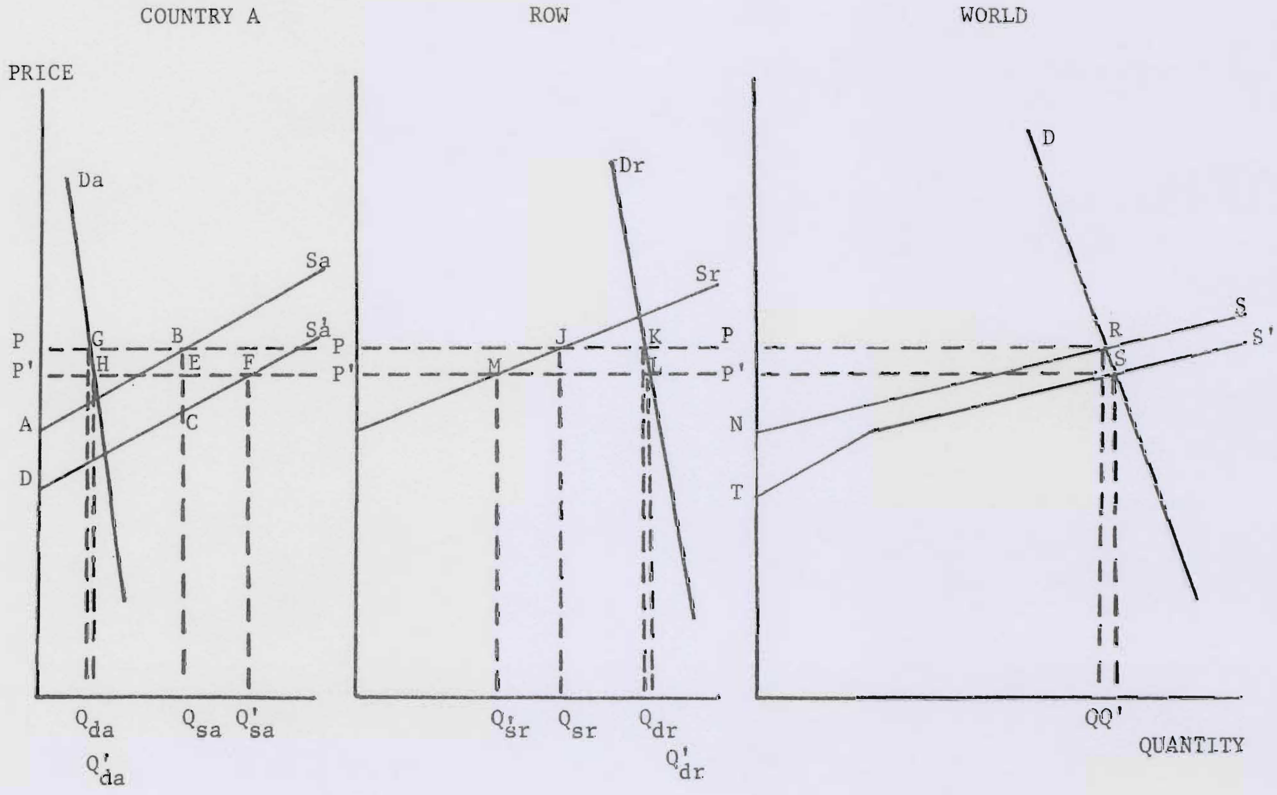
A diagrammatic version of the Edwards/Freebairn model is shown in Figure 1. The model is a simple free-trade, market-clearing one, with world supply and demand being obtained by horizontal addition of supply and demand, respectively, in the two sectors. Supply and demand are assumed to be linear. The world price determined in the right hand panel applies to producers and consumers throughout the world. Exports by one sector equal imports by the other.

Research causes a downward shift in the supply curve in country A and/or in ROW. Following the argument of Rose [1980] that it is typically most reasonable to assume a

---

* Geoff Edwards is a Senior Lecturer in Agricultural Economics, La Trobe University, Melbourne and Visiting Professor, Department of Agricultural and Resource Economics, University of Maryland, College Park, MD, 1986-87.

Figure 1. Economic Benefits from Research for a Traded Commodity



parallel shift, a parallel shift is used. The research that causes supply to shift could be carried out in country A or in ROW. Research benefits may be defined net or gross of research costs, depending on whether those costs are included in the price of new technology to producers and hence in the 'with research' supply curve.

Figure 1 is drawn for the case where country A is an exporter of the commodity, and research shifts supply only in country A. Country A producers gain economic surplus equal to area (ABCD+CEF-PBEP') from the research, and gains to country A consumers are equal to area PGHP'. Aggregate gain to country A equals area (ABCD+CEF-GBEH). The fall in world price resulting from the research - induced shift in supply causes gains to ROW consumers equal to area PKLP', losses to ROW producers of area PJMP' and a net gain to ROW equal to area JKLM. The increase in world welfare can be obtained by adding the welfare gains for country A from the left panel and for ROW in the center panel, or by calculating the area NRST in the right hand panel. Expressions for calculating gains to producers and to consumers in country A, ROW and the world as a whole are given if Edwards and Freebairn [1984].

A more general summary of the gainers and losers from shifts in supply in a two-sector market is given in the left-hand side of Table 1. Producers in a sector gain from cost reductions in that sector and lose from cost falls in the other sector. Consumers in a sector benefit from price falls resulting from downward shifts in supply in either sector. The aggregate welfare gain to producers plus consumers in a sector is necessarily positive for a research-induced reduction in domestic costs. The aggregate welfare gain to sector A from a cost reduction in ROW is negative if country A is an exporter of the commodity and positive if country A imports the commodity.

Table 1

Gainers and Losers from Falls in Supply and Rises in Demand in a Two-Sector Market

Group	Fall in Supply Occurring in		Rise in Demand Occurring in	
	The Group's Sector	The Other Sector	The Group's Sector	The Other Sector
Producers in a sector	+	-	+	+
Consumers in a sector	+	+	+	-
Producers plus consumers in a sector[(a)]	+	-(x) or +(m)	+	+(x) or -(m)

(a) x and m indicate that the sector is respectively an exporter or an importer of the commodity.

Some Implications

Seven implications of the analysis are mentioned here.

First, the gain to country A (producers plus consumers) from research will be positive so long as

$$(1) \quad \frac{k}{h} > \frac{e_{sr} Q_{sr}(Q_{sa} - Q_{da})}{(e_{da} Q_{da} + e_{dr} Q_{dr} + e_{sr} Q_{sr})Q_{sa} + e_{sa} Q_{sa} Q_{da}}$$

where k and h are research-induced cost reductions per unit of output in country A and ROW, respectively; e_{sr}, e_{dr}, e_{sa}, and e_{da} are elasticities of supply in ROW, demand in ROW, supply in country A and demand in country A, respectively, all defined at the initial equilibrium; and Q_{sr}, Q_{dr}, Q_{sa} and Q_{da} are initial equilibrium quantities supplied in ROW, demanded in ROW, supplied in country A and demanded in country A, respectively. Expression (1) can be used to calculate minimum ratios of domestic to ROW cost reductions for a country to gain from research. Table 2 presents a selection of such break-even price ratios for the case where the four elasticities e_{sr}, e_{dr}, e_{sa} and e_{da} are of any identical (absolute) size.

Table 2

Minimum Ratios of Domestic to Rest-of-World Cost Reductions (k/h) for a Country to Gain from Research

Ratio of Domestic Production to World Production	Ratio of Domestic Consumption to Domestic Production				
	0.00	0.25	0.50	0.75	1.00
0.01	0.497	0.373	0.248	0.124	0.000
0.10	0.474	0.351	0.231	0.114	0.000
0.20	0.444	0.324	0.211	0.103	0.000
0.30	0.412	0.296	0.189	0.091	0.000
0.40	0.375	0.265	0.167	0.079	0.000

Source: Edwards and Freebairn (1984).

When country A's share in world production does not exceed 20 percent, the break-even ratio is close to one-half with no domestic consumption, approximately one-quarter with half of production consumed domestically, and zero when all production is consumed domestically. The value of k/h required for country A to benefit from research for an export commodity decreases as A's share in world production rises. This is because the price effect of a given cost reduction in ROW diminishes as ROW's share in world production decreases. Inspection of expression (1) reveals that any combination of cost reductions in country A and ROW results in welfare gains to A if it is an importer of the commodity. Although the break-even values of k/h are unaffected by the values of the elasticities of supply and demand when these are identical in size, changes in individual elasticities influence the break-even cost reduction ratios. For export commodities, the break-even k/h increases with increases in the elasticity of supply in ROW and falls with increases in the elasticity of supply in country A and with the elasticity of demand in A and ROW.

Second, country A's producers will always gain from a research-induced parallel downward shift in supply of a traded commodity if supply is unaffected in ROW. This is contrary to the suggestions of some researchers. However, a fall in costs confined to a country that represents part of the total market will reduce price less than the reduction in costs unless demand in the market as a whole is perfectly inelastic and supply in the whole market is perfectly elastic.

Third, while producers in country A have their gains reduced if research lowers costs in ROW as well as in A, they will lose from the research only if the cost reductions in ROW exceed their own by a sufficiently large margin. For producers in country A the gain from their fall in costs, net of their losses from the fall in world price, will be positive so long as

$$(2)\quad \frac{k}{h} > \frac{e_{sr}\, Q_{sr}}{e_{da}\, Q_{da} + e_{dr}\, Q_{dr} + e_{sr}\, Q_{sr}}$$

Application of expression (2) can be illustrated by reference to the first column of Table 2. With no consumption of the commodity in country A (research gains to the country accrue entirely to producers), and A's production one percent of world production, country A producers will gain from the research if they experience a unit cost reduction at least half the cost reduction in ROW. With country A's production equal to 40 percent of world production the break-even cost reduction ratio falls to 37.5 percent. (The reason for the fall as the ratio of domestic to world production increases is the same reason that caused the break-even ratio of k/h to decrease with Q_{sa}/Q in the case of gains to producers plus consumers in country A). Changes in the proportion of production exported have no influence on producers' gains or, therefore, on the break-even k/h. As in the case of aggregate gains to country A for an export commodity, the break-even cost ratio, below which country A producers lose from research, decreases with increases in the domestic and foreign elasticities of demand and increases with increases in the foreign elasticity of supply.

Fourth, the analysis implies that for export industries research that overcomes problems unique to a country will give a higher national economic return, other things being equal, than research into problems that are also significant in ROW. Research directed to adapting foreign research findings to the domestic environment may also be attractive on this basis. For research that does reduce costs in country A and in ROW, A's gain will be greater the more quickly the research findings can be put into effect in country A relative to country B. In the case of research that reduces costs for an import industry, country A's gain will be greater if its research (or ROW's) reduces costs in other countries as well as in A, and if cost reductions in both sectors occur quickly rather than slowly.

Fifth, with identical values for initial production and consumption in country A, and identical values for elasticities of supply and demand, country A gains more from research that causes given cost reductions in A and in ROW for an imported commodity than it does for an export commodity. While producer gains are equal in the two cases, consumer gains are greater for the imported item because consumption is greater.

Sixth, for a given cost reduction per unit applying in an export industry, in an import industry and in a non-traded industry all having equal initial production in country A, the ranking of industries from largest to smallest welfare gains to country A is: import, non-traded, export. For a non-traded industry, country A's gain depends almost entirely on the size of the cost reduction parallelogram applying to initial production; the triangle between the 'with research' supply curve and the demand curve is normally small relative to the cost savings on initial output (e.g. Hertford and Schmitz, [1977]). The price reduction due to research represents a welfare transfer from producers to consumers in the case of non-traded commodities, whereas it influences country A's research benefits in the case of traded commodities. The margin by which A's benefits from research for a non-traded commodity exceed its benefits for an export commodity is increased if costs for the export commodity are reduced in ROW as well as in A. The reason A benefits more from a given cost reduction for an import commodity than a non-traded one when its production is set at identical levels for the two is that it consumes more of the imported commodity. The margin in favor of the import is increased if research lowers costs in ROW.

Of course, the <u>distribution</u> of research benefits is likely to be very different for non-traded commodities on the one hand and traded ones on the other. Because falls in world price for traded commodities due to a given cost reduction in country A will normally be much smaller than the fall in domestic price of a non-traded commodity experiencing the same cost reduction, producers would usually obtain a higher proportion of the research benefits for an import or export commodity than for a non-traded commodity.

Seventh, and finally, the analysis suggests that conflicts can exist between the research investments that are optimal for a country if it considers the economic return to its own citizens and those that are optimal from the view of the world as a whole. Scitovsky [1954] pointed out that effects on foreigners through changes in world prices make investment in export industries less desirable from a national view than from a world view, and investment in import industries more attractive from a national view than from a world view. Another concern for those taking a world view is the possibility that individual countries may find it economically beneficial to emphasize research for export commodities expected to have little applicability in other countries and research for import commodities expected to be useful to other countries.

An Application

An application of the model to the wheat industry is shown in Table 3. Benefits are presented for Australia, the rest of the world, and the world from research-induced cost reductions equal to 10 percent of the initial equilibrium price. The cost reductions are assumed to occur in Australia or in ROW or in both. The initial equilibrium price and quantity data is for the period 1979-80/1980-81. Further information is in Edwards and Freebairn [1984].

The results in Table 3 illustrate the dramatic increases that can occur in welfare of consumers in a 'small country' from a downward shift in supply in ROW, and the large losses that can accrue to producers and (for an export commodity) to the country as a whole from such a shift.

FURTHER ISSUES IN EVALUATING RESEARCH BENEFITS FOR TRADED COMMODITIES

Choice of Objective Function

Some national and regional productivity increases for export commodities have been evaluated by researchers within the countries concerned from a world view rather than a national view. Specifically, net gains to ROW from the fall in world price have been counted as benefits from the downward shift in supply in country A (e.g. Vere, Sinden and Campbell 1980; Zentner 1985; Ulrich, Furtan and Schmitz 1986). It is not always clear whether use of this catholic welfare function is intentional. In my view, it would nearly always accord more closely with the motivation of national governments to carry out benefit-cost analysis of research, and other government-funded projects, from a national view than from a global view. At the very least, it would seem desirable to justify departures from the principle that only benefits and costs accruing to a country's own citizens be counted when the objective is to assess the efficiency of resource allocation decisions within that country. It remains true, as discussed earlier, that the ranking of some investments in agricultural research - and of other investments - may differ when the unit of concern is a particular country and when it is the world.

Further Disaggregation

With another level of disaggregation, the model outlined in the first part of the paper can be applied to situations where productivity increases in only a part of country A's industry. Edwards and Freebairn [1982] used such a model to estimate the economic benefits from the control of serrated tussock weed in the wool industry in the tablelands area of New South Wales. The region gained from weed control, the rest of Australia lost (though less than the region's gain) and the rest of the world (an importer of wool) gained.

Market Distortions and Research Benefits

A substantial proportion of world trade in agricultural commodities is affected by tariffs and other trade restrictions. These policies, when applied in ROW, reduce world prices and hence country A's cost savings from research. A further loss to country A arises in the case of its export industries because ROW's protection policies reduce the elasticity

Table 3

Gains to Australia, Rest of World, and World from Research that Reduces Costs of Producing Wheat (Present Values in Millions of Dollars Summed Over 30 Years)

	Cost Reduction 10% in Australia 0% in ROW				Cost Reduction 10% in Australia 10% in ROW				Cost Reduction 0% in Australia 10% in ROW			
	Elasticities of Supply and Demand											
	0.3	1.0	0.3	1.0	0.3	1.0	0.3	1.0	0.3	1.0	0.3	1.0
	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2
Gain to Australia												
Consumers	8	9	6	9	256	310	205	285	248	300	199	276
Producers	1,789	1,835	1,798	1,840	453	165	727	303	-1,301	-1,578	-1,043	-1,406
Total	1,797	1,844	1,804	1,849	709	475	932	589	-1,053	-1,228	-844	-1,130
Gain to ROW												
Consumers	1,347	1,633	1,078	1,498	44,419	53,880	35,608	49,561	43,063	52,234	34,519	48,042
Producers	-1,313	-1,590	-1,051	-1,458	14,438	5,254	23,149	9,666	15,761	6,862	24,212	11,150
Total	34	43	27	40	58,757	59,134	58,757	59,227	58,824	59,096	58,730	59,192
Gain to World												
Consumers	1,355	1,642	1,084	1,508	44,675	54,190	35,813	49,846	43,311	52,534	34,718	48,318
Producers	476	245	747	382	14,891	5,419	23,876	9,969	14,460	5,334	23,169	9,744
Total	1,831	1,887	1,831	1,890	59,566	59,609	59,689	59,815	57,771	57,868	57,887	58,062

Source: Edwards and Freebairn (1984).

of excess demand in ROW, increasing the price fall caused by research-induced supply shifts in A. The effect of market distortions in ROW on gains to country A from supply shifts for its import industries is ambiguous because the cost savings effect and the price effect are in opposite directions.

A closer examination of the effects of several types of market distortions on the size and the distribution of research benefits is given in Alston, Edwards and Freebairn [1986]. That study found that a country's benefits from research that lowered its supply curve for a commodity could be reduced, left unchanged, or increased by its own market distortions, depending on the nature of the intervention and the country's trading status. It was found, for example, that a country's gains from research would be: reduced by a target price with deficiency payments and, for a large exporter or importer, by a subsidy on output or exports, or a tax on imports; left unchanged by a subsidy on output or exports or a tax on imports for a small country trader; and increased by a home consumption price scheme with equalization of prices to producers in the case of a small country exporter. These results rest on the assumptions that the research-induced cost reduction is independent of commodity price and hence of the market distortions. For the tax and subsidy policies, linear demand and supply with parallel supply shifts due to research is also assumed. Consideration of the sensitivity of results to relaxing the assumption of exogenously determined research and supply shift, in particular, is a challenge.

Property Rights and Trade in Inputs

A firm or industry in country A that supplies inputs to producers of a commodity in ROW will cause a loss to producers of the commodity in country A (and to producers plus consumers of the commodity in A if it is an export) if it make a technological advance that is applicable in ROW but not in A. There may be a loss for country A producers and a social loss in the commodity market even if the advance reduces costs in A <u>and</u> in ROW, if the reduction in ROW is sufficiently large relative to that in A. With zero government intervention in markets, input suppliers would have no incentive to allow for any adverse effect that sale of its technological progress to foreigners exerted on other domestic industries. Would the situation be different if the optimal set of trade taxes was in place? (The optimal set of trade taxes may be changed by the technical advance in the input supply industry). Exports of inputs would then be restricted to the optimal extent, from a national view, before and after the new technology was developed. However, optimal trade taxes are defined for given production functions, and they do not ensure that a country will always gain from shifts in that function in an input supply industry.

The benefits to the input supplying industry from a technological development for which it is responsible, and also the benefits to country A, will be influenced by the effectiveness of the supplier's property rights in the development. The more complete these property rights are, the greater the proportion of the value of the technological development that the input supplier will be able to capture, <u>ceteris paribus</u>. More complete property rights need not always be to the advantage of country A, however. If fuller rights cause the input supply industry to invest more in developing technologies that are useful only or mainly in ROW, the greater returns to country A from sale of technology could be more than offset by the additional losses to country A's commodity exporters.

Shifts in Demand

The framework outlined in the first part of the paper can readily be modified to analyze the effects of shifts in demand. The effects of upward shifts in demand on welfare of producers, consumers and producers plus consumers in a two-sector market are shown in the right-hand side of Table 1. The effects are symmetric with those caused by downward shifts in supply.

The demand for a commodity may rise as a result of certain research activities or of promotion. The derived demand for wool, for example, may rise as a result of new knowledge that allows a cost reduction in any of the industries between the wool-growers and the consumers of wool products, or that allows a new characteristic to be imparted to the wool product. Research which allows a more highly valued bundle of characteristics to be embodied in each pound of wool produced by wool-growers may cause a rise in demand for their output. (The fact that the nature of wool-growers' output is changed by this research raises problems for evaluating research benefits that do not arise with cost-reducing research in the marketing chain or with research that changes the characteristics of the final wool product). Another possible cause of a rise in the demand for wool at farm level is promotion of wool-growers' commodity or of wool products.

It will sometimes be important to look beyond the market of direct concern to obtain a comprehensive picture of the welfare effects of rises in demand due to research or promotion. However, even if a rise in the demand for one commodity due to research or promotion causes significant welfare effects in other markets, those effects will sometimes be regarded as irrelevant because of the perspective of the analyst. In an investigation of the economic benefits to Australia from investment in extra research or promotion to raise the demand curve for wool, losses to overseas producers of natural or synthetic fibers would be disregarded.

Equity in the Distribution of the Benefits and Costs of Research and Promotion

Australia's Industries Assistance Commission [1976] supported on equity grounds the principle of sharing the costs of research and promotion between producers and consumers in the same proportions as the benefits. While research shifts the curve down, a levy (tax) for research or promotion shifts the supply curve upwards. A levy paid by consumers shifts the market-place demand curve downwards. For a non-traded good, the equity principle favored by the IAC can be achieved by means of a tax on either production or consumption if supply and demand in the relevant ranges are approximately linear. The analysis is similar to the analysis of the incidence of an excise tax. When the market comprises two sectors, it is necessary for research or promotion that shift supply in a sector to be paid for initially by that sector's producers and for activities that shift sector demand to be funded initially by the sector's consumers to meet the equity criterion [Edwards, 1984]. When research funded by one sector shifts supply down or demand up in the other sector it is not in general possible to achieve symmetry in the distribution of the costs and benefits of research.

REFERENCES

Akino, M. and T. Hayami. "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development." Amer. J. Agr. Econ. 57, 1-10. 1975.

Alston, J.M., G.W. Edwards and J.W. Freebairn. "The Effects of Protection Policies on Research Benefits." Economics and Marketing Branch Workpaper Series No. 20, Department of Agriculture and Rural Affairs, Melbourne, Australia. 1986.

Edwards, G.W. and J.W. Freebairn. Measuring a Country's Gains from Research: Theory and Application to Rural Research in Australia. A Report to the Commonwealth Council for Rural Research and Extension, Canberra, Australian Government Publishing Service. 1981.

Edwards, G.W. and J.W. Freebairn. "The Social Benefits from an Increase in Productivity in a Part of an Industry." Rev. Mktg. and Agr. Econ. 50, 193-210. 1982.

Edwards, G.W. and J.W. Freebairn. "The Gains from Research into Tradable Commodities." Amer. J. Agr. Econ. 66, 41-49. 1984.

Edwards, G.W. "The Allocation of Resources to Shifting Supply and Demand for Traded Commodities." Paper presented at 13th Conference of Economists, Western Australian Institute of Technology, Perth, August 26-31. 1984.

Hertford, R. and A. Schmitz. "Measuring Economic Returns to Agricultural Research." In Resource Allocation and Productivity in International Agricultural Research, ed. T.M. Arndt, D.G. Dalymple and V.W. Ruttan. Minneapolis, University of Minnesota Press. 1977.

Hueth, D. and R. Just. "Policy Implications of Agricultural Biotechnology." Paper presented at the Allied Social Science Associations Annual Meeting, New Orleans, December 28-30. 1986.

Industries Assistance Commission. Financing Rural Research. Canberra: Australian Government Publishing Service. 1976.

Kalter, R. and L. Tauer. "Potential Economic Impacts of Agricultural Biotechnology." Paper presented at the Allied Social Science Associations Annual Meeting, New Orleans, December 28-30. 1986.

Martin, M.A. and J. Havlicek. "Some Welfare Implications of the Adoption of Mechanical Cotton Harvesters in the United States." Amer. J. Agr. Econ. 59, 739-44. 1977.

Ramalho de Castro, J.P. and G.E. Schuh. "An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study." Resource Allocation and Productivity in International Agricultural Research, ed. T.M. Arndt, D.G. Dalrymple and V.W. Ruttan. Minnesota, University of Minnesota Press. 1977.

Rose, R. "Supply Shifts and Research Benefits: Comment." Amer. J. Agr. Econ. 62, 834-37. 1980.

Sarris, A.H. and A. Schmitz. "Toward a U.S. Agricultural Export Policy for the 1980's." Amer. J. Agr. Econ. 63, 832-39. 1981.

Scitovsky, T. "Two Concepts of External Economies." J. Polit. Econ. 62, 143-51. 1954.

Ulrich, Alvin, Hartley Furtan and Andrew Schmitz. "Public and Private Returns from Joint Venture Research: An Example from Agriculture," Quart J. Econ., CI, 103-29. 1986.

Vere, D.T., J.A. Sinden and J.A. Campbell. "Social Benefits of Serrated Tussock Control in New South Wales." Rev. Mktg. and Agr. Econ. 48, 123-38. 1980.

Zentner. R.P. "Returns to Public Investment in Canadian Wheat and Rapeseed Research." Economics of Agricultural Research in Canada, ed. K.K. Klein and W.H. Furtan. Calgary, University of Calgary Press. 1985.

THE ROLE OF THE PRIVATE SECTOR IN TRANSFERRING HYBRID CORN TECHNOLOGY

Carl E. Pray and Ruben G. Echeverria*

INTRODUCTION

It is widely accepted that new technology is an important source of agricultural growth. Developing countries have tried a variety of policies to accelerate the development and diffusion of new technology. These policies include: (1) government investment in agricultural research and extension, (2) tax breaks and other incentives to private companies that conduct agricultural research, and (3) incentives to transfer new technology developed outside the country. At the same time, many countries have other policies that reduce the incentive of private companies to do research or transfer technology. These include restrictions on importing technology and importing research inputs, restrictions on which companies are allowed to do research, and regulations that reduce the profitability of innovation.

The opposite side of this issue is the U.S. farmer's complaint that multinational companies are transferring U.S. technology to other nations. Some farmers and their representatives argue that this transfer of technology hurts American farmers by increasing the productivity of our competitors and reducing the amount of U.S. grain demanded by importing nations. There are reports of attempts by U.S. farmers to restrict the outflow of technology by restricting seed exports.

At present, the debate about these issues is hampered by the absence of empirical studies on the importance of these flows of technology or the impact of policies on these technology transfers. In practical terms, it is not clear how much technology can be transferred directly and how much has to be substantially modified before it can be used in a new country. Without such information, it is impossible to determine how important policies which impede the flow of material technology like seeds or chemicals will be or whether foreign research will make these technologies available anyway.

In this paper, we have attempted to measure the impact of public sector research, the transfer of technology embodied in a product, and private sector research by multinationals on one major crop - corn. The results indicate that technology transfer through trade and private sector research by multinational seed companies play an important role in increasing agricultural productivity.

TECHNOLOGY TRANSFER AND GOVERNMENT POLICY

There are a number of ways in which a country can improve the supply of new technology to farmers. In the corn crop, there is evidence that four sources of new technology have been important: (1) imported technology in the form of varieties or hybrid seed; (2) local research and seed production by multinational companies; (3) research and seed production by local companies; (4) research and seed production by local government sometimes with the assistance of international organizations like CIMMYT or the Rockefeller Foundation.

---

* Carl E. Pray is Associate Professor, Department of Agricultural Economics, Rutgers University and Ruben G. Echeverria is Graduate Research Assistant, Department of Agricultural and Applied Economics, University of Minnesota. The research upon which this report was based was supported by the U.S. Agency for International Development (Contract No. OTR-0091-G-SS-4195-00) and the Minnesota Agricultural Experiment Station. The paper reflects the opinion of the authors and not necessarily the opinion of the supporting agencies.

Private sales of hybrid corn seed and research by the private sector may be important sources of new technology. The U.S. seed industry has been in the export business for some time. Table 1 shows the quantity and value of exports of different kinds of seeds since 1950. Grain seeds have been the major seed exports since 1970. Figure 1 shows the growth of U.S. exports of hybrid corn seed. The deflated values of these exports show a substantial increase since the mid-1970's.

The direction of corn seed exports and its variation over time is shown in Table 2. Most of the exports go to Europe and Canada. These exports have been a very important source of new technology for a number of countries.

Table 1: U.S. Seed Exports by Type of Seed, 1950-1984.

Fiscal Year		Forage	Vegetables	Grains	Others	Total
Avg. 1950-1954	(Q)	10,488	1,670	17,131	84	26,273
	(TV)	6,557	2,466	1,790	394	11,207
Avg. 1955-1959	(Q)	18,597	1,987	16,008	108	36,701
	(TV)	10,432	3,345	3,012	571	17,360
1960	(Q)	28,630	2,107	16,461	148	47,341
	(TV)	12,750	4,244	2,815	728	20,537
Avg. 1960-1964	(Q)	26,928	2,675	17,131	151	46,886
	(TV)	13,571	5,302	3,299	781	22,953
1965	(Q)	28,734	2,865	1,845	2,963	49,408
	(TV)	15,569	6,094	3,531	2,557	27,856
1970	(Q)	32,432	4,882	51,360	17,626	106,301
	(TV)	21,814	11,666	13,669	6,814	53,963
1975	(Q)	36,033	6,359	37,429	19,965	99,787
	(TV)	43,838	30,045	22,246	16,886	113,116
1980	(Q)	48,795	38,411	80,260	32,295	199,762
	(TV)	74,866	81,277	58,507	20,453	235,102
1984	(Q)	92,614	17,110	217,642	35,226	362,592
	(TV)	73,144	99,499	146,718	46,280	365,641

Source: USDA Foreign Agricultural Circulars.
Quantity (Q) in metric tons. Total Value (TV) in $1,000.

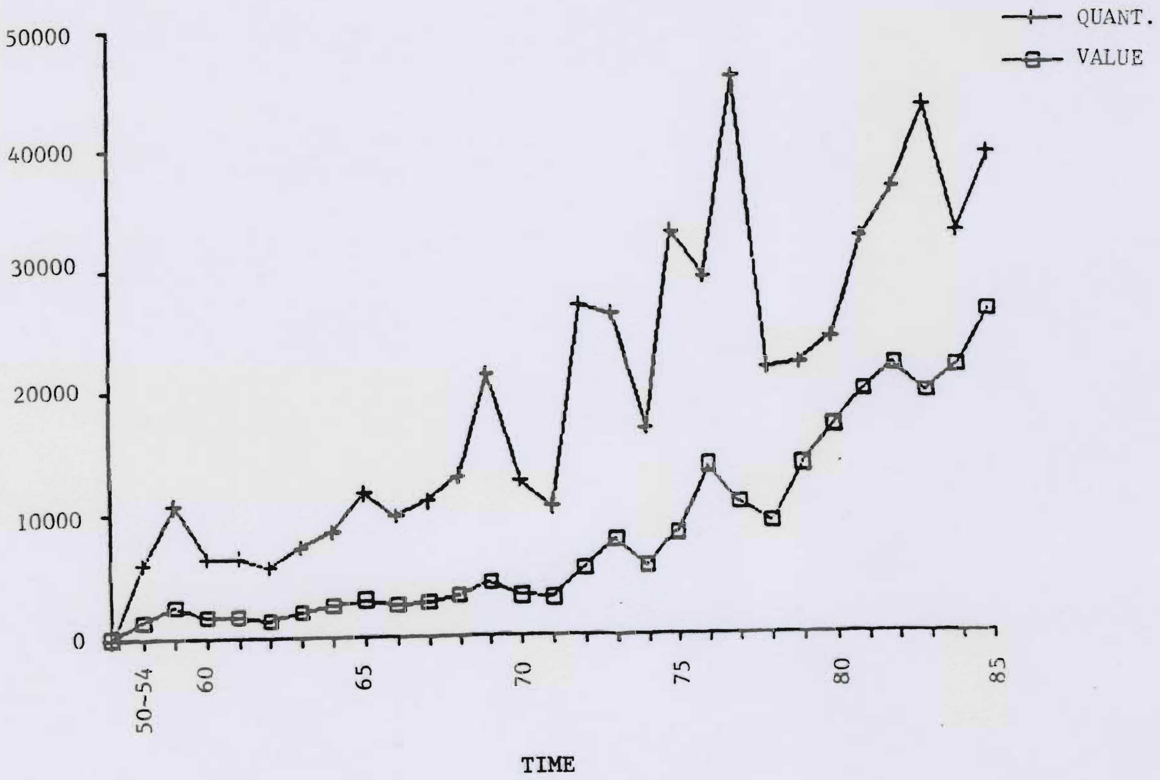
Table 2: U.S. Corn Seed Exports by Region, 1967-1985.

Country	1967	1970	1975	1980	1985
	Calendar Years, Quantity in Metric Tons				
Canada	2,380	4,661	12,987	4,460	1,920
Mexico	986	2,846	3,929	1,652	2,446
C&S America	552	1,255	1,225	1,213	1,311
EC	4,722	5,049	7,818	14,494	21,933
Asia	219	537	860	2,947	1,959
World Total	9,234	15,114	27,185	26,465	37,964

Source: U.S.D.A. Foreign Agricultural Circulars.

Table 3 shows the percentage of total corn area and hybrid area under U.S. hybrids in 1985-6, for selected corn producing countries of the world. The range is considerable. Italy and Greece import about half their hybrid corn seed from the U.S. Fourteen percent of Chile's total corn area is planted with U.S. seed, or 20% of its hybrid area. The rest of these countries, analyzed later in this study, have about ten percent or less of their corn under U.S. seed. However, there are countries, like Turkey, that U.S. seed represents an important share of the area under hybrids.

Figure 1. U.S. Corn Seed Exports



Source: USDA. Quantity in Metric Tons. Value in U.S.$ deflated by CPI (1967=100).

Table 3: Importance of U.S. Corn Seed Exports
Selected Countries, 1985-86.

Country	Estimated Total Area Planted with U.S. Seed	Estimated Hybrid Area Planted with U.S. Seed
	%	%
Italy	54	54
Greece	53	53
Turkey	8	24
S. Korea	11	20
Chile	14	20
Austria	11	11
Spain	11	11
Mexico	2	8
Egypt	1	8
Hungary	7	7
Canada	6	6
Portugal	1	6
France	5	5
Japan	5	5

Source: Column 1 was calculated using USDA corn seed export data (average 1984-86) and CFMMYT total corn area and hybrid seed planting rate per country.

Column 2 was calculated using USDA seed export data and CFMMYT estimations on area under hybrid corn in each country.

Scientific crop breeding by the private sector started in the U.S. in the 1930's and 1940's with the development and spread of hybrid corn. Hybrid corn sales and research by U.S. companies spread to Europe in the late 1940's and early 1950's. Corn research in Argentina by private U.S. companies also started in the late 1940's and in Brazil in the early 1960's. Private research by multinationals in Asia started in the 1950's in the Philippines and in the 1960's in India. However, these early research efforts in Asia were discontinued in the mid-1960's, and it was not until about 1970 that sustained private corn research programs in Asia were underway.

Companies expanded into Africa starting with South Africa around 1960, Egypt around 1980, and the Ivory Coast, Kenya and Zimbabwe in the last three years.

At present, multinationals play an important role in testing, breeding and transferring corn technology around the world. Major companies like Pioneer or Cargill are testing hybrids in 90 to 100 countries. They have experiment stations in 15 to 20 countries. These experiment stations tend to be concentrated in Europe and Argentina. In many countries, they developed the first private sector corn breeding programs. Their impact appears to have been quite important in several countries. For example, about half of the corn acreage in France is under hybrids of one American company and 87 percent of the hybrid corn in Argentina is from multinational seed companies (Obschatko, Pineiro and Jacobs, 1986).

Research by local companies has been an important source of technology in several countries. European seed companies have been important in producing hybrid corn and varieties of other crops. In Zimbabwe, a local company began production of hybrid corn in the 1940's. It now produces 100 percent of the improved corn in that country and is selling corn seed to neighboring African countries (Eicher, 1984). In Brazil, a local company started in the early 1960's is now producing 39 percent of the country's hybrid corn seed and three other local companies produce an additional 12 percent (Obschatko, Pineiro and Jacobs, 1986). In India, a local company founded in the mid-1960's is now producing about a quarter of the hybrid corn seed.

Public sector research is an important source of improved corn varieties in many countries. In many others, public sector research provided germplasm and the breeding techniques that were the basis of private sector breeding programs. The importance of public sector research in the Third World was nevertheless subject to debate particularly in the early years after World War II.

The development literature has gone through a transformation in the importance it gives to technology transfer versus local research. During the 1940's and 1950's, people writing about development assumed that the transfer of technology was a relatively easy and costless process and that little public sector research was required (Moseman, 1970). This assumption was based in part on the experience on transferring hybrid corn from the U.S. to Europe after World War II. In agriculture, this resulted in policies with an extension bias. Governments and donors invested in public extension systems but not in public research because they assumed technology was available locally or could be easily transferred.

The failure of these policies to bring rapid agricultural growth coupled with the research of Hayami and Ruttan (1971), Evenson and Binswanger (1978) and others pointed out the importance of local research in adapting technology to local conditions. These studies argued that governments should invest in developing domestic agricultural research capacity. A large literature has grown up which shows very high rates of return to investments in agricultural research in developed and developing countries (Ruttan, 1982). Evenson and Kislev (1975) attempted to estimate the impact of government research on wheat and corn yields in the period 1948 to 1968 in 64 and 49 countries, respectively. They found that government research by other countries in similar agroclimatic regions was an important factor in explaining yields. In addition, they found that there was no impact of regional research on yields unless there was some local research on the commodity. This supports the idea that agricultural technology cannot be readily transferred without local research.

Many studies have measured the impact of the International Agricultural Research Centers, but only a few have measured the impact of the Centers on corn. A study by Harvey and Timothy (1986) trace the spread of the International Maize and Wheat Improvement Center (CIMMYT) genetic material in considerable detail. Recent work by Evenson (1985) has shown that national research programs in collaboration with CIMMYT have had a significant impact on corn yields in the Third World.

There has been considerable debate about what combination of technology will lead to most rapid agricultural growth. For example, debate is quite heated in some countries about the appropriate role of the private sector in research and technology transfer. Most countries want to build their own technological capacity but are not sure about the best mix of public and private research, the role of import barriers or the barriers to investments by foreign companies. This lack of consensus is reflected in the variety of laws on seed imports and private research. Commercial seed imports are effectively prohibited in India, while in Thailand, there are very few policy barriers to imports. Until recently, private companies were prohibited from doing maize research in Pakistan while in India and the Philippines, tax incentives were provided to companies that do research. Until last year, subsidiaries of multinationals were not allowed to operate in the seed industry in India unless their equity is under 40 percent. In Argentina and the Philippines, multinationals have been encouraged to participate in R&D and seed sales.

As mentioned above, the importance of public sector research has been debated in the past and continues to be debated at present. Many government officials in developing countries are not convinced that their research program can produce much technology which will have high economic payoffs. In developed countries, some farmers argue that productivity increases due to public research have hurt them while large seed companies argue that public research should be reduced so that it does not compete against private companies.

If governments are going to make better decisions about which policies to choose, they must have more information on the costs and benefits of such policies. To estimate these costs and benefits requires information on: (1) the marginal value product (MVP) of seed imports, the MVP of R&D by local and foreign companies, and the MVP of public research; (2) the relationship between government policies and the amount of imports and/or amount of private R&D; and (3) the financial costs of implementing government policies. With this information, for example, one could estimate the costs and benefits of prohibiting seed imports as net benefits from inducing a local seed industry minus the foregone income to farmers who were prohibited from using imported seed. The net benefits from local seed would require an estimate of how much more rapidly the local seed industry grew than it would have in the absence of import restrictions, the technical superiority of local vs. imported seeds and the differences in price between local and imported seeds. The foregone income of farmers would come from estimates of the value of imported seed. One would also have to subtract the cost of enforcing the ban on corn seed imports.

The next section of this paper contains a method for estimating the benefits (or costs) of public research and other policies that encourage (or restrict) seed imports and private research. It does not provide sufficient information for a complete cost benefit analysis because it provides information only on number (1) above not (2) or (3). It is, however, a necessary step in the process of estimating costs and benefits and does add to the very limited number of studies in this area.

MODEL AND EMPIRICAL RESULTS

To test the relative importance of research and technology transfer on crop productivity, we have developed the following model. We used a partial Cobb-Douglas production function (F) of the following form:

$$YIELD_{it} = F(HSI^{b_1}\ FERT^{b_2}\ EDUC^{b_3}\ PUBR^{b_4}\ PRIVR^{b_5}\ ACD^{b_6})_{it}$$

where: $i = 1...50$ countries, $t = 1...25$ periods from 1961 to 1984.[1]

Table 4 describes the variables utilized in this study and the sources of data.

The model is a partial one since not all possible variable explaining yield are included. As an initial attempt at assessing the costs and benefits of importing technology, encouraging local research or investing in public sector research, we applied this model to data on the corn crop. This crop was chosen for several reasons. First, this is an important crop worldwide, ranking third worldwide by production after wheat and rice. Second, the United States dominates the corn seed trade so data is readily available on the U.S. corn seed exports to a large number of countries. Third, there is a considerable amount of corn research conducted by private companies. From interviews and annual reports, we were able to generate some rough indicators of private sector research on corn in most of those countries.

All of the variables are on a per hectare basis. The Hybrid Seed Imports (HSI) variables attempts to measure the direct transfer of technology embodied in hybrid seed rather than the more indirect measure of borrowing used by Evenson and Kislev (1975) - research in similar agroclimatic zones. HSI is clearly not a perfect measure since other countries export hybrid corn seed, but the U.S. is the large exporter of corn seed worldwide.

Three variables were used to measure local public sector research activity. The first, following Evenson and Kislev, is the number of research publications on corn in a country that are abstracted in Plant Breeding Abstracts. The second measure is calculated by multiplying the ratio of corn publications to all commodity publications by total research expenditure. The third measure of public research was constructed by cumulating the number of corn lines released in each country since 1948 as published in the Illinois Foundation Seeds Manual (1984). The private research variable was the most difficult to calculate. After some experimentation, we settled on a measure which is based on the number of research stations of the major multinational companies located in each country. This underestimates private corn research in countries where the local private research is most important and yields are highest, like Europe and Argentina.

Table 4: Explanation of Variables and Sources of Data.

YIELD	CORN YIELD in metric tons per hectare, from FAO Production Yearbook.
HSI	HYBRID SEED IMPORTS. Metric tons of hybrid corn seed (and inbred lines) imports from the U.S. divided by corn area in country i at t. To construct this variable, the average quantity of U.S. corn seed exports per period was divided by the average corn area in each country. The seed exports information is from the U.S.D.A. Area from F.A.O. Production Yearbooks.
FERT	FERTILIZER. NPK per ha of arable land in country i at t. Since there is no information available on amount of fertilizer used in corn per country, the average total NPK consumption from F.A.O. Fertilizer Yearbooks was divided by average area of arable land in each period, in order to approximate the level of fertilizer usage in each country.
EDUC	EDUCATION. Approximated by adult literacy rate in country i at period t, from UNESCO Statistical Yearbooks.
$PUBR_1$	PUBLIC RESEARCH #1. Number of corn, sorghum and millet publications published in "Plant Breeding Abstracts." This variable was measured as a stock starting in 1948 and deflated by corn area in each country. For the first period, the total number of publications from 1948 to 1961 was used. For period (2) and (3), the number of publications up to 1968 was utilized. For period (4) up to 1975, and for period (5) from 1948 to 1979.
$PUBR_2$	PUBLIC RESEARCH #2. A different variable estimating corn research expenditures was also constructed for the 1960's and the 1970's. Since data on corn research expenditures is not available on a per country basis, this information was estimated using the percentage of corn publications on the total agricultural research expenditures of each country. This estimation was then adjusted by area of corn in each country, in order to have inputs as well as output on a per hectare basis.
$PUBR_3$	PUBLIC RESEARCH #3. Number of inbred lines, open pollinated varieties, synthetics and other breeding stocks released since 1948 divided by area of corn in period (5). From Maize Research and Breeders Manual No. X, Illinois Foundation Seeds, Inc. Dec., 1984.
PRIVR	PRIVATE SEED COMPANY RESEARCH. The impact of five major private multinational seed companies (Pioneer, Northrup-King, Dekalb, Cargill and Funk) doing corn research in each country was approximated by constructing a variable reflecting the number of years of research activities and number of research stations up to 1985.
ACD	AGROCLIMATIC DUMMY VARIABLE. 1 for "TEMPERATE" and 0 for "TROPICAL."

Discussions with seed companies and with CIMMYT indicated that there were important differences between growing conditions in temperate and tropical regions. We attempted to control for this factor by including variables on agroclimatic conditions of three types: the FAO Agro Ecological Zone Map, the Papadakis World Climatological Classification, and a temperate vs. tropical dummy.

Using the property that the Cobb-Douglas function is linear in logs, the coefficients are estimated by applying Ordinary Least Squares to the following regressions, under standard assumptions, where the error term represents cumulative effect of all left-out variables.

$$\begin{aligned}[\mathrm{YIELD}] = \mathrm{CONSTANT} + b_1[\mathrm{HSI}] + b_2[\mathrm{FERT}] + b_3[\mathrm{EDUC}] +{} \\ b_4[\mathrm{PUBR}] + b_5[\mathrm{PRIVR}] + b_6\mathrm{ACD} + \mathrm{ERROR\ TERM}\end{aligned}$$

Here [] denotes logarithms of the variables, and the error term is assumed to be a random variable with mean 0 and variance σ^2.

Table 5 summarizes the regression results for each time period. The dependent variable is yield, standard errors are in parentheses.

Table 5: Cross-section Results for the Five Time Periods.

	(1)	(2)	(3)	(4)	(5)	(5)	(5)	(5)
HSI	.015 (.012)	.019 (.014)	.005 (.014)	.029** (.013)	.031** (.013)	.030** (.013)	.015 (.014)	.016 (.015)
FERT	.046 (.032)	.124** (.049)	.130*** (.048)	.106** (.041)	.141*** (.046)	.137*** (.046)	.144*** (.044)	.15*** (.045)
EDUC	.113 (.082)	.102 (.142)	.171 (.40)	.169 (.127)	.225 (.142)	.223 (.143)	.126 (.145)	.133 (.146)
PUBR#1	-.008 (.012)	-.016 (.016)	-.004 (.015)	-.005 (.015)	-.009 (.022)	-- --	-- --	-.012 (.021)
PUBR#3	-- --	-- --	-- --	-- --	-- --	-.008 (.040)	-.032 (.040)	
PRIVR	-- --	-- --	-- --	-- --	-- --	-- --	.117** (.056)	.107* (.054)
ACD	.353*** (.116)	.446*** (.137)	.538*** (.135)	.597*** (.130)	.492*** (.142)	.511*** (.143)	.520*** (.138)	.476*** (.138)
ADJ.R^2	.44	.50	.60	.69	.65	.65	.67	.67
S.E.R.	.35	.41	.39	.38	.41	.41	.40	.40

Note: (*) significant at P=0.10, (**) at P=0.05 and (***) at P=0.01. Adj. R^2 is adjusted R-squared. S.E.R. is standard error of regression.

The results indicate that climate is the most important determinant of yields in each period - corn yields are significantly higher in temperate regions. Fertilizer use is the next most important determinant. It is statistically significant in all periods except the early 1960's. Seed imports from the U.S. are significant in the last two periods. Education had the expected sign but approached a 10 percent significance level only in the last period. The public sector research coefficient did not have the expected sign and was not significant in any of the regressions. We tried several other measures of public sector research, but they also had statistically insignificant coefficients.

These results indicate that the private transfer of technology in the form of hybrid seed was an important factor in determining corn yield per acre in the late 1970's and 1980's. As Figure 1 showed before, it was not until 1975 that corn seed exports from the U.S. were consistently over 20 thousand tons.

We do not have good data for all five periods for private sector research. We suspect that the seed imports variable may actually be picking up some of the impact of local private research. For the last period we do have data on the number of experiment stations of private multinational companies in each country. This is incomplete because it does not include all multinationals and does not include local private research. It is, however, the best data available at the moment. The last two columns of Table 5 include the private sector research variable (PRIVR). Private research is significant at the five or ten percent significance level. The coefficient on the seed import variable is reduced in size and is no longer significant. This supports the hypothesis that the seed imports variable is a proxy for local private research.

Table 6 shows the results of pooling the data for the fifty countries over different periods of time. First, the whole period 1961-1984 is analyzed using the same variable as in Table 5 for the cross-section results.

Table 6: Pooled Estimation, 1961-1984.

	(1)	(2)	(3)
HSI	.023***	.017***	.006
	(.006)	(.006)	(.006)
FERT	.109***	.102***	.100***
	(.018)	(.018)	(.017)
EDUC	.127***	.112***	.073
	(.049)	(.048)	(.048)
PUBR#1	-.010	--	--
	(.006)	--	--
PUBR#3	--	.025	.010
	--	(.016)	(.016)
PRIVR	--	--	.086***
	--	--	(.23)
ACD	.474***	.470***	.478***
	(.059)	(.059)	(.058)
ADJ.R^2	.60	.60	.62
S.E.R.	.39	.39	.38

Note: Specification (1) is a poded estimation 1961-1984 for the 50 countries, including a proxy for public research based on number of publications. Specification (2) includes the number of lines released as a proxy for public research. Specification (3) accounts also for private international research, using number of research stations and years of activities in each country.

The results of pooling the five cross sections are quite good in the first two specifications. All of the coefficients except public research had the expected sign and are significant. When the number of lines released (PUBR#3) rather than the number of publications (PUBR#1) is used for the public research variable, the coefficient of research is positive but is still not significant.

The coefficients on the fertilizer variable and the temperate-tropical variable are significant as they were in the cross section results. The education variable is also significant unlike the cross sectional results.

We did make an initial attempt to see if private research was important. In specification 3, Table 6, the private research variable used in Table 5 was added. It is the number of stations weighted by the number of years between 1960 and 1977 that each station was open. Thus, all the variation is between countries, it does not vary between time periods. This variable was very significant. It also reduced the seed imports' variable in size, and imports is no longer significant. It also reduced the size of the coefficient and significance of the education and public research variables.

Seed imports and multinational research are the only technology transfer variables that are statistically significant in the pooled data and in some of the cross sectional results. Public sector research was not significant in any of the regressions. Previous research (Griliches (1957), Evenson and Kislev (1975), Binswanger and Ruttan (1978)) suggests that local research is necessary - particularly for a location sensitive plant like corn. The fact that a very crude measure of private research is significant and reduces the size and significance of the seed imports variable supports this position.

Seed imports and local private research activity are closely related. Case studies from Asia and Latin America suggest two patterns. In temperate regions, companies start selling hybrids developed in the U.S. after a minimum amount of testing and then invest in research to tailor the hybrids to local conditions as their market expands. At first they import the hybrid seed from the U.S. because it is cheaper than establishing their own production and processing operation. As the market grows, companies usually establish their own local operations and only occasionally import seed from the U.S. In the tropics, research either by the public or private sector is required first to develop suitable hybrids. Companies then start selling seeds that are multiplied in subtropical parts of the U.S. Eventually they build production facilities in the tropical country.

The lack of significance of the public sector research variable is puzzling. In temperate climates, public sector research still appears to play an important role in improvements of corn germplasm and management practices although the private sector may now be investing more money than the public sector in corn research. In most countries in the tropics the public sector invests more in corn research than the private sector although there are some notable exceptions like Argentina and the Philippines. Public research has played a key role in increasing yields in several of these countries (Sethboonsarng, S. and R.E. Evenson, 1987). These impressions are reinforced by Evenson's studies of twenty-four developing countries which indicate that public research was an important determinant of corn production (Evenson, 1985). It may be that past studies which have not had an explicit technology transfer variable have overestimated the importance of public research. This is an issue that requires further study.

In order to take the policy analysis one step further, we have calculated the VMP for seed imports. The other policy variables - public research and private research - are either insignificant or the data is still questionable. The seed import variable is estimated using quite reliable data from USDA. It is positive and significant after controlling for climatic zones, fertilizer use, education and public research. The estimated coefficient may be biased upward as discussed above. However, even when we use our somewhat shaky measure of private research (Table 5, last two columns has the best private research variable), it still is the right sign and has an important impact on yield although it is no longer significant.

To find out if the countries in this study have been importing too much or too little hybrid corn seed, we have calculated the VMP for the 1981-84 period using both the high (.031) and low (.015) estimates of the coefficient of the import variable in Table 5. Using these coefficients, the geometric mean of imports and the average international price of corn[2] 1981-84 we calculated a VMP of $4,099 for $1,984 per kg. This is much higher than the average price paid for corn seed during this period as reported by USDA of $1.70. This suggests that countries could increase their well being by importing more hybrid corn seed.

This is a very preliminary result and must be accompanied by a number of caveats. First, because of agroclimatic differences many countries can not simply import U.S. seed and expect any positive results. Second, our preliminary data on private research suggests that the seeds variable may be biased upwards by the absence of a good private research variable. Thus, even our lower bound estimate of impact of private seed imports could be too high. The results are suggestive, however, and support the idea that restrictions on the trade of seeds hurts the importing country.

SOME PRELIMINARY POLICY IMPLICATIONS

Our statistical analysis indicates that countries which restrict the import of corn seed are losing out on an important source of growth in corn productivity. Groups that lose from these policies are the farmers and the companies that would import seeds. Consumers of corn and cornfed livestock are also losers at least in the short run. Therefore, when governments evaluate policies that restrict seed imports, they must add foreign investment into their cost benefit analysis of these policies.

There is also preliminary evidence that research by multinationals can be a source of economic growth. This means that policies which restrict the activities of multinational seed companies may also impose a large cost on farmers in terms of foregone productivity. This cost to farmers and consumers is rarely, if ever, calculated.

The beneficiaries of such policies are local seed companies who are protected from foreign competition and allowed to develop their own capacity to do R&D. Farmers will also benefit if the technology local firms develop is superior to or less expensive than technology produced by foreign firms. As yet, there is little empirical evendice to show the size of such benefits to farmers. We are currently conducting research with which we hope to estimate the benefits to farmers and consumers of local research.

The evidence does suggest that U.S. farmers are right that private companies are transferring technology to foreign countries. However, these companies are also transferring useful germ plasm back to the U.S. In addition, a larger seed market can support more research in their headquarters which is usually in the U.S. This research will have benefits for U.S. farmers. Finally, policies that attempt to stop the transfer of seeds will probably not have much impact on technology transfer because the foreign research by multinationals will also be important in increasing yields.

These results are very preliminary. Much more research is required before any strong conclusions can be drawn. The next step is to develop more accurate measures of some of the variables and see if the results remain the same. Then the question of which policies will speed the development and transfer of new technologies need to be explored. To do this, a series of fairly detailed country studies is needed. We are presently conducting such studies on six countries.

FOOTNOTES

[1] Countries - A ranking by production of corn was constructed for the period 1981-1984 using the F.A.O. Production Yearbook. The first fifty countries of that list were chosen for this study. The countries are: China, Brazil, Mexico, Romania, USSR, Yugoslavia, Argentina, France, South Africa, Hungary, India, Italy, Canada, Indonesia, Thailand, Egypt, Philippines, Bulgaria, Korea DPR, Spain, Kenya, Zimbabwe, Nigeria, Greece, Tanzania, Austria, Ethiopia, Turkey, Malawi, Guatemala, Pakistan, Germany FR, Colombia, Zambia, Czechoslovakia, Afghanistan, Nepal, Zaire, Peru, Chile, Paraguay, Venezuela, Portugal, El Salvador, Vietnam, Bolivia, Honduras, Uganda, Cameroon and Ivory Coast. Time Periods - The five periods covering from 1961 to 1984 were: (1) 1961-1965, (2) 1966-1970, (3) 1971-1975, (4) 1976-1980, (5) 1981-1984.

2 $0.115/kg is the average annual price for US no. 2 yellow corn in St. Louis during 1981-84.

REFERENCES

Binswanger, H.P., V.W. Ruttan and Others, Induced Innovation: Technology, Institutions, and Development, Baltimore: Johns Hopkins, 1978.

Eicher, C., "International Technology Transfer and the African Farmer: Theory and Practice," Department of Land Management, Working Paper 3/84, University of Zimbabwe, 1984.

Evenson, R.E., "Impact of the CGIAR Centers on Agricultural Productivity in Developing Countries," paper prepared for the CGIAR Impact Study, 1985.

Evenson, R.E. and Y. Kislev, Agricultural Research and Productivity, New Haven: Yale University Press, 1975.

Griliches, Zvi, "Hybrid Corn: An Exploration in the Economics of Technical Change," Econometrica, Vol. 25, 501-522, 1957.

Harvey, P.H. and D.H. Timothy, "USDA/OICD Maize Study," unpublished paper, USAID, Washington, 1986.

Hayami, Y. and V.W. Ruttan, Agricultural Development. An International Perspective, Baltimore: Johns Hopkins, 1985.

Illinois Foundation Seeds Inc., Maize Research and Breeders Manual No. X. Inbreds, Breeding Stocks, Maize Investigations and Academic Research Personnel. 9th Revision. Champaign, Illinois, December 1, 1984.

Moseman, A.H., Building Agricultural Research Systems in the Developing Nations, New York: Agricultural Development Council, 1970.

Obschatko, Edith S., Martin Pineiro and Eduardo Jacobs, "The Private Sector in the Agricultural Technological Development: Some Conclusions and New Subjects for Analysis," presented at Agricultural Research Policy Seminar, University of Minnesota, April 1986.

Ruttan, V.W., Agricultural Research Policy, Minneapolis: University of Minnesota, 1982.

Sethboonsarng, S. and R.E. Evenson, "Research Extension Literacy, Output Supply and Factor Demand in Thailand's Agriculture," forthcoming in Robert Evenson, Carl Pray and Jaime Quizon (eds.), Research, Productivity and Incomes in Asian Agriculture, forthcoming from Cornell University Press, 1987.

ECONOMIC EVALUATION OF FORESTRY RESEARCH: SYNTHESIS AND METHODOLOGY

Barry J. Seldon*

INTRODUCTION

Interest in the economic impacts of research and development (R&D) among forest economists is of relatively recent vintage when compared with the long history of such inquiries in agricultural economics. In contrast to the literature in agricultural economics, which can be traced to the seminal works of Schultz (1953) and Griliches (1958), such work in forest economics was not of widespread interest until 1979 when the USDA Forest Service responded to the Forest and Rangeland Renewable Resources Planning Act of 1974 by initiating an examination of policy concerning public support for R&D (Callaham, 1981). In 1980 the Forest Service began a national program to develop methods for the economic evaluation of R&D in forest product technologies under the initial direction of Allen Lundgren at the North Central Forest Experiment Station.[1]

The research program established by the North Central Forest Experiment Station had five broad components ranging from the identification of the users of forestry research evaluation and their needs to the development of methods for evaluating that research (Lundgren, 1983). The bulk of the work which has been completed may be classified, following Bengston (1986), as impact evaluations and process evaluations. Impact evaluations examine effects of R&D on the economy, and are represented by estimates of the increase of producer and consumer surplus due to R&D, estimates of the marginal productivity of R&D expenditures, and studies of the effect of R&D on employment, income and income distribution, the balance of trade, the environment, and market structure. Process evaluations examine the research process itself within the economic organization in order to determine how decisions are made and R&D is carried out. Such studies focus on how the agency or firm selects, plans, monitors, and evaluates projects. The goal of this kind of evaluation is to improve the research decision-making.

A broad overview of many of the impact and process evaluation studies in forestry may be found in Bengston (1986). This paper concentrates instead of two types of impact evaluation approaches which have been adopted and modified for forestry R&D evaluation from agricultural economics. Results of such studies in forest economics are presented in the next section. Following that section, methodologies are discussed. While the theoretical underpinnings of these methodologies are well known to agricultural economists, details differ to a lesser or greater extent in the forestry studies, and may be of interest. The methodology developed in Seldon (1987) and Seldon and Newman (1987) is described in detail.

EVALUATION OF RETURNS TO RESEARCH IN FORESTRY ECONOMICS

Two methods which have been adopted for measuring returns to research expenditures in forest economics are quite familiar to agricultural economists.[2] Following Norton and Davis (1981), the first method is often referred to as the consumer and producer surplus (or CS) approach, and measures increases to these surpluses net of research costs. This method is most often used to calculate an internal rate of return (IRR) to R&D expenditures. The economic benefits calculated by this method are presumed to be generated by the shifting of the supply curve or reductions in marginal cost caused by (process) R&D. The second method is the production function (PF) approach which allows the calculation of the value of the marginal product of research expenditures and is sometimes used to calculate a <u>marginal</u> internal rate of return (MIRR) to R&D expenditures.

---

* Barry J. Seldon is Assistant Professor, Department of Economics, Ohio University. This research was supported by the USDA Forest Service and the Cooperative State Research Service. The author thanks David Bengston and Bob Eddleman for helpful comments. Any errors are my own.

Due to the deficiency of detailed data, the CS method is the most commonly applied in forestry studies. The techniques for measuring benefits and costs in different studies vary according to the availability of data. A somewhat different approach which ties the CS and PF approaches together has been developed by Seldon (1985 and 1987) and is currently being applied to several forest product industries in on-going research at Duke University.[3]

Details of some CS and PF studies are discussed in the next section. First, however, the results of forestry studies completed to date are presented in Table 1. Most of the CS

Table 1. Estimated Returns to Forestry Research

Product	Author	IRR Calculated for:	IRR Range (Percent)	MIRR Range (Percent)
Structural Particleboard	Bengston (1984)	Consumer Surplus	18-22	--------
Lumber, Plywood, Pulp & Paper	Haygreen et al. (1986)	Consumer Surplus	14-36	--------
Timber (Containerized Seedlings)	Westgate (1986)	Consumer Surplus	37-111	--------
Aggregate Lumber & Wood	Bengston (1985)	Consumer Surplus	34-40	--------
Timber (Forest Nutrition)	Bare and Loveless (1985)	Consumer Surplus	9-12	--------
Softwood Plywood	Seldon (1987)	Consumer Surplus	244-440	--------
--------	--------	Total Economic Benefit	375-661	--------
Softwood Plywood	Seldon and Newman (1987)	--------	--------	236-438
Preserved Wood	Brunner and Strauss (1986)	Total Economic Benefit	73	--------
Southern Softwood Stumpage	Newman (1986)	Total Economic Benefit	0-7	--------

Brunner and Strauss (1986) do not calculate the IRR, but rather report the net present values of the 1950-1980 research program in wood preserving. The estimate presented here is a preliminary estimate of the IRR from their data and is reported in Hyde (1986).

Chang (1986) considers returns to growth and yield models for loblolly pine. He does not report an IRR, but does calculate a benefit/cost ratio of 16/1.

studies have calculated the IRR from consumer surplus only, but two of the studies also calculate the IRR from total economic benefit (the sum of consumer surplus and producer surplus). The calculation of producer surplus is valid only where the market may be assumed competitive or contestable, but this seems to be true for forestry markets.[4] Most of the calculated returns are within the neighborhood of returns calculated in agricultural studies (see Evenson et al. 1979, Ruttan 1980, or Evenson 1982) with the exception of the results for softwood plywood. The softwood plywood study uses a rather different approach which will be examined in more detail in a later section. For now it suffices to note that the same approach is being used for the wood preserving industry, and preliminary results of that study are close to the estimates for other forest (and agricultural) products.

Some Details of Selected Studies

In this section, the methodologies employed by Bengston (1983 and 1984), Seldon (1987) and Seldon and Newman (1987) are discussed. The approach used by Bengston is similar in many respects to previous CS studies, and is easily understood by the reader familiar with the literature. Bengston's analysis is representative of many of the forestry R&D studies. The method developed by Seldon will be introduced in this section in order to compare some of its aspects with Bengston's approach, but details are reserved for the next section. This method is used in Brunner and Strauss (1986) and is intended for use in further studies at Duke University's Center for Resource and Environmental Policy Research.

The first CS study completed in forestry economics was an evaluation of innovations which led to the development of structural particleboard (Bengston 1983 and 1984). While structural particleboard was a new product, Bengston treats the innovation as a new process which lowered the equilibrium price of sheathing material, since structural particleboard substitutes for softwood plywood in this capacity. The supply curve before the innovation may be conceptualized, then, as the supply curve for softwood plywood, while the supply curve after the innovation is properly considered to be the supply curve for structural particleboard. Bengston then applies an index number version of the CS method to calculate benefits in terms of consumer surplus, using previous estimates of the price elasticity of demand for softwood plywood as a proxy for the structural particleboard elasticity and assuming that the supply curves in both cases are perfectly elastic as in Griliches (1958).[5] Bengston forecasts future quantities of structural particleboard to the year 2000 using logistic growth curves. For any period t, then, the increase in consumer surplus is

$$\Delta CS_t = (P_t^{pw} - P_t^{pb})\, Q_t^{pb}\, (1 - k_t n/2)$$

where ΔCS_t = the change in consumer surplus

P_t^{pw} = the price of plywood sheathing

P_t^{pb} = the price of structural particleboard

Q_t^{pb} = the quantity of structural particleboard consumed

n = the price elasticity of demand for softwood plywood (used as proxy for the elasticity of structural particleboard)

$k_t = (P_t^{pw} - P_t^{pb}) / P_t^{pw}$

all at time t. This follows the formula given in Griliches (1958, p. 422) which is also reported in Norton and Davis (1981, p. 686).

To overcome data availability problems, Bengston devises a method to estimate costs which is subsequently used in Westgate (1986). For public sector expenditures, Bengston uses a count of screened publications to estimate government scientist years and multiplies this by an estimate of the cost of a scientist year. The cost series is developed using an academic R&D price index series (Sonka and Padberg, 1979) and Callaham's (1981, p. 26) estimate of the cost per scientist year to the Forest Service in 1977. Private cost estimates were obtained from industry specialists. Then these two costs are summed. Bengston calculates the cost of continuing research to the year 2000 under the assumption that research will remain at its estimated 1981 level in terms of scientist years, but that the cost of a scientist year will increase at a real rate of 4.1 percent annually (the average annual increase in research costs between 1947 and 1979 in Sonka and Padberg (1979)). The IRR to structural particleboard in terms of consumer surplus is calculated to be between 18 to 22 percent under various assumptions imposed to check sensitivity of the estimate.

The method used by Bengston has appeal due to its simplicity and modest data requirements. The same cannot be said about the alternative approach used in Seldon (1987), Seldon and Newman (1987), and Brunner and Strauss (1986). The latter method, however, ties the CS and PF approaches together, and rather than assuming that all measurable benefits are due to R&D, this method statistically estimates the output elasticity of R&D expenditures in order to control for economic benefits due to factors other than R&D. In this section the approach is introduced and the more obvious comparisons are made with the method used by Bengston. Further justification for and explanation of the approach is reserved for the next section.

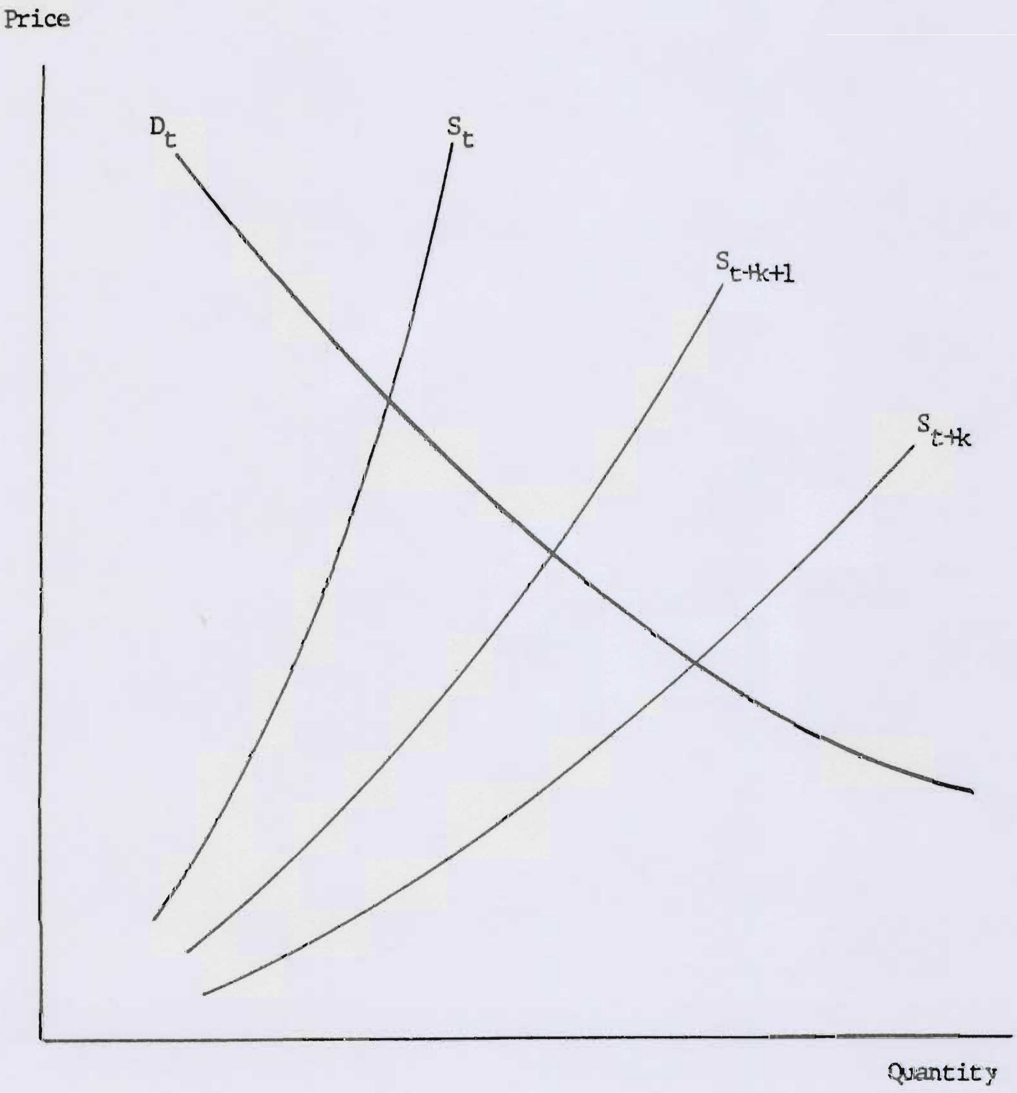
The studies by Seldon (1987), Seldon and Newman (1987), and Brunner and Strauss (1986) estimate the returns to public R&D only; the effects of privately initiated R&D are statistically controlled in a manner to be made clear in the next section. The approach is to specify a production function for the industry which includes research effort as a factor of production and which has a specific functional form, solve the profit maximization problem, and then derive the supply curve. This supply curve is then estimated simultaneously with a demand curve. This endogenously generates estimates of price elasticities of supply and demand so that the researcher does not have to rely on existing estimates which may be biased through the omission of research inputs. Since the production function includes research effort as a factor of production, the output elasticity of research falls through into the supply function as a shift parameter. The estimation of returns to research then follows.

The measurement of returns to consumer surplus and total economic benefit in the method is conceptually straightforward and is similar to the estimation of the effects of an exogenous shock in any stable system. For a given period t, one has observations of price and quantity and estimates of price elasticities of supply and demand and the output elasticity of research. Suppose, for instance, that the price and quantity observations and price elasticity estimates give rise to demand curve D_t and supply curve S_t in Figure 1. Suppose further that R&D conducted today begins to impact production k periods in the future (since it is unlikely that current R&D can be applied immediately). Given the research effort observed during period t and the output elasticity for that research at time t+k, the supply curve for period t+k can be constructed as S_{t+k} in Figure 1. Note that this is the supply curve which would be expected in period t+k given the research effort in period t, _ceteris_ _paribus_. The returns to research are then easily calculated mathematically.

The impact of R&D conducted at time t does not end in period t+k in general, but usually carries over into the future. The lag structure of the production function and econometric estimation of the supply and demand curve will suggest an output elasticity of research conducted in period t for supply in period t+k+1. Thus the supply curve for period t+k+1 may be constructed as, for example, S_{t+k+1} in Figure 1, and the returns in period t+k+1 for research conducted in period t may be calculated, _ceteris_ _paribus_. As pictured here, the benefits of R&D are depreciating as new research replaces the old. In subsequent periods, R&D effects will continue to depreciate with subsequent supply curves approaching S_t until the difference is arbitrarily small and further benefits from R&D in period t can be ignored. Benefits are similarly estimated for all periods under consideration. Note that the estimation procedure is conservative since it does not consider any depreciation in the _initial_ supply function over time.

The costs for public R&D in Seldon (1987), Seldon and Newman (1987), and in Brunner and Strauss (1986) are estimated by multiplying estimates of government scientist time (recorded in U.S. Forest Products Laboratory attainment reports) by an estimate of the cost of that time constructed in a manner similar to Bengston (1983 and 1984). Private implementation costs of publicly funded R&D are estimated for particular projects where data exist to obtain an estimate of the ratio of private expenditures to public expenditures necessary to

Figure 1. Future Returns To Research Conducted At Time t.



operationalize the public research.[6] Private implementation costs are then calculated from this ratio and estimates of public costs, and the private and public costs are then summed.[7]

The two approaches described in this section differ in the way returns to research are estimated. The first approach considers all measurable benefits caused by an outward shift of the supply curve to be the result of R&D. Since all residual benefits are attributed to R&D, one may call this a "residual" approach. The second approach tries to measure the output elasticity of R&D while controlling for other effects which may cause the supply curve to shift. Hence this approach may be called a "nonresidual" approach. This approach is a straightforward extension of the PF approach which is nonresidual in nature. The details are provided in the following section.

The Nonresidual Approach

The approach developed by Seldon is to specify a functional form for the industry production function and to derive the supply equation. Griliches (1979, pp. 95-6) suggests that the Cobb-Douglas form is useful in PF studies since the interactions among inputs are not of particular interest.[8] As Griliches (1979, p. 96) points out, a more general form would require observations with very different combinations of factors of production, but in many cases of interest there have not been radical changes in factor combinations.

The most general Cobb-Douglas form is

$$Q_t = Ae^{\theta t} L_t^{\alpha_1} K_t^{\alpha_2} Z_t \tag{1}$$

where t = time
Q_t = quantity produced
A = constant
e = base of natural logarithms
L_t = labor services
K_t = capital services
Z_t = index of technology

For expositional ease, let $A = 1$ and $\theta = 0$, so

$$Q_t = L_t^{\alpha_1} K_t^{\alpha_2} Z_t.^{9} \tag{2}$$

The index of technology is a function of past R&D. The particular functional form which is used in any study depends on the particular market under consideration. In agricultural markets, the inverted V provides a close fit (Evenson, 1967). In manufacturing industries it is common to assume that, after the initial period of impact, the effect of R&D monotonically decreases.[10] For reasons discussed elsewhere (Seldon, 1985 and 1987) that assumption is adopted here. The particular functional form is

$$Z_t = \prod_{i=i_0}^{\infty} \left(S_{t-i}^{\eta}\, G_{t-i-j_0}^{\mu}\right)^{\lambda^{i-i_0}} \quad ; \quad i_0 > 0,\ j_0 \geq 0 \tag{3}$$

where S_t = private R&D expenditures
G_t = government R&D effort.

These lags suggest that R&D results are not used immediately and that publically funded R&D may be subject to lengthier lags than private R&D.[11]

It is assumed that firms (and hence the industry) maximize cash flow each period and finance their R&D from the cash flow (Kamien and Schwartz, 1982, pp. 28-9). Thus the industry solves the problem

$$\max_{L,K} \Phi_t = P_t Q_t - W_t L_t - R_t K_t$$

subject to equations (2) and (3) where

Φ_t = cash flow
P_t = real price per unit of output
W_t = real hourly wage
R_t = real user cost of capital

S_t is <u>not</u> a control variable for this problem since current R&D expenditures raises profit in the <u>future</u>. The industry will fund current R&D (S_t) from this cash flow.[12]

Setting the first derivatives equal to zero and solving the two equations simultaneously yields

$$L^* = \alpha_1^{\gamma(1-\alpha_2)} \alpha_2^{\gamma\alpha_2} (PZ)^{\gamma} R^{-\gamma\alpha_2} W^{-\gamma(1-\alpha_2)} \tag{5}$$

and $$K^* = \alpha_1^{\gamma\alpha_1} \alpha_2^{\gamma(1-\alpha_1)} (PZ)^{\gamma} R^{-\gamma(1-\alpha_1)} W^{-\gamma\alpha_1} \tag{6}$$

where $\gamma = (1-\alpha_1 - \alpha_2)^{-1}$. (7)

Asterisks indicate optimal levels, and time subscripts have been suppressed for convenience.

The profit each period after funding R&D expenditure is

$$\Pi_t = P_t Q_t^* - W_t L_t^* - R_t K_t^* - S_t \tag{8}$$

where Q_t^* is given by equation (2) subject to equations (5), (6), and (7). It has often been noted and empirically supported that firms (and the industry aggregates) spend a stable fraction of total revenue on research.[13] Let f be the fraction, then

$$S_t = fP_t Q_t. \tag{9}$$

Then substituting equations (2), (3), (5), (6), (7) and (9) into (8), equating (8) to zero, and rearranging terms yields the supply equation

$$Q_t = (1-f)^{-1} AP_t^{\gamma(\alpha_1+\alpha_2)} W_t^{-\gamma\alpha_1} R_t^{-\gamma\alpha_2} \prod_{i=i_0}^{\infty} (S_{t-i}^{\gamma\eta\lambda^{i-i_0}} G_{t-i-j_0}^{\gamma\mu\lambda^{i-i_0}}) \tag{10}$$

where $A = \alpha_1^{\gamma\alpha_1} \alpha_2^{\gamma(1-\alpha_1)} + \alpha_1^{\gamma(1-\alpha_2)} \alpha_2^{\gamma\alpha_2}$ (11)

Taking the log of (10) and subtracting $\lambda \ln Q_{t-1}$ yields the Koyck transformation which is free of the infinite lag:

$$q_t = (1-\lambda) \ln A + \gamma(\alpha_1 + \alpha_2)(p_t - \lambda p_{t-1}) - \gamma\alpha_1 (w_t - \lambda w_{t-1})$$

$$- \gamma\alpha_2 (r_t - \lambda r_{t-1}) + \{(\lambda-1) \ln(1-f)\} + \gamma\eta s_{t-i_0} + \gamma\mu g_{t-i_0-j_0} + \lambda q_{t-1} \tag{12}$$

where capitalized Roman letters have been replaced by their lower cases to represent logarithms, and γ and A are defined by (7) and (11), respectively. The constant term in brackets is extremely small for reasonable estimates of f and λ, and may be excluded. Also $\ln(P_{t-i_0} Q_{t-i_0})$ can act as a proxy for s_{t-i_0}.

A demand function is specified next. In practice, a log linear demand function has been employed:

$$q_t = \underline{\beta x} + \beta_1 p_t \tag{13}$$

where $\underline{x}$ is a vector of demand shifters and $\underline{\beta}$ is a vector of coefficients. The supply and demand system is then estimated simultaneously using nonlinear methods.

Once this estimation is completed, the calculation of the VMP of government research is straightforward and similar to Griliches (1964): divide the (geometric) mean value of the output of the industry (in base year prices) by the geometric mean of public expenditures (also in base year prices) and multiply this by μ. Since the impact is not realized until $i_0 + j_0$ periods later, the value should be discounted:

$$VMP_{GM} = \mu(PQ)_{GM} \;/\; (1-\rho)^{i_0 + j_0} E_{GM}$$

where E is public R&D expenditures (or, where appropriate, the sum of public expenditures and associated private implementation costs), GM signifies the geometric mean and ρ is a discount rate. The MIRR is then calculated following Davis (1981): the MIRR is the value of ρ such that[14]

$$VMP_{GM} \sum_{i=i_0+j_0}^{\infty} [\lambda^i/(1+\rho)^i]$$

$$= VMP_{GM} \{[(1+\rho)/(1+\rho-\lambda)] - \sum_{j=0}^{i_0+j_0-1} (\lambda/(1+\rho))^j\} = 1$$

The calculations of changes in consumer surplus and total economic benefit are more complex. Let a_1 and a_2 be the price elasticity of supply and R&D elasticity of supply respectively; that is,

$$a_1 = \gamma(\alpha_1 + \alpha_2)$$

$$a_2 = \gamma\mu.$$

Research today begins to impact supply in period $t+i_0+j_0$. Given the conditions and technology at time t, one would expect to observe the following future supply equations:

$$q_{t+i_0+j_0} = F_t^s + a_1 p_{t+i_0+j_0} + a_2 g_t$$

$$q_{t+i_0+j_0+1} = F_t^s + a_1 p_{t+i_0+j_0+1} + \lambda a_2 g_t$$

.

.

.

$$q_{t+i_0+j_0+k} = F_t^s + a_1 p_{t+i_0+j_0+k} + \lambda^k a_2 g_t$$

.

.

.

where F_t^s is the intercept of the supply curve in period t, so that in general

$$Q_{t+i_0+j_0+k} = A_t^s G^{\lambda^k a_2} P_{t+i_0+j_0+k} \quad ; \; k = 0,1,2,\ldots \tag{14}$$

where A_t^s is the antilogarithm of F_t^s. Similarly, the expected future demand curve would be

$$Q_{t+i_0+j_0+k} = A_t^d P_{t+i_0+j_0+k}^{-\beta_1} \quad ; \; k = 0,1,2,\ldots \tag{15}$$

Equating (14) and (15), equilibrium future prices are

$$P^e_{t+i_0+j_0+k} = (A_t^d/A_t^s)^\delta \, G^{-a_2\delta\lambda^k} = P_t G_t^{-a_2\delta\lambda^k}$$

where $\delta = (\beta_1 + a_1)^{-1}$. The last inequality results from solving for the price at time t from the original supply and demand equations:

$$Q_t = A_t^s \, P_t^{a_1} \tag{16}$$

and $$Q_t = A_t^d \, P_t^{-\beta_1} \tag{17}$$

The change in consumer surplus in time period $t+i_0+j_0+k$ due to government R&D at time t is

$$\int_{P^e_{t+i_0+j_0+k}}^{P^t} A^d_t \, P_t^{-\beta_1} \, dP = A^d_t \, (1-\beta_1)^{-1} \, (1-G^{\xi\lambda^k}) \, P_t^{1-\beta_1}$$

where $\xi = -a_2(1-\beta_1)\delta$. The discounted value of the consumer surplus for research conducted at time t is then

$$PV^{cs}_t = \sum_{i=i_0+j_0}^{\infty} (1+\rho)^{-i} \, (1-\beta_1)^{-1} A^d_t \, P_t^{1-\beta_1} \, (1-G_t^{\xi\lambda^{i-i_0-j_0}})$$

$$= (1-\beta_1)^{-1} \, P_t Q_t \sum_{i=i_0+j_0}^{\infty} \{(1+\rho)^{-i} \, (1-G_t^{\xi\lambda^{i-i_0-j_0}})\}$$

where ρ is the appropriate discount rate. The last equality results from equation (17). This infinite summation may be approximated by limiting the summation to a finite number of time periods when current R&D has "decayed" to the point where the future supply equation is close to the original supply equation. Once this is done for each period, expenditures may be subtracted and the IRR to consumer surplus may be calculated as the discount rate which equates

$$\sum_{n=0}^{N-1} (1+\rho)^{-n} \, (PV^{cs}_n - E_n) = 0$$

where N is the number of periods in the sample and E_n is R&D expenditure in period n.[15]

In order to calculate the total economic benefit, the change in producer surplus is calculated and then added to consumer surplus. The shift of the supply curve induces a gross gain to producers (the area between the two supply curves and below price) and a gross loss to producers (a transfer to consumer surplus as price falls). The change in producer surplus in time period $t+i_0+j_0+k$ due to government R&D at time t is

$$\int_{0}^{P^e_{t+i_0+j_0+k}} A^s_t \, (G_t^{a_2\lambda^k} - 1) \, P^{a_1} \, dP - \int_{P^e_{t+i_0+j_0+k}}^{P_t} A^s_t \, P^{a_1} \, dP$$

$$= A^s_t \, (1+a_1)^{-1} \, (G_t^{\Psi\lambda^k} - 1) \, P_t^{1+a_1}$$

where $\Psi = a_2(\beta_1 - 1)\delta$. The discounted return to producers is

$$PV_t^{ps} = \sum_{i=i_0+j_0}^{\infty} (1+\rho)^{-i} (1+a_1)^{-1} A_t^s P_t^{1+a_1} (G_t^{\Psi\lambda^{i-i_0-j_0}} - 1)$$

$$= (1+a_1)^{-1} P_t Q_t \sum_{i=i_0+j_0}^{\infty} \{(1+\rho)^{-i} (G_t^{\Psi\lambda^{i-i_0-j_0}} - 1)\}$$

where the last equality results from equation (16). The infinite summation should again be approximated. The IRR in terms of total economic benefit is then calculated as the discount rate ρ such that

$$\sum_{n=0}^{N-1} (1+\rho)^{-n} (PV_n^{cs} + PV_n^{ps} - E_n) = 0.$$

CONCLUSIONS

In this paper the history of research evaluation in forestry has been discussed and estimated returns to research have been presented. These estimates are similar to estimates for agricultural research with the exception of Seldon (1987) and Seldon and Newman (1987).

Methodologies were then discussed. The residual method for calculating the IRR is an adaptation of the CS approach discussed in Norton and Davis (1981). The nonresidual method is an extension of the PF approach and uses the duality of production and cost functions. The former approach has appeal due to its simplicity and modest data requirements. The latter approach has extensive data requirements, but certain advantages:

1. It ties the CS and PF approach together, so that economies of scope in the research evaluation process can be realized.
2. It avoids the need for collecting data on input levels for the PF approach, and instead uses cost data which are often more readily available.
3. It imposes theoretically correct constraints on regression coefficients which in turn mitigates collinearity problems.
4. It avoids simultaneity bias which can occur when only a production function is estimated.[16]
5. It estimates the IRR from <u>all</u> research (not just successful research) in a particular industry.
6. It controls for other supply shifters in calculating the IRR. Through this control it credits R&D with retarding rising prices due to rising factor costs, but does <u>not</u> credit R&D when prices have fallen due to falling factor costs.

FOOTNOTES

[1] Institutions involved in such studies include the North Central Forest Experiment Station, the Mississippi Agricultural and Forest Experiment Station, the Southern Forest Experiment Station, the Southeastern Forest Experiment Station, the Pacific Southwest Forest Experiment Station, the University of Minnesota College of Forestry, the Duke University School of Forestry and Environmental Studies, the Mississippi State University Department of Forestry, and the University of Washington College of Forest Resources.

[2] Excellent reviews are Norton and Davis (1981) and Davis (1981).

[3] Researchers at the University of Minnesota and the North Central Forest Experiment Station have divided their efforts between impact evaluations, and process evaluations while researchers at Duke University have concentrated on impact evaluations. See Bengston (1986).

[4] Forest products are often homogeneous or standardized by the government or industry, and entry costs are often low (with some exceptions such as particleboard and paper). Four-firm concentration ratios also are low; the largest four-firm concentration ratio for four-digit SIC Code forest industries in 1977 was 48 percent for both particleboard (SIC code 2492) and pulp mills (SIC code 2611). For 23 four-digit SIC code forest industries examined by the author, the average ratio was 23.7 percent.

[5] The index number variant of the CS approach is explained in Norton and Davis (1981).

[6] These private implementation costs for public R&D are distinct from private implementation costs for privately initiated R&D.

[7] Extension costs are not so large in the forest products cases as they are in agricultural cases and are usually included in the estimates of R&D since these estimates account for time to publish. There are fewer producers to contact than there are in agriculture and the producers of forest products often take the initiative in maintaining ongoing contact with the U.S. Forest Products Laboratory and experiment stations through visits and telephone calls.

[8] If one were less demanding of the data concerning the link between past research and current output, one could use a more general functional form as suggested, for instance, in Evenson (1981). But the focus on marginal productivity and output elasticity of R&D coupled with a general paucity of data often require the use of a more restrictive form. For recent examples, see Griliches and Mairesse (1984), Pakes and Schankerman (1984a) and Mansfield (1984).

[9] This is the form which performed most satisfactorily for Seldon (1985 and 1987) and Seldon and Newman (1987). The details of the more complex case are found in Seldon (1987).

[10] See, for example, Griliches and Mairesse (1984), Pakes and Schankerman (1984a), and Suzuki (1985).

[11] Empirical support for the first assertion is found in Pakes and Schankerman (1984b). The latter assertion is suggested in Griliches (1979, p. 102). Government research is often more basic than private firms would undertake due to the higher risk and longer payback period.

[12] A similar theoretical problem is considered in Nerlove and Arrow (1962). The authors solve the dynamic optimization problem and their results support the derivation of the supply curve presented here, including the fixed fraction assumption to follow.

[13] See Bullard and Straka (1987), Grabowski (1970), Hay and Morris (1979, p. 446), Mansfield (1968, p. 62) as well as National Science Foundation (1981) and annual reports of R&D expenditures in <u>Business Week</u>.

[14] Note that ρ enters VMP_{GM} as well as the infinite summation. A sample FORTRAN program which solves this problem iteratively is available from the author.

[15] The social discount rate ρ enters each PV_n^{cs} as well as the summation. A sample FORTRAN program to solve this problem is available from the author.

[16] For a discussion of this problem see Griliches (1979, pp. 106-8).

REFERENCES

Bare, B. Bruce, and Robert Loveless. "A Case History of the Regional Forest Nutrition Research Project: Investments, Results, and Applications," University of Washington Final Report Submitted to the USDA Forest Service North Central Forest Experiment Station Under Project Number PNW 82-248, 1985.

Bengston, David N. "Forestry Research Evaluation: An Example." In *Economic Evaluation of Investments in Forestry Economics*, Hyde, W.F. (Ed.). Durham, N.C.: Acorn Press, 1983.

_____. "Economic Impact of Structural Particleboard Research," *Forest Science*, 30:685-97, 1984.

_____. "Aggregate Returns to Lumber and Wood Products Research: An Index Number Approach." In *Forestry Research Evaluation: Current Progress, Future Directions*, Risbrudt, C.D. and P.J. Jakes (Eds.). General Technical Report NC-104. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station, 1985.

_____. "Economic Evaluation of Forestry Research: State of the Arts," Paper presented at the 40th annual meeting of the Forest Products Research Society, Spokane, Washington, June 22-26, 1986.

Brunner, Allan D., and Jack K. Strauss. "The Social Returns to Public R&D in the U.S. Wood Preserving Industry (1950-1980)," Duke University mimeo (preliminary), 1986.

Bullard, Steven H., and Thomas J. Straka. "Role of Company Sales in Funding Research and Development by Major U.S. Paper Companies," *Forest Science*, 32:936-43, 1987.

Callaham, Robert Z. *Criteria for Deciding About Forestry Research Programs*, USDA Forest Service General Technical Report WO-29, 1981.

Chang, Sun Joseph. "The Economics of Optimal Stand Growth and Yield Information Gathering," University of Kentucky Final Report Submitted to the USDA Forest Service North Central Experiment Station Under Cooperative Research Agreement 23-83-27, 1986.

Davis, Jeff. "A Comparison of Procedures for Estimating Returns to Research Using Production Functions," *The Australian Journal of Agricultural Economics*, 25:60-72, 1981.

Evenson, Robert E. "The Contribution of Agricultural Research to Production," *The Journal of Farm Economics*, 49:1415-25, 1967.

_____. "Research Evaluation: Policy Interests and the State of the Art." In *Evaluation of Agricultural Research*, Norton, G.W., W.L. Fishel, A.A. Paulsen, and W.B. Sundquist (Eds.) Miscellaneous Publication 8-1981. St. Paul: Minnesota Agricultural Experiment Station, 1981.

_____. "Agriculture." In *Government and Technical Change: A Cross-Industry Analysis*, Nelson R.R. (Ed.) New York University Graduate School of Business Administration Center for Science and Technology Policy, 1982.

_____, Paul E. Waggoner, and Vernon W. Ruttan. "Economic Benefit from Research," *Science*, 205:1101-7, 1979.

Grabowski, Henry G. "Demand Shifting, Optimal Firm Growth, and Rule-of-Thumb Decision Making," *The Quarterly Journal of Economics*, 84:217-35, 1970.

Griliches, Zvi. "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66:419-31, 1958.

_____. "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *American Economic Review*, 54:961-74, 1964.

_____. "Issues in Assessing the Contribution of Research and Development to Productivity Growth," Bell Journal of Economics, 10:92-116, 1979.

_____, and Jacques Mairesse. "Productivity and R&D at the Firm Level." In R&D, Patents, and Productivity, Griliches, Z. (Ed.). Chicago: The University of Chicago Press, 1984.

Hay, Donald A., and Derek J. Morris. Industrial Economics: Theory and Evidence. Oxford: Oxford University Press, 1979.

Haygreen, John, Hans Gregerson, Irv Holland, and Robert Stone. "The Economic Impact of Timber Utilization Research, " Forest Products Journal, 36:12-20, 1986.

Hyde, William F. "Gains From Public Forestry Research: Methods and Case Studies in Biological Forestry and Forest Utilization," Voluntary paper presented at the S4.05.05 of the 18th IUFRO World Congress, Ljubljana, Yugoslavia, Oct. 1986.

Kamien, Morton I., and Nancy L. Schwartz. Market Structure and Innovation. Cambridge: Cambridge University Press, 1982.

Lundgren, A.L. "Methods for Evaluating Forestry Research: A Prospectus." In Economic Evaluation of Investments in Forestry Economics, Hyde, W.F. (Ed.). Durham, NC: Acorn Press, 1983.

Mansfield, Edwin. The Economics of Technological Change, New York: Norton, 1968.

_____. "R&D and Innovation: Some Empirical Findings." In R&D, Patents, and Productivity, Griliches, Z. (Ed.). Chicago: The University of Chicago Press, 1984.

National Science Foundation. Research and Development in Industry, 1980. Washington: National Science Foundation NSF 82-317, 1981.

Nerlove, Mark, and Kenneth J. Arrow. "Optimal Advertising Policy Under Dynamic Conditions," Economica, 29:129-42, 1962.

Newman, David H. "An Econometric Analysis of Aggregate Gains From Technical Change in Southern Softwood Forestry," Ph.D. Dissertation, Duke University, 1986.

Norton, George W., and Jeffrey S. Davis. "Evaluating Returns to Agricultural Research: A Review," American Journal of Agricultural Economics, 63:685-99, 1981.

Pakes, Ariel, and Mark Schankerman. "An Exploration into the Determinants of Research Intensity." In R&D, Patents, and Productivity, Griliches, Z. (Ed.). Chicago: The University of Chicago Press, 1984a.

_____. "The Rate of Obsolescence of Patents, Research Gestation Lags, and the Private Rate of Return to Research Resources." In R&D, Patents, and Productivity, Griliches, Z. (Ed.). Chicago: The University of Chicago Press, 1984b.

Ruttan, Vernon W. "Bureaucratic Productivity: The Case of Agricultural Research," Public Choice, 35:529-47, 1980.

Seldon, Barry J. "The Marginal Productivity of Public Research in the Softwood Plywood Industry," Ohio Economic Studies Working Paper 85-15, Ohio University, 1985.

_____. "A Nonresidual Estimation of Welfare Gains From Research: The Case of Public R&D in a Forest Product Industry," Southern Economic Journal, 54:64-80, 1987.

_____, and David H. Newman. "Marginal Productivity of Public Research in the Softwood Plywood Industry: A Dual Approach," Forest Science, forthcoming, 1987.

Schultz, T.W. The Economic Organization of Agriculture, New York: McGraw-Hill, 1953.

Sonka, S.T., and D.I. Padberg. "Estimation of an Academic Research and Development Price Index," University of Illinois at Urbana-Champaign Department of Agricultural Economics Paper No. 79 E-100, 1979.

Suzuki, Kazuyuki. "Knowledge Capital and the Private Rate of Return to R&D in Japanese Manufacturing Industries," International Journal of Industrial Organization, 3:293-306, 1985.

Westgate, Robert A. "Benefits and Costs of Containerized Forest Tree Seedling Research in the United States." In Evaluation and Planning of Forestry Research, Burns, D.P. (Ed.). General Technical Report NE-GTR-111. Broomall, PA: USDA Forest Service Northeastern Forest Experiment Station, 1986.

EVALUATING SOCIAL SCIENCE RESEARCH IN AGRICULTURE

George W. Norton*

Federal financial support for agricultural research has stagnated in real terms for the past 20 years while pressures to justify research budgets have increased. Partly in response to these pressures, agricultural economists have conducted a variety of studies to evaluate the public agricultural research investment. Several of these evaluation efforts have examined aggregate agricultural research and extension; others have assessed particular technologies. Few studies, however, have attempted to quantitatively measure impacts of social science research (SSR) including agricultural economics research (AER). The need to evaluate SSR arises from two primary sources. First, as budgets tighten, there are increasing requests from public decision makers to provide evidence on the value of that research including AER. Second, an introspective look at the value of SSR can provide guidance for future research directions.

In an invited address to the American Agricultural Economics Association at Cornell in 1984, Ruttan argued that social scientists have only begun to conceptualize the contribution of knowledge in social sciences. He hypothesized that the demand for knowledge in economics and in other social sciences is derived primarily from the demand for institutional change and improvements in institutional performance. Interestingly, the fact that economists have devoted so much time to evaluating agricultural research over the past few years in response to the demands of administrators and policy makers responsible for institutional performance would seem to support that hypothesis. Ruttan cited other examples. He did not, however, provide quantitative estimates of the benefits of SSR although he noted that the lack of economic knowledge has at times imposed very heavy costs on American farmers and the American Economy (Ruttan, p. 557).

The objective of the current paper is to suggest not only conceptual but empirical means for assessing the value of SSR. The focus is on empirical issues and procedures because of both the need for and the relative lack of quantitative evaluation of SSR. Furthermore, the paper concentrates on AER due to its relative importance, in terms of funding, within agricultural SSR. In the first section, the importance of AER relative to total agricultural, forestry, and home economics research is highlighted. This is followed by a discussion of the problems and conceptual issues inherent in evaluating AER. Possible empirical procedures are described and an application is presented which utilizes an approach for valuing information. Finally, implications for future evaluations of agricultural economics research are discussed.

MAGNITUDE OF AGRICULTURAL ECONOMICS RESEARCH IN THE U.S.

Prior to considering methods for evaluating AER, it is useful to gain a perspective on its magnitude. The USDA Current Research Information System (CRIS) publishes research expenditure data by Commodity Group and Research Problem Area (RPA). The most recently published CRIS data were examined and an effort made to sort out those RPS's containing primarily agricultural economic research. Out of the total 100 RPA's in the CRIS system, 21 appear to contain primarily AER components and are listed in Table 1. In 1985, out of 1,928 million dollars spent on research by the State Agricultural Experiment Stations, USDA, Forestry Schools, and other cooperating institutions, approximately 125.5 million dollars, or 6.5% was spent on these "agricultural economics" RPA's. Figures for 1981 for the same RPA categories reveal that 7.0% of total expenditures was spent on AER. This indicates that from 1981 to 1984 AER slipped marginally in funding vis a vis other types of agricultural research in the aggregate. Substantial funding declines occurred in the rural development RPA's (803, 804, 806, 807). These figures must be used with caution because some of the RPA's listed contain non-AER components. Furthermore, several RPA's not listed, particularly in the soil and water areas, contain substantial AER. Nonetheless, these figures provide a rough indication of the magnitude of AER in relation to total agricultural research performed at

---

* George W. Norton is Associate Professor, Virginia Tech. The author would like to thank Patricia Norris, Edward Adusei and John Norton for assistance with data collection and Bob Evenson for comments on a preliminary draft of this paper.

Table 1: Expenditures on Major Agricultural Economics Research Categories in 1985 Classified by Research Problem Area (RPA), Total USDA-SAES-Forestry Schools - Other Cooperating Institutions.

RPA	Title	No. of Projects	Scientist Years	Total Funds($)
104	Alternative Uses of Land	191	115.4	8,614,078
108	Econ. and Legal Prob. of Water Management	56	24.2	2,599,623
114	Rsch. on Mgt. Research	50	51.3	6,985,885
316	Farm Business Mgt.	173	75.1	7,222,637
503	Marketing Eff. of Agr. Production and Inputs	201	70.9	7,964,031
506	Supply, Demand and Price Analysis	244	141.1	14,797,322
507	Competitive Interrelationships in Agriculture	67	21.0	2,448,241
508	Domestic Market Development	39	6.8	1,263,645
509	Performance of Marketing Systems	188	96.7	10,504,291
510	Group Actions and Market Power	32	11.6	1,469,326
511	Improvement in Agr. Statistics	36	8.6	1,792,389
601	Foreign Market Development	150	154.3	15,380,055
602	Evaluation of Foreign Food Aid Programs	5	.5	52,528
703	Food Consumption Habits	152	42.3	11,313,127
803	Rural Poverty	30	7.5	768,964
804	Improve Econ. Potential of Rural People	96	34.4	3,939,467
806	Adjustment of Change	197	54.1	2,851,413
807	Structural Changes in Agriculture	205	101.2	10,258,112
808	Govt. Programs to Balance Farm Output and Demand	72	37.8	4,211,918
907	Improve Income Opportunities in Rural Communities	103	46.9	4,812,836
908	Rural Institutional Improvement	176	58.7	6,266,950
	Subtotal, Agricultural Economics Research Problem Areas			125,516,838
	Total, All Research Problem Areas			1,927,991,221

Source: USDA, CSRS <u>Inventory or Agricultural Research</u>, FY1985, Vol. II, 1986, pp. 2-3.

public institutions. While AER is not large in relation to total agricultural research, it still represents a sizable public investment.

CONCEPTUAL PROBLEMS AND ISSUES

The list of RPA's in Table 1 suggests some of the difficulties inherent in AER evaluation. Agricultural economics research is diverse, directed at various goals, and produces a variety of hard to measure outputs. Some research projects are concerned with increasing or stabilizing aggregate income while others are directed toward facilitating a more equitable income distribution or improving health and safety. Some are aimed at multiple goals.

Many of the problems of AER evaluation relate to measurement of research output. A common thread running through most AER is that the output is information. Biological, physical, and mechanical research also produces information, but in those cases the information is eventually imbedded in new inputs or products or can be identified in a more tangible way. In the case of AER we do not have such imbedding. To the extent that it does occur, the information is imbedded in new policies and institutions. As noted above, Ruttan has suggested that the demand for knowledge in economics and other social sciences is derived primarily from the demand for institutional change or increased efficiency in institutional performance. The value of AER therefore results from reduction in the cost of institutional innovation, analogous to the reduction in cost of technical innovation resulting from new biological, physical, and mechanical technologies. In fact, as Ruttan, Bonnen, and Schultz have each noted, the demand for institutional change itself often results when new biological and physical technologies are introduced, resulting in disequilibria in factor and product markets.

The conceptualization of AER producing information which reduces the cost of institutional change is useful, but other difficulties remain in attempting to measure the value of AER. One is the problem of determining causality of change which occurs following AER. One can link yield changes to plant breeding research easier than he can link change in farmer behavior or institutions to AER. Even if institutional change occurs following a piece of research which suggested the change, one can never be certain that the change would not have been made anyway for political or other reasons. Related to this is the fact that information is available to economic agents from sources other than public research and extension.

Occasionally the linkage between research and institutional change can be made confidently. For example, Adams documented the role of AER which resulted in the creation of the IMF Cereal Import Facility. That study also illustrates, however, the common phenomenon of multiple research studies contributing pieces of information which eventually add up to a useful whole. Often it is difficult to account for the various pieces in determining the real research cost.

An issue related to the multiple researcher case is the problem of placing value on basic as well as applied research. An applied study which utilizes a modeling tool which itself is the product of basic statistical or econometric research creates difficulties in measuring research costs. There are cases where one can argue that the marginal value and marginal cost of the applied study represents the relevant benefit and cost, but clearly there is a complementarity between applied and basic research which must be accounted for lest the value of basic research continually be undervalued. Of course this is true for non-agricultural economics as well as agricultural economics research.

The complementarity issues arises again with respect to the interaction between research and extension, and this too is a familiar problem with non-agricultural economics research. An additional complementarity problem is described by Bonnen who notes the important interaction among human capital, technology, and institutions. He says that it is a major intellectual misunderstanding to attribute the entire increment of an increase in productivity to any one of these three complementary factors (Bonnen, p. 959).

Timing is another critical element affecting the value of AER. Adams mentions the importance of timing in determining the usefulness of the AER behind the creation of the IMF Cereal Import Facility. One could argue that the forces which create the demand for institutional change will improve the likelihood of the information produced by AER being timely, at least for applied research. Another timing related issue is the adoption rate of AER information and its implications for distribution of research benefits. Just as the benefits of new biological and physical technologies accrue to early adopters, so too with AER. Those firms able to obtain information on a more timely basis may gain a competitive advantage over other firms creating an information treadmill effect with implications for structural change in agriculture.

When one takes the perspective that the output of AER is information, it is useful to consider what types of information are produced and who the users are. The major types of information provided by AER can be classified into three groups: (1) management and price information used primarily by producers, consumers, and policy makers, (2) institutional information used primarily by administrators and policy makers, and (3) disciplinary information (mainly related to economics, statistics, and operations research) used by other researchers. Regardless of who the initial users are, the ultimate beneficiaries tend to be individual economic agents, typically producers and consumers. As noted above, AER projects can impact on various goals (e.g., growth, equity, security), but many if not most projects have some effects which can be measured or at least conceptualized in terms of having an economic value. Let's examine briefly how this value arises.

Management and Price Information

Many agricultural economics research projects provide management or price information to facilitate attainment of technical or allocative efficiency. Technical efficiency gains can result from improved timing of input usage, fuller exploration of the complementary relationships among inputs, etc. Allocative efficiency gains result from the potential to provide producers with improved knowledge of the most profitable or utility maximizing contributions of inputs and outputs given the technology. Management and price information on consumption of food and fiber similarly can increase the efficiency of household production and subsequent utility. The value of management and price information is derived from the reduction in uncertainty facing economic agents. Reduced uncertainty results in efficiency gains and to the extent that these agents are risk adverse, management and price information results in additional utility gains through lower income variability.

Institutional Information

Information produced by AER often is used by policy makers or groups of individuals who redefine public policies, property rights, or in more general terms, institutions and then these changes in turn lead to actions on the part of individual economic agents. The term institution can be defined as the set of behavioral rules that govern a particular pattern of actions and relationships (Ruttan, 1978). Changes in farm programs, environmental regulations, or rural development programs can be considered institutional change. Frequently, new institutional information affects allocative and technical efficiency. It perhaps affects equity and security more often than does management and price information.

Disciplinary Information

Disciplinary information can be thought of as being produced by basic research in agricultural economics. An improved econometric technique or an improved procedure for measuring economic welfare gains unrelated to a specific public policy provides information which more applied researchers can utilize. Just as the demand for institutional change is derived in part from new biological and physical technologies, the demand for disciplinary research is derived from the need for theories and tools to conduct price and management (structural) and institutional research. Because this demand is so diffuse, however, it is virtually impossible to isolate the benefits of specific types of disciplinary research.

EMPIRICAL PROCEDURES FOR EVALUATING AER

The output of AER is information. Two approaches commonly used to empirically assess the value of information have been the net social benefits approach and the decision theoretic approach. The net social benefits (consumer-producer surplus) approach has been applied by Hayami and Peterson, Bullock; Freebairn (1976, a,b); Bradford and Kelegian (1977, 1978); Thabet, Ray and Bullock; and Norton and Schuh to evaluate net benefits of more accurate outlook and price information.

The benefits of research leading to improved outlook and price information are illustrated in its simplest form in Figure 1a.

Figure 1a. Welfare effects when price is overestimated.

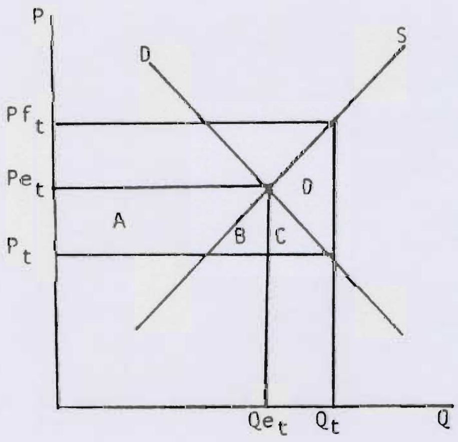
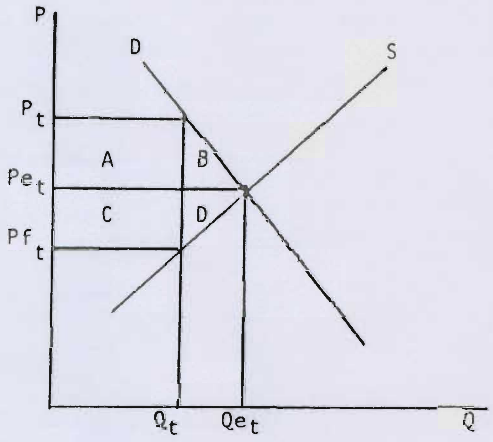


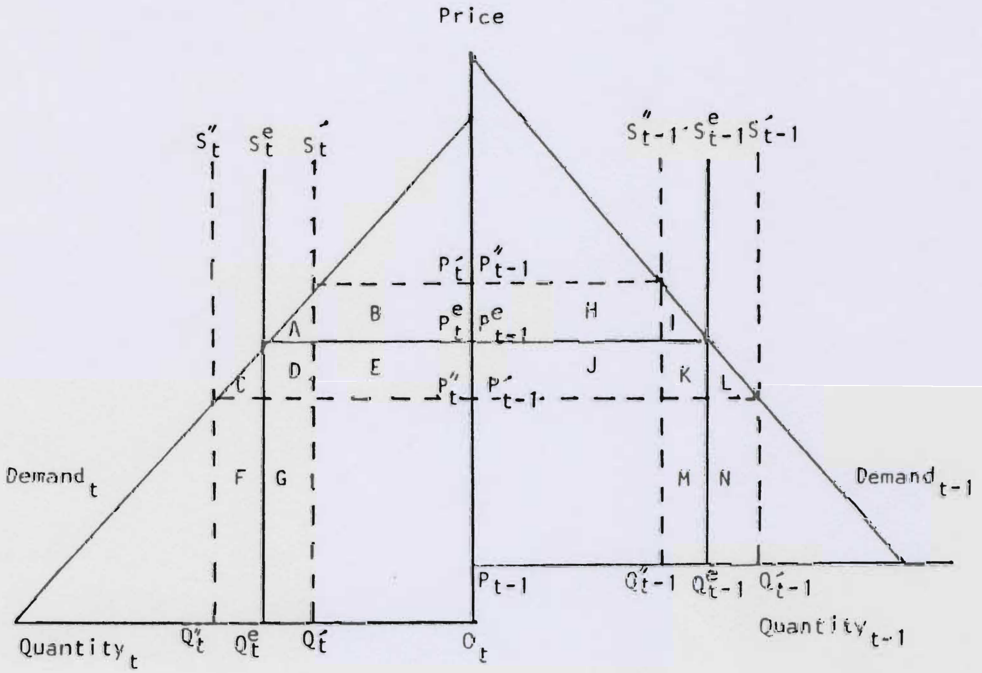
Figure 1b. Welfare effects when price is underestimated.



Assume producers estimate the price of the commodity to be Pf_t which is above the equilibrium price Pe_t. In this case they produce a quantity of Q_t which is larger than the equilibrium quantity Qe_t. The resulting price is P_t and resulting change in net social benefit is $A + B + C - (A + B + C + D) = -D$. Likewise when producers underestimate price (Figure 1b), the change in net social surplus is $-(A + B) + (A - D) = -(B + D)$. Bearing in mind the well known limitations of consumer-producer surplus measures, if AER efforts lead to price forecasts which are closer to Pe_t, then net social losses will be reduced. Most of the studies noted above separate the cases where production as opposed to only inventory adjustments can occur. Thabet, Ray, and Bullock also consider cross-commodity effects of outlook information. This model has been employed by Freebairn (1976, a,b) who also derives expressions for expected welfare effects on producers, consumers, and society of producers using perfect foresight prices relative to rational (but inaccurate) forecast prices in supply decision making.[1] Freebairn (1976,b) and Thabet, Ray, and Bullock extend the model to capture cross-commodity effects from inventory behavior.

The model is Figure 1 abstracts from inventory behavior. Potential gains and losses also can be realized from research which results in more accurate outlook and price information which in turn leads to intertemporal inventory changes. This is illustrated with a two period model in Figure 2. In equilibrium, the price in period two (Pe_t) equals the price in period one (Pe_{t-1}) plus the cost of storage. If too much were sold in period one (Q'_{t-1}), the observed period one price would drop to P'_{t-1} and the amount available for sale in period two (Q'_t) would result in the period two price, P'_t. Consumers would gain J + K + L in period one and lose A + B in period two. The change in producer surplus would be N - J - K in period one and B - D - G in period two. The net economic surplus change would be L + N - A - D - G. Likewise if too little were sold in period on (Q''_{t-1}) and too much in period two (Q''_t), the period one price would be P''_{t-1}, the period two price, P''_t, consumers would lose H + I in period one and gain C + D + E in period two, the change in producers surplus would be H - K - M in period one and F - D - E in period two, and the net change in producer surplus would be H - K - M in period one and F - D - E in period two, and the net change in economic surplus would be C + r' - I - K - M. This basis model is similar to those considered by Hayami and Peterson, Bullock, and Bradford and Kelegian (1977, 1978), and Norton and Schuh. Thabet, Ray and Bullock extend the models in Figures 1 and 2 by allowing for both production and inventory adjustment as well as multiple commodities.

Figure 2



Freebairn (1976,b) evaluates the welfare effects of more accurate forecast prices in terms of more precise knowledge about factors causing shifts in the demand for and supply of agricultural commodities. He assumes that price expectations are formed rationally in the sense described by Muth.[2] He assumes that supply and demand curves have known parameters on the price variable but random error terms. The intercept terms reflect the effects of all other variables on the demand and supply of the commodity. Cyert and DeGroot argue that this is a black box concept of a rational expectation and that a process has to be developed if the rational expectations hypothesis is to be anything other than a religious belief. They assume Bayesian learning in describing the process by which expectations, once formed, lead to an equilibrium. Learning takes place in the market and has the effect of continually modifying the prior probability distribution with which the firms start. Prior distributions are assigned to the unknown values of all parameters wherever they appear in the model (including the parameters on the price variables). Cyert and DeGroot show that it is in the Bayesian framework that the rational expectations approach finds its natural setting.

Bradford and Kelegian (1977, 1978) and Norton and Schuh apply Bayesian decision theory to evaluate outlook and price information. In effect they argue that the rational expected price is arrived at through Bayesian learning, but that learning results not only from observing market behavior but from public outlook and price information. This information not only causes speculative inventory holders to revise their prior probability distribution, but affects the commodity price distribution. These changes are evaluated using the net social surplus approach described previously. The value of information is the difference between maximum utility with and without outlook information. Bradford and Kelegian (1978) implement their model for the case of wheat crop forecasting in the United States. Norton and Schuh consider the case of soybean outlook information provided each fall by agricultural economists at the University of Minnesota.

One advantage of the decision theory approach is that it explicitly considers the fact that the value of information is an outgrowth of the economic theory of uncertainty. As Hirschleifer points out, uncertainty is summarized by the dispersion of individuals' subjective probability distributions over possible states of the world. Information consists of events tending to change these probability distributions.[3] The major problem with using the decision theory approach is in the estimation of subjective probabilities in the prior and posterior situation. Norton and Schuh assumed that subjective priors were based on historical probabilities of price movements for the previous 15 years. Conditional probabilities were determined by looking at past outlook projections and actual states of nature which occurred. These probabilities were then used to calculate the posterior probabilities using Bayes formula. Another problem is that the appropriate utility function must be determined unless a linear utility function is assumed so that maximizing expected profits is equivalent to maximizing expected utility (Eidman, Carter, and Dean). This is in fact what Bradford and Kelegian (1978) and Norton and Schuh assume. A third problem is that one can argue with the hypothesis that economic agents behave as though their priors are updated according to Bayes theorem.

The net social benefits and decision theoretic approaches are feasible for evaluating certain types of agricultural economic research projects, especially when profit maximizing or risk neutral behavior is assumed. Attempts to evaluate broader classes of research output such as the management-price, institutional, or disciplinary classes of information will likely require alternative approaches, especially if one considered that agents are risk adverse.

Antonovitz and Roe (1982, 1985) suggest alternative measures for valuing information under price uncertainty while Roe and Nygaard present a measure for the value of information when the parameters of the underlying technology are not known with certainty by the producers. These studies rely on the notions that producers allocate resources based on their subjective estimates of prices and parameters of the underlying technology, and that these estimates are not entirely accurate. However, rather than assuming that producers behave as though their priors are updated by Bayes Theorem, they suggest means for valuing information based on "subjective" and "actual" or "more informed" production and/or profit functions. They provide one ex post and two ex ante measures of the value of information. The ex post measure is determined by comparing profit realized in the subjective state with profit realized in the state of perfect information. In the two ex ante cases, the actual output price is not assumed to be known, but rather decisions made in the subjective state are compared with those made in a more informed state. As with the decision theory approach, value of information generated for the individual firm then can be translated into a measure of the value of information to society using the economic surplus approach.

The procedures suggested by Antonovitz and Roe appear to provide a means for evaluating the broad program areas of farm marketing and management research and extension. An example is presented below to illustrate a possible method for estimating returns to agricultural economics research and extension aimed at improving allocative efficiency.

EMPIRICAL EXAMPLE OF EVALUATING AER

Assume in our example that producers exhibit profit maximizing risk neutral behavior. Profit is $\pi = Pq - C(q)$ where P is stochastic input price, q is quantity, and C(q) is the cost function. Expected profits $\pi^e = p^e q^o - C(q^o)$ where p^e equals expected price when input decisions are made, and q^o is the quantity produced. When q^o is sold at the realized price p^r, realized profit $\pi^r = p^r q^o - C(q^o)$. Because P is stochastic, p^r may not equal p^e. Denote the optimal output choice under perfect information as q^t. Profits under perfect information = $\pi^t = p^r q^t - C(q^t)$. In this situation, Antonovitz and Roe point out that one measure of the value of information is defined to be the difference between profits earned in the state of perfect information, π^t, and profits earned in the realized state π^r. The value of information (also allocative error) which can be denoted by VI is given by:

$$VI = \pi^t - \pi^r = (p^r q^t - C(q^t)) - (p^r q^o - C(q^o))$$

The usefulness of this concept becomes apparent when one considers that π^r and q^o are observable, π^t can be estimated as shown below, and then the relationship between $\pi^t - \pi^r$ and certain types of agricultural economics research can be estimated. $\pi^t - \pi^r$ represents a measure of potential allocative efficiency gains.

Profit functions arise naturally out of duality theory which implies that properties of production technology and choice can be fully described by expected profit, input demand and output supply functions. Assume firms choose a (1xm) vector of planned output levels q^o, and a (1xn) vector in input flows, x^o, in order to maximize expected profit, π^e, subject to a (1xp) vector of fixed factors, Z, a (1xm) vector of expected output prices, p^e, a (1xn) vector of input prices, R, and a production technology that satisfies the usual neoclassical properties. The indirect profit function relates maximized expected profit π to P, R, and Z:

$$(1) \quad \pi = \pi(P,R,Z),$$

and by Hotelling's lemma, the output supply and input demand functions are as follows:

$$(2) \quad \frac{d\pi}{dP_i} = q_i = q_i(P,R,Z) \quad i = 1 \ldots m,$$

$$(3) \quad \frac{d\pi}{dR_h} = x_h = -x_h(P,R,Z) \quad h = 1 \ldots n.$$

Fixed factors, Z, include fixed inputs such as land and farmers' education as well as public policy variables such as agricultural research and extension. Note that the aggregate impact of all agricultural research on output of a particular commodity q_i can be obtained as $\frac{dq_i}{dz_j}$ where Z_j is measured as agricultural research expenditures (See Huffman and Evenson for an example).

The impact of AER can be derived by estimating the system of equations (1)-(3) using expected prices and then using the parameters so estimated along with actual prices and fixed factors to determine optimal profits, π^t. The following relationship can then be estimated:

$$(4) \quad \pi^t - \pi^r = f(Ex, AER, ED, CV)$$

where Ex is extension expenditures on business management and marketing; AER is public expenditures on farm management, marketing efficiency, and price analysis research; ED is education; and CV is a coefficient of variation of output prices.

Econometric Models

A set of 10 output supply and input demand equations were estimated jointly using data for 42 U.S. states pooled over agricultural census years 1978 and 1982. The normalized quadratic flexible functional form was employed for the profit function. It imposes homogeneity in prices and results in output supply and input demand functions which are linear in normalized prices. The normalized quadratic profit function can be represented as:

$$(5)\quad \pi = a_o + \sum_{i=1}^{m} a_i P_i + \frac{1}{2}\sum_{i=1}^{m} b_i P_i^2 + \sum_{h=1}^{n} c_h R_h + \frac{1}{2}\sum_{h=1}^{n} d_h R_h^2 + \frac{1}{2}\sum_{i=1}^{m}\sum_{h=1}^{n} e_{ih} P_i R_h + \sum_{j=1}^{p} f_j Z_j + \sum_{j=1}^{p}\sum_{k=1}^{p} g_{jk} Z_j Z_k$$

$$+ \sum_{i=1}^{m}\sum_{j=1}^{p} d_{ij} P_i z_j + \sum_{h=1}^{n}\sum_{j=1}^{p} V_{hj} R_h Z_j$$

where a,b's, c's, d's, e's, f's g's, l's, and v's are the unknown parameters of the profit function. The output supply and input demand functions can be represented as in equations (6) and (7) respectively:

$$(6)\quad q_i = a_i + \sum_{i=1}^{m} b_i P_i + \sum_{h=1}^{n} e_{ih} R_h + \sum_{j=1}^{p} d_{ij} Z_j$$

$$(7)\quad X_h = C_h + \sum_{h=1}^{n} d_h R_h + \sum_{i=1}^{m} e_{ih} P_i + \sum_{j=1}^{p} V_{hj} Z_j$$

The above model is normalized on one of the prices and the equation (output supply or input demand) associated with that price is obtained residually from the parameters of the remaining equations following estimation. Cross equation symmetry restrictions, $e_{ih} = e_{hi}$, are imposed to reduce the number of unknown parameters to be estimated. The equations represented by (5) and (6) were estimated jointly using Zellner's seemingly unrelated regression procedure to increase efficiency. Equation (4) was then estimated in linear form using OLS.

Variables and Data

Farmers' output and input choices by state were condensed into seven per farm output indexes (small grains, other major grains and potatoes, hay, other crops, milk, poultry, and other livestock)[4] and four variable inputs (commercial fertilizer, labor, petroleum products, and feed). Inputs assumed to be fixed or exogenous within each observation period include land, deviation from annual average July rainfall, the stock of breeding livestock, other capital items, agricultural research, agricultural extension, and education. We assume that other miscellaneous inputs are not contemporaneously related to prices or fixed inputs so their exclusion will not bias the estimated coefficients. These fixed factors together with normalized output and variable input prices are assumed to explain farmers' output and input choices.

The data collection and subsequent transformation to construct output and input quantities and prices required a sizable effort. Quantity and price data on all major agricultural commodities for each state were collected. The output quantity indexes were constructed with quantity data collected from the Census of Agriculture and price data collected from Agricultural Prices. Expected output prices used in the output price index variables were either (1) futures market prices for harvest contracts observed at planting time adjusted by the basis between each state and the state where the futures market is located, or (2) for those commodities for which no future markets exist, one year lagged state average prices received by farmers. The expected milk price is the numeraire price in the model and all output and input prices are divided by it.

Farm labor includes operator (adjusted for age and days worked off the farm) and hired and contract labor and was derived from Census of Agriculture data. The wage rate for farm labor is the state average wage rate for hired labor (Agricultural Statistics). The petroleum (fuel) quantity and price variables are indexes of gas, diesel, and L.P. gas derived from data in the Census of Agriculture and Agricultural Prices. The quantity of feed variable was from the Census of Agriculture and the fertilizer quantity from Agricultural Prices. The prices of fertilizer and feed were obtained by dividing the values of commercial fertilizer and feed from the Census by their respective quantities.

The land variable is a quality (price) weighted index with the weights obtained from Davis. Capital items include the service flow from machinery and custom services based on

Census of Agriculture data, and the breeding stock variable is a weighted index of cows (1), sows (.4), and ewes (.2), also from the census. Rainfall data were obtained from Weiss et al. Agricultural extension is measured as the one year lagged value of each state's agricultural extension funds. These data were obtained from the Extension Service, USDA in Washington. Agricultural research is measured as a 12-year quadratic distributed lag of research expenditures with the data obtained from the Inventory of Agricultural Research. Education is based on a variable constructed by Davis. An intercept dummy on peanuts and a slope dummy on peanut price was included in the other grain's equation to account for differences arising from the small number of states producing peanuts. Similar dummies were included for the Southern States and "other crop" price because the mix of "other crops" differed substantially between Northern and Southern states.

The extension variable in equation (4) is current expenditures on business management and agricultural marketing extension. Data were obtained from the Extension Service, USDA in Washington. Agricultural economics research is measured as current expenditures on business management, marketing, and supply and prices analysis lagged one year. These data were obtained from RPA's 316, 503, and 506 in the Inventory of Agricultural Research.

The measure of price variations in equation (4) is the coefficient of variation calculated by estimating the weighted variance of prices in each state:

$$\text{coefficient of variation} = \frac{\sqrt{\Sigma\, q_i^2 \; \sigma p^2{}_i \; + \; 2\Sigma q_i q_j \operatorname{cov}(P_i P_j)}}{\Sigma E(P_i q_i)}$$

where $\sigma p^2{}_i$ is the variance of P_i, $\operatorname{cov}(P_i P_j)$ is the covariance of $P_i P_j$ and $E(P_i q_i)$ is the expected value of gross returns. The variable is included to account for the fact that allocative error should be greater in states with more variable prices from year to year.

Results of Product Supply and Input Demand Estimation

Results from fitting the output supply and input demand equations to the 92 pooled observations are presented in Tables 2 and 3. The six New England states plus Alaska and Hawaii were omitted in data estimation because of the absence of substantial numbers of products, particularly grains. An indication of goodness of fit is provided by the R^2 obtained from single equations OLS estimates of the individual equations. These measures are .68 for small grains, .65 for other grains and potatoes, .65 for other crops, .90 for hay, .40 for poultry, .90 for other livestock, .48 for feed, .82 for fertilizer, .94 for fuel, and .89 for labor. All own-price coefficients on outputs and inputs have the expected signs except for other crops and poultry and those coefficients were non-significant at the 5% level. Other grains and other livestock also were non-significant at the 5% level. A number of the estimated coefficients on cross prices and fixed factors exhibit low levels of significance. Among the fixed factors, capital strongly and positively affects the demand for feed, fertilizer, fuel, labor and the supply of small grains, other grains, hay, other crops, and livestock. The expected sign on the research variable is negative because it represents the "α" coefficient from a quadratic distributed lag. Research increases the demand for fertilizer and the supply of "other crops". Breeding stock reduces the demand for fertilizer but increases the demand for fuel and labor. Not surprisingly it increases the supply of livestock and is also positively correlated with the supply of hay.

Among the price variables, fertilizer and feed and fuel and feed are complements but other input-input cross-price effects were non-significant at the 5% level. Higher feed prices reduce the supply of hay, but contrary to expectations, increase the supply of livestock. A higher price of fertilizer reduces the "other" grains but contrary to expectations, increases the supply of small grains. A higher labor price reduces the supply of small grains. "Other crops" and livestock are complements. The dummy variables on other grain and poultry had little effect. A good deal of information could be obtained from these equations by calculating elasticities, factor biases, rates of return on research, etc. The major purpose of estimating this set of equations, however, is to provide parameters which will enable the calculation of π^t and the estimation of equation (4). The results of that analysis are presented in the next section.

Table 2. Estimates of Output Supply Functions for U.S. Agriculture, 42 states, 1978-1982.[a]

Explanatory Variables	Output Supply Equations					
	Small Grains	Other Grains	Hay	Other Crop	Poultry	Live-Stock
Normalized Prices						
Feed	.011	-.009	-.01	-.005	-.009	.003
	(1.89)	(1.01)	(2.58)	(1.36)	(1.70)	(2.05)
Fertilizer	.02	-.013	.001	-.0008	.002	.0005
	(4.24)	(4.78)	(.19)	(1.22)	(.20)	(.11)
Fuel	-.0006	-.0002	.0007	.00002	.135	-.177
	(1.17)	(.77)	(1.45)	(.29)	(.98)	(1.71)
Labor	-.02	-.009	.01	.0004	.155	.02
	(1.58)	(2.03)	(1.01)	(.38)	(1.96)	(.51)
Small Grains	.125	-.02	-.03	-.006	-.007	-.007
	(3.86)	(.88)	(1.20)	(1.02)	(.38)	(.72)
Other Grains	-.02	.03	-.02	-.002	.015	.002
	(.88)	(.70)	(1.51)	(.23)	(1.28)	(.42)
Hay	-.03	-.02	.08	.001	.003	-.03
	(1.20)	(1.51)	(2.28)	(.27)	(.12)	(2.82)
Other Crops	-.006	-.002	.0010	-.003	.0009	.001
	(1.02)	(.24)	(.27)	(.47)	(.21)	(.84)
Poultry	-.007	.02	-.003	.0009	1.79	-1.14
	(.38)	(1.28)	(.12)	(.21)	(-.30)	(.45)
Livestock	-.007	.002	-.03	.001	-1.14	2.55
	(.71)	(.42)	(2.82)	(.84)	(.44)	(1.11)
Other G.X.D_1	.009	.004	.001	-.007	-.002	-.0008
	(1.55)	(.45)	(.27)	(.86)	(.34)	(.54)
Other C.X.D_2	.02	-.03	-.01	-.007	-.0004	-.004
	(1.21)	(1.12)	(1.34)	(.32)	(.03)	(.85)
Fixed Factors						
Land	.001	-.03	-.02	.0005	-.004	.005
	(.18)	(2.98)	(3.77)	(.06)	(.74)	(3.17)
Rain	-2.48	13.42	-.78	7.61	2.74	.71
	(.71)	(2.23)	(.33)	(1.65)	(.98)	(.85)
Education	.003	.0004	-.007	-.01	-.02	.0005
	(.20)	(.02)	(.83)	(.70)	(1.47)	(.15)
Extension	.000001	6.45^{9}	-9.7	-.000003	4.15^{-7}	-2.17^{7}
	(1.37)	(.004)	(1.51)	(2.63)	(.54)	(.92)
Research[b]	4.81^{9}	1.97^{9}	-1.29^{-9}	-1.9^{-8}	3.43^{9}	-1.36^{-9}
	(1.44)	(.35)	(.56)	(4.57)	(1.26)	(1.53)
Capital	15.27	27.46	6.35	4.90	4.00	1.52
	(4.82)	(5.26)	(2.99)	(1.31)	(1.50)	(1.75)
Breeding Stock	-.37	-.29	3.16	.18	.005	.33
	(1.01)	(.61)	(13.07)	(.36)	(.01)	(3.55)
Other						
D_1	81.6	-3.16	-37.8	-31.35	6.77	3.82
	(3.32)	(.07)	(2.38)	(1.0)	(.35)	(.63)
D_2	-60.4	-61.23	3.85	113.7	-3.02	-3.00
	(1.99)	(1.17)	(.19)	(2.82)	(.12)	(.38)
Intercept	-170	29.62	-49.2	85.8	109.9	1.03
	(1.72)	(.17)	(.72)	(.70)	(1.41)	(.04)

[a] t-statistics in parenthesis.

[b] α coefficient on quadratic distributed lag.

Table 3. Estimates of Input Demand functions for U.S. Agriculture, 42 states, 1978-1982.[a]

Explanatory Variables	Input Demand Equations Feed	Fertilizer	Fuel	Labor
Normalized Prices				
Feed	-.012	-.003	-.0002	.0003
	(2.87)	(3.03)	(3.49)	(.69)
Fertilizer	-.0026	-.005	-.00006	.007
	(3.03)	(2.26)	(.35)	(1.50)
Fuel	-0002	-00006	-.36	-.002
	(3.49)	(.35)	(8.60)	(.77)
Labor	-.0009	.007	-.002	-.06
	(.67)	(1.50)	(.79)	(1.32)
Small Grains	-.011	0.02	.0006	-.02
	(1.89)	(4.24)	(1.17)	(1.58)
Other Grains	.009	.013	-.0002	-.009
	(1.01)	(4.78)	(.77)	(2.03)
Hay	.011	.001	.0007	-.01
	(2.58)	(.18)	(1.45)	(1.02)
Other Crops	.005	.0009	-.00002	-.0004
	(1.36)	(1.22)	(.29)	(.38)
Poultry	.009	.0015	-.136	-.155
	(1.70)	(.20)	(.97)	(1.96)
Livestock	-.003	-.0005	.177	-.02
	(2.06)	(.11)	(1.70)	(.51)
Other G.X.D_1	-.006	-.001	.00007	.002
	(1.65)	(1.50)	(1.31)	(1.41)
Other C.X.D_2	-.011	-.006	.0005	.01
	(.98)	(2.33)	(2.77)	(2.93)
Fixed Factors				
Land	-.003	.001	.000008	-.007
	(.62)	(1.29)	(.13)	(5.65)
Rain	-3.78	.41	.001	.71
	(1.61)	(.91)	(.04)	(1.05)
Education	-.005	.003	.00001	-.009
	(.58)	(.159)	(.10)	(3.14)
Extension	$-.045^{-7}$	-1.65^{7}	-1.96^{-8}	-2.66^{-8}
	(.72)	(1.31)	(2.04)	(.13)
Research[b]	1.00^{-9}	-1.89^{-9}	-2.99^{-11}	$-1.38-^{10}$
	(.46)	(4.19)	(.81)	(.18)
Capital	6.58	3.57	.54	7.36
	(3.11)	(8.01)	(15.24)	(10.15)
Breeding Stock	-.33	-.23	.01	.28
	(1.31)	(4.57)	(2.79)	(3.60)
Other				
D_1	-10.2	-1.21	.82	12.79
	(.64)	(.38)	(3.43)	(2.58)
D_2	29.68	6.74	-.71	-22.61
	(1.47)	(1.62)	(2.23)	(3.47)
Intercept	61.4	-4.68	2.26	.99
	(.97)	(.34)	(2.17)	(9.38)

[a] t-statistics in parenthesis.

[b] α coefficient on quadratic distributed lag.

Result of estimating the impact of agricultural research and extension

The difference between actual profits and profits under perfect information was calculated by substituting actual output prices for each state into the profit equation derived with the coefficients from the estimated supply and input demand equations. The results were are follows:

$$
\begin{array}{llllll}
(8)\quad \pi^{t} - \pi^{r} = 7877 & - \; 694.9Ex & - \; .018AER & + \; 14.36ED & - \; 1235313CV \\
\qquad\qquad\qquad (.13) & (-2.87) & (-.67) & (1.6) & (-.87)
\end{array}
$$

One would expect the coefficients on EX, AER, and ED to be negative because they are hypothesized to reduce allocative error. The coefficient on CV should be positive because allocative error should be directly related to price variability. Unfortunately ED and CV had unexpected but non-significant signs.[5] The only variable explaining reductions in allocative error is the marketing and management extension variable. The R^2 for the equation is .13. It appears that extension in the management and marketing area has had a greater effect than research in influencing allocative efficiency.

A Note of Caution

Preliminary results above indicate a possible procedure for measuring impacts of agricultural economics research. However, the results of the output supply and input demand estimation were mixed and the dependent variable in equation (8) is only as good as the profit function model used to generate it. That model was estimated previously with only one cross-section and with outputs aggregate into two output indexes (Norton and Norris). The current effort is an improvement over that earlier work because the additional cross section adds needed variability and because aggregation bias is reduced. Aggregation bias occurs because price per pound of commodity often bears an inverse relationship to pounds per acre and per farm when one adds several commodities.

Nonetheless, disaggregation increases corner solution problems (bias due to zero values for some commodities). This problem requires the use of dummy variables or some other procedure. Additional testing also is needed to ascertain the most appropriate groupings of commodities. Another problem that may be creating difficulties in the estimation is simultaneity. It is often said that one of the advantages of the profit function (as compared to the primal) approach is that is that prices are exogenous and therefore simultaneity is not a problem. The use of aggregate data may mean, however, that price is not exogenous.

Additional study is needed on the proper specification (length and shape of lag) of the research and extension variables. Work is currently underway on this topic. Furthermore, policy variables as suggested by Huffman and Evenson are also needed. The profit function model above assumes risk neutrality. If most decision makers are risk averse and attach a cost to uncertainty, the model underestimates the value of AER. Refinement along the lines suggested by Antonovitz and Roe (1986) should be considered.

Equation (8) needs refinements to account for spillovers from agricultural economics research. Finally welfare impacts at the market level should be considered to allow for the distribution of benefits between producers and consumers. In summary, there are many potential pitfalls and improvements needed in the procedure described above for valuing marketing and management research.

THOUGHTS ON EMPIRICAL PROCEDURES FOR ESTIMATING THE BENEFITS OF INSTITUTIONAL AND DISCIPLINARY INFORMATION

A close look at Table 1 illustrates Ruttan's point that much of agricultural economics research is policy or institutionally related. How might one quantitatively measure the impacts of research designed to improve institutions? The net social benefits approach is likely to be the most useful because it allows for calculations of both efficiency and distributional (equity) impacts. Some types of institutional changes (e.g. pricing policies, credit policies) can affect the adoption of technologies. A multi-stage procedure in which the effects of research on affecting the design of particular policies are first assessed, followed by statistical assessment of the impacts of those policies on the timing and magnitude of technology adoption, followed by an evaluation of the economic impacts of those technologies using a net social surplus approach is one possibility. This example illustrates, however, a major difficulty in evaluating SSR or AER aimed at institutional change: it is difficult to conduct an evaluation for a large set of research activities. One of the useful aspects of previous research evaluation work has been the ability of economists to estimate rates of return for large aggregates of research activities. Unless assessments are made for large aggregates like "management and marketing," or "institutional research," or "AER disciplinary" research, the credibility of any rates of return generated is reduced because policy makers can suggest that only successful cases were selected for evaluation. Most observers are perceptive enough to realize that high rates of return to research are generated by the average of some very very successful efforts and some very dry holes. Nonetheless, with a small amount of ingenuity economists should be able to make some calculations for institutional research with some, albeit small, level of aggregation. Given the severity of many rural development problems today and the declining level of support mentioned earlier, the rural development area might be a good place to start.

CONCLUSIONS

Attempts to measure the value of agricultural economics research by agricultural economists may appear to be somewhat self-serving. There is increasing evidence, however, that social science research in general and agricultural economics research in particular may be bearing a disproportionate share of recent tightening of research budgets especially at the federal level. Economic theory provides some guidance for conceptualizing AER impacts. Measurement procedures are available, especially for research which provides management or price information. Evaluation of research which provides institutional or disciplinary information will likely be more difficult but some attempt should be made, at least for the former. One has to be more pessimistic about the potential for evaluating disciplinary or basic SSR. We have little success with such evaluations even for research which eventually led to new technologies.

FOOTNOTES

[1] Bullock; Bullock, Ray, and Thabet; Thabet, Ray and Bullock; and Freebairn (1976, a,b) consider the implications of decomposing the supply response function into a planned supply curve and a current period supply curve. The planned supply curve is a function of producers' forecast price with the forecast price determining the position of the current period supply curve. The latter is more inelastic due to the difficulty of making short run production adjustments.

[2] Muth's approach to defining a rational expectation was in terms of conditions on just the mean value of a distribution. An alternative definition of a rational expectation of a variable is that the actual value and the anticipated value of the variable have the same probability distribution.

[3] The decision theory approach can be summarized as follows: A variety of actions are open to the decision maker, $a_1, a_2 \ldots a_m$. Several states of nature $S_1, S_2 \ldots S_n$ are also possible and the decision maker has some knowledge of the likelihood (prior probability) of such state occurring, $P(S_i)$. With a given amount of knowledge, the decision maker will choose the action a_i which maximized his expected utility. The expected utility of the jth action is $\Sigma_i u(aj|S_i)P(S_i)$. Now if additional information, $Z_1, Z_2 \ldots Z_m$ becomes available to the decision maker and he has knowledge of the probability of the information coming true, i.e., $(Z_j|S_i)$. By Bayes Theorem:

$$P(S_i|Z_j) = \frac{P(S_i)P(Z_j|S_i)}{\sum_i P(S_i)P(Z_j|S_i)}$$

The revised expected value of aj is now $\sum_j u(ajSj)P(S_i Z_j)$. The value of additional information is the difference between the maximum utility with the without the information and this can be compared with the cost of obtaining the information.

[4] Small grains = wheat, barley, oats, rice

Other major grains and potatoes = corn, sorghum, soybeans, peanuts, potatoes
Other crops = sunflowers, sugar beets, sugar cane, cotton, tobacco, peaches, apples, grapes, oranges, grapefruit, vegetables.
Poultry = broilers, chickens, turkey, eggs.
Other Livestock = cattle, hogs, sheep

[5] The number in parenthesis for equation (8) are t tests.

REFERENCES

Antonovitz, F. and T. Roe, "Measure of the Value of Information for the Competitive Firm Under Price Uncertainty," Staff Paper P82-28, Dept. of Agr. and Applied Economics, University of Minnesota, 1982.

Antonovitz, F. and T. Roe, "A Producer's Willingness to Pay for Information under Price Uncertainty: Theory and Application," Southern Economic Journal, 52 (October 1985): 382-391.

Antonovitz, F. and T. Roe, "A Theoretical and Empirical Approach to the Value of Information in Risk, Markets," Rev. of Econ. and Stat., 68(1986): 105-114.

Bonnen, J.T., "Historical Sources of U.S. Agricultural Productivity: Implications for R & D Policy and Social Science Research," Amer. J. Agr. Econ., 65(1983): 958-966.

Bradford, D.F., and H.H. Kelegian, "The Value of Crop Forecasting with Bayesian Speculation: Theory and Empirical Results," Bell J. Econ., 9(1978): 123-144.

Bradford, D.F., and H.H. Kelegian, "The Value of Crop Forecasting in a Market System: Some Theoretical Issues," Rev. of Econ Studies, 44(1977): 519-531.

Bullock, J.B., "Social Cost Caused in Agricultural Production Forecasts," American J. Agr. Econ., 58(1976):76-80.

Cyert, R.M, and M.H. DeGroot, "Rational Expectations and Bayesian Analysis," J. Pol. Econ., 82(1974): 521-536.

Eidman, V.R., G.W. Dean, and H.O. Carter, "An Application of Statistical Decision Theory to Commercial Turkey Production," J. Farm Econ., 49(1967): 852-868.

Freebairn, J.W., "The Value of Distribution of the Benefits of Commodity Price Outlook Information," Economic Record, 52(1976a): 199-212.

Freebairn, J.W., "Welfare Implications of More Accurate National Forecast Prices," Aust. J. Agr. Econ., 20(1976b): 92:102.

Hayami, Y. and W. Peterson, "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Commodities," Amer. Econ. Rev., 62(1972):119-130.

Hirschleifer, J., "Where are We in the Theory of Information?," Amer.Econ. Rev., 63(1973): 31-39.

Huffman, W.E. and R.E. Evenson, "Supply and Demand Functions for Multi-product U.S. Cash Grain Farms: Biases Caused by Research and Other Policies, 1948-1974, Staff Paper no. 155, Department of Economics, Iowa State University, April, 1986.

Muth, J.F., "Rational Expectations and the Theory of Price Movements," Econometrica, 29(1961):315-335.

Norton, G.W., and P.E. Norris, "Evaluating Agricultural Economics Research"; paper presented at the American Agricultural Economics Association annual meetings, West Lafayette, Indiana, August, 1983.

Norton, G.W., and G.E. Schuh, "Evaluating Returns to Social Science Research: Issues and Possible Methods," in G.W. Norton et al. ed., Evaluation of Agricultural Research, Misc. Pub. 8-1981, Minnesota Agr. Exp. Station, April, 1981.

Roe, T. and D. Nygaard, Wheat, Allocation Error and Risk, Northern Tunisia, University of Minnesota Economics Development Center Bulletin V, March, 1980.

Ruttan, V.W., "Induced Institutional Change," Chapter 12 in Induced Innovation, ed. Hans P. Binswanger and Vernon W. Ruttan, Baltimore, Johns Hopkins University Press, 1978.

Ruttan, V.W., "Social Science Knowledge and Institutional Challenge," Amer. J. Agr. Econ. 66(1984): 549-559.

Schultz, T.W., "The Value of the Ability to Deal with Disequilibria," J. Econ. Lit., 13(1975): 827-846.

Thabet, B., D.E. Ray, and J.B. Bullock, "On Extending the Conceptual Basis for Estimating the Information Value of USDA Production and Price Reports,"; paper presented at the Southern Agricultural Economics Association meetings, Atlanta, Georgia, Feb. 7, 1983.

U.S. Dept. of Agriculture, (a) A National Program of Research for Agriculture, Washington, D.C., 1966.

U.S. Dept. of Agriculture, (b) Agricultural Prices Annual Summary (1977, 1978, 1981, 1982), Washington, D.C., 1979, 1980, 1983, 1984.

U.S. Dept. of Agriculture, (c) Agricultural Statistics, (1978, 1982), Washington, D.C., 1979, 1983.

U.S. Dept. of Agriculture, (d) Economic Indicators of the Farm Sector: State Income and Balance Sheet Statistics, 1980 ERS Statistical Bulletin 678, Washington, D.C., 1981.

U.S. Dept. of Agriculture, (e) Inventory of Agricultural Research, SEA, Vol. I and II (various issues).

U.S. Dept. of Commerce, Bureau of the Census, 1978 Census of Agriculture, Washington, D.C., 1980, 1984.

Weiss, M.D., M.W. Whittington, and L.D. Teigen, Weather in U.S. Agriculture: Monthly Temperature and Precipitations by State and Farm Production Region, 1950-1984, USDA, ERS, Stat. Bulletin, No. 737, Washington, D.C., Dec. 1985.

ECONOMIC EVALUATION OF POSTHARVEST (MARKETING) RESEARCH: CONCEPTUAL AND EMPIRICAL ISSUES

Max R. Langham and Joseph C. Purcell*

Economic returns to food and agricultural research have been of long standing interest to the U.S. Congress, state legislatures, and other appropriating agencies, and USDA and Land Grant College administrators. However, attempts to quantify economic returns to agriculture (ag)-food-kindred[1] research are of relatively recent vintage (reviews of this research are available in Ruttan and Norton and Davis). Moreover, most of the effort to quantify returns to ag-food research has been directed to production related research. This focus is understandable in that most of the government appropriated funds have been spent on primary production problems - specifically, crop and animal production. Genetics and/or breeding, nutrition, and protection are the areas of central focus of most of the primary production oriented research.

To date, very little of the effort to evaluate returns to ag-food research has been directed to the postharvest or marketing sector of the ag-food-kindred system. This too is understandable in that only a small proportion of the publicly appropriated funds are devoted to marketing research.

However, as the 1980s roll on, increasing interest is being focused on the preservation, fabrication and distribution of foods. In addition, there is an apparent increasing awareness of exchange, equity, policy, competitiveness, international trade, and rural decay issues, to name a few. The financial crisis in U.S. agriculture during the 1980s verifies that many of the researchable issues confronting the U.S. ag-food system lie before and beyond farm production.

Nevertheless, research directed to the marketing, trade, policy and related issues is difficult to formulate and execute. And it is even more difficult to evaluate and quantify the returns to or determine the value of marketing oriented research.

Freebairn, Davis, and Edwards have demonstrated that innovation in one stage of a multistage production system provides benefits throughout the system. Using some rather strong assumptions to simplify their argument, they find that the distribution of benefits is the same regardless of where cost reductions occur in the system. And their conclusion held when they relaxed the assumption of competitive behavior, although the degree of competitiveness did alter the proportion of the benefits passed on to other segments of the system.

Freebairn et. al. further conjectured that, "There is little reason to argue that research opportunities are greater or research costs are less at the farm level than at the marketing and input levels." They concluded, "...that the choice of agricultural research projects should recognize opportunities at all levels in the system." To the extent that there is less competition and substantially larger firms in the marketing channels than on farms, incentives for public investments in marketing research are weakened. However, larger sizes of firms in the marketing stages provide incentives for private investments. This is especially true where firms can capture profits through product development and differentiation.

There may be less pressure for publicly supported research from firms in some stages of the marketing system because the knowledge created would be in the public domain and more freely available. However, the ability of a firm to capture benefits from publicly supported research is becoming increasingly possible because of institutional innovations (e.g. university research parks) which encourage joint public-private research efforts.

---

* Max Langham is Professor of Food and Resource Economics, University of Florida, and Joe Purcell is Professor of Agricultural Economics, Georgia Experiment Station, University of Georgia. Authors are listed alphabetically and no seniority in authorship is implied.

To the extent that incentives for investment in marketing research have led to underinvestments in research beyond the farm gate, higher marginal rates of return to research in the nonfarm than in the farm production stages of the food chain are expected.[2]

ECONOMIC PROGRESS AND RESEARCH

Joseph Shumpeter observed long ago that economic progress (rising affluence) stems from doing the old things better and spawning new goods and services. Thus, economic progress and research (advancement of knowledge) have slept together for a long time.

Research contributes to economic progress in three basic ways by permitting a society to:

1) save resources to use in the production of other goods and services,
2) increase output that adds to the stock of wealth contributing to rising real incomes per capita. (Wealth is defined as those things - goods and services - that provide people with sustenance, comfort, convenience and pleasure), and
3) helps to mitigate inflationary pressures by increasing productivity of labor, management, and resources.

Although there is little doubt that research provides substantial benefits to the greater society, there is no clear pathway to accurately quantify the benefits or value of research.

Food needs of the highly developed nations are near satiety and problems of food surpluses are more prevalent in such countries than are problems of food shortages. This situation does not preclude the fact that agricultural research can still lead to significant net benefits to such countries through knowledge of how to use resources more efficiently and provide additional services to consumers. Little information is available on the quantities and qualities of goods and services created via resource savings in the food system. Although basic food needs may be fully satisfied, our human wants never are.

IMPORTANCE OF MARKETING TO A COMMERCIAL FOOD SYSTEM

Marketing was relatively unimportant in the subsistence type agriculture-food system that dominated our U.S. society until well into the 20th Century. Only the preservation of food, in addition to production, was considered important. Moreover, research effort was devoted to making relatively small geographic areas and even households nearly self-sufficient in foodstuffs.

However, as agricultural production technology evolved, the U.S. ag-food-kindred system became more commercialized and industrialized. The bulk of the population (consumers) and agricultural production became progressively separated. In fact, evolving technologies could not have been implemented without a simultaneous commercialization of the food system. A market and cash in-flow are required to implement most farm production technologies.

Agricultural production technologies that evolved mostly during the mid-two quarters of the 20th Century vastly enhanced labor efficiency on farms and were of a labor displacing character. Labor requirements on the farm declined drastically; but labor requirements increased in the prefarm sector to provide industrial inputs for farms, and in the post farm sector, to assemble, fabricate, and distribute food to a rapidly growing urban population. Thus, the importance of marketing to the implementation of on-farm production technology cannot be over emphasized.

The relative importance of the postharvest or marketing component of the ag-food-kindred system is contained in a study conducted by USDA's ERS (Harrington, et. al. 1986). This study revealed that the U.S. ag-food-kindred system accounted for $648 billion GNP and 21.3 million employment in 1984. The pre-farm sector accounted for 2 million employed and nearly $64 billion GNP. The farm sector accounted for 2.7 million employment and nearly $65 billion GNP. The relative importance of the post farm (marketing) sector is emphasized by this sector accounting for 16.6 million employment and nearly $520 billion GNP. On a per person employed basis, the pre-farm sector accounted for $31,900 GNP, the farm sector $23,963 GNP, and the post farm sector $31,295 GNP. The proportion of total ag-food-kindred GNP attributed to the three sectors was pre-farm 9.8%, farm 10.0%, and post farm 80.2%.

APPROACHES TO EVALUATION OF RESEARCH

Two basic ex post evaluation approaches have been employed in an effort to quantify or place a value on research:

1) the production function approach (or, its more modern counterparts, the indirect-profit and indirect-cost function approaches), and
2) the estimation of economic surplus.

Both these approaches have sound theoretical underpinning and are conceptually linked, but both are subject to near insurmountable empirical estimation problems. Norton and Davis (pp.685-92) provide a review of studies using these two approaches.

The production (or indirect profit) function approach attempts to measure the rate of change of production (profits) attributed to research expenditures. The objective is to determine how research affects value added in production, and value added is the source of producers' surplus. This approach is haunted by the problems of collinearity among factors that contribute to production which stems in part from profit maximizing behavior. The production function approach is also subject to problems of input and output variables being simultaneously determined which can result in least-squares bias. In addition to the knowledge gained through research, technical innovation requires capital expenditures for machinery and specialized equipment, seeds, fertilizers, pesticides, growth stimulants and the like. In fact, the benefits to welfare result from both the new knowledge and the new inputs which are necessary to carry the knowledge to the production process. To the extent that the benefits represent a joint product, the knowledge and the new inputs may be so wed that divorce is near impossible in the empirical estimation of the source of benefits.

There are two conceptual problems in attempting to measure returns to marketing research from the production side alone. First, aggregate industry behavior affects product prices so one cannot consider output prices and perhaps some input prices as exogenously determined. This situation creates problems for both the production function and the indirect-profit-function approach. Second, estimating from the production side ignores any effects on the consumer demand side of the market and marketing research which can, as we argue later, function as a quasi-demand shifter.

The economic surplus approach is based on the theoretical concepts of a supply and a demand function. In a competitive environment and for a given product, the intersection of these two functions establishes equilibrium price and quantity and determines economic surplus which can be partitioned into consumers' and producers' surplus.

A partial market equilibrium model which incorporates demand and supply functions and market clearing conditions provides an empirically operational approach to measuring returns to market research. Another economic surplus approach on the producers' side of the market is to measure value added at each production activity along the multimarket chain and attempt to relate the value added to research expenditures. This approach is demanding in terms of accounting data and effort. This direct value-added approach would also need to be augmented to include welfare gains from final consumption to obtain a measure of total benefits from research.

These two economic surplus approaches are useful for different purposes. The partial market equilibrium approach represents a gross abstraction of reality and masks complex microeconomic activities. As a consequence, the results from such an approach would be most useful for estimating aggregate rates of return on investments in research in a given sector of the food-and-fiber portion of our economy. The approach can also provide insights into the distribution of net benefits from research activities. Such measures would be of benefit for broad policy and allocative decisions at the interindustry level but would be of less use at intraindustry levels.

On the other hand, the direct value-added approach could conceptually provide insights into successive economic activities at any level in the system. And, since value added can be aggregated without bias, the direct value-added approach provides a way of determining benefits to society by economic activities by states or other regional delineations. For examples, we do know (Harrington, et. al. 1986) that opportunities for direct labor saving in the food-fiber-kindred marketing system is more than five times that in primary agriculture and nearly four times that upstream from the farm gate. We also, know that the value added in the postharvest sector is about eight times the value added in the farm sector.

CONCEPTUAL ISSUES

Of the many conceptual issues involved in attempting to measure returns to research beyond the farm production level, two seem most critical - particularly with reference to the partial market equilibrium approach. Markets by their very nature vertically integrate activities from factors used in farm production to consumers. Also, the economic activities along this multimarket chain are each capable of generating surpluses to society. The partitioning of producers' and consumers' surplus to particular activities is a conceptual puzzle if one is to identify the distributional effects of marketing research. We will refer to this problem as that of "partitioning surplus".

A second issue concerns how research shifts structural parameters to generate surplus. In measuring returns to purely production research, it seem fairly clear that research shifts the cost structure and hence the supply side of the market. However, marketing research can shift the demand for a product. This capability creates another puzzle which we refer to as "supply and demand effects."

Partitioning Surplus

In a partial equilibrium framework, the work by Just and Hueth (p.952) indicates that if one estimates ordinary supply and demand functions, the surplus obtained is for consumers and producers in that market only. However, if surplus is based on a general equilibrium model (i.e. prices in other industries in the multimarket chain are not fixed but left free to adjust), then price induced changes in welfare are general and estimates of changes in surplus will include that for consumers and producers at all levels in the multimarket, vertically-integrated chain.

The work of Just and Hueth is helpful in clarifying the conceptual issue of partitioning surplus. Whether one can partition producers' surplus by markets depends critically on whether one can empirically obtain partial equilibrium estimates (directly or indirectly).

This partitioning problem does not create a conceptual or empirical problem if value added is estimated from accounts for each industry in the marketing process. However, the task of estimating value added in this manner is very demanding in terms of both data and effort for even one production period. To estimate value added by years which would be required to estimate the effect on value added as a consequence of changes in research investments is a task of monumental proportions.

Supply and Demand Effects

In addition to the objective of increasing technical and economic efficiency in production activities, marketing research is often directed toward objectives of increasing the demand for a product. An example is advertising research directed toward obtaining a maximum increase in demand for a given outlay for advertising and promotional activities.

To complicate matters further, changing consumer tastes and preferences are sometimes a recognized objective in research directed primarily toward farm production processes. An example is provided by tomato breeding research and development activities designed to improve the retail shelf quality and appearance of the product. This research as been coupled with educational programs to instruct consumers on how best to ripen the tomatoes in the home so as to enhance color and flavor.

Tastes and preferences of consumers may also be a factor in the rate of adoption of a new technology and hence will affect the lag in response to the technology. Perhaps the clearest example here is provided by preferences for traditional varieties of rice and corn over high yielding hybrid varieties in societies where rice and corn are basic food crops.

Some will argue that the above examples simply represent changes in product quality and that market activities and research are simply being directed toward supplying the qualities demanded and hence that the benefits still derive from the supply side of the market. Undoubtedly marketing activities and research have developed to a level of sophistication to permit the recognition and exploitation of consumers' wants. However, from an empirical point of view where changes in product quality are very difficult to quantify, it is more tractable to treat these "quality aspects" as being reflected in the market as shifts in the demand for a homogeneous product. Perhaps such shifts in demand should be identified with a new term, e.g. quasi-demand shifts.

EMPIRICAL ISSUES FROM CURRENT STUDIES

This section focuses on the earlier discussion of conceptual issues. We will also use studies in progress in Florida and Georgia to focus our remarks.

The first attempt to measure the returns to postharvest research in Florida (Stranahan, Shonkwiler and Stranahan) recognized only the processing of frozen concentrated orange juice (FCOJ). The research treated FCOJ as a homogeneous product and attempted to measure the extent to which research expenditures shifted processing cost. The approach represented a partial look at the producer surplus side of the issue. Product price did not enter their model so their estimate measured the rate of change in cost, given the quantities produced, as a consequence of changes in research expenditures. Consumer benefits were not included and one would expect that the authors underestimated the benefits to research. Also, by ignoring the demand side, the model did not capture the effects of advertising and promotional research and the effects of changes in product quality.

To obtain more accurate estimates of the returns to research beyond the grove level, Suzanne H. Hinckley (a Ph.D. candidate) is developing a partial equilibrium model of the market for oranges and grapefruit. The model includes three production regions (Florida, California-Arizona, and Brazil) supplying the U.S. market. James S. Ansoanuur, another Ph.D. candidate at the University of Florida, is studying the winter tomato market. He is using a two production region (Florida and Mexico) model serving the U.S. These studies are similar in their methodology. The second model is somewhat simpler to specify and is utilized here to discuss the conceptual issues previously identified.

The tomato model has nine equations. The model encompasses three markets. A market at the packing house (shipping point) level, in Florida, a market in Nogales (shipping point) in Mexico, and the U.S. retail market for tomatoes. In each market there are ordinary demand and supply equations and market clearing conditions. The model is being estimated with time series over a 23 year period, 1962 to 1984.

Two variables representing research expenditures are included in the model. Observations on these variables are being developed from CRIS (Cooperative Research Information System) and Pre-CRIS data on research expenditures. In essence total research expenditures are being partitioned into a dichotomy, production and marketing research. The expenditures data also include known private as well as public research expenditures.

Returning to the conceptual issue of partitioning surplus, the sectors involved in the case studies roughly satisfy the small-sector economic industry assumptions of Just and Hueth. The surplus measures - utilizing supply and demand equations at the U.S. retail market level - provide an estimate of welfare benefits of the industry to society. The partial equilibrium surplus estimates at the Florida packing houses and the Nogales shipping point provide estimates of the benefits to producers and input suppliers. If we are successful in our partial equilibrium analyses, the difference between the U.S. and the shipping point surpluses should provide estimates of the surplus accruing to production activities between the shipping points and retail levels.

The work by Just and Hueth indicates that multicollinearity problems can thwart attempts to obtain partial equilibrium estimates. Indeed, if we are only able to obtain efficient estimates of linear combination of price variables, what we hoped to be partial equilibrium results could be general equilibrium measures. If this comes to pass, the estimates of surpluses at the shipping points will include all welfare benefits. The bottom line is that we cannot be certain at this time as to whether we will be able to obtain useful estimates of benefits to the four groups - producers and input suppliers in the U.S., producers and input suppliers in Mexico, handlers (agents between shipping points and consumers) in the U.S., and consumers.

By deriving surplus estimates analytically from the model, one can obtain equations of the general form[3]:

1) $PS_{FL} = f_1(RD_1, RD_2, W)$,
2) $PS_{MX} = f_2(RD_1, RD_2, X)$,
3) $PS_{USM} = f_3(RD_1, RD_2, Y)$, and
4) $CS_{US} = f_4(RD_1, RD_2, Z)$ where

PS_{FL} is producers surplus accruing to producers and suppliers of inputs to producers for tomato production in Florida,
PS_{MX} is producers surplus accruing to producers and input suppliers for tomato production in Mexico,
PS_{USM} is producers surplus accruing to handlers in the marketing of tomatoes in the U.S.,
CS_{US} is consumers surplus accruing to consumers of fresh winter tomatoes in the U.S.,
RD_1 is a measure of real R & D expenditures on farm level production technology, appropriately lagged,
RD_2 is a measure of real postharvest research expenditures on fresh winter tomatoes appropriately lagged, and
W,X,Y, and Z are vectors of other variables specified to be associated with the respective markets generating the surplus.

These equations provide a basis for estimating rates of change in net benefits accruing to the four groups as a consequence of a change in expenditures for either production or marketing research. We also hope to be able to obtain estimates of spillover effects of U.S. research expenditures from the surplus accruing to producers and input suppliers in Mexico.

The conceptual issues discussed under the heading "Supply and Demand Effects" is recognized but the effects are somewhat confounded in the model. In the definition of consumers' surplus (equation 4), one could hold supply fixed at the means of the variables and look at the partial effects of both marketing and production research expenditures on surplus when the research is permitted to act only as a quasi-demand shifter. These rates of change could be interpreted as benefits to consumers for research leading to "quality" improvements.

The fresh winter tomato model is based on the assumption of a competitive environment in the markets described by the model. John VanSickle who is quite familiar with the industry has indicated that this assumption is reasonable. However, specification errors would exist if noncompetitive behavior were present in the markets, and there would be bias in the estimation of total surplus and hence the components of surplus as a function of research expenditures.

A more general specification could be provided by defining the supply equation as the result of a horizontal summation of marginal cost functions and P_d and P_s as the demand price and the ordinate of the resulting marginal cost function at the quantity consumed, respectively. Then, $P_d - P_s$ would define marginal (and average) monopoly profits at the equilibrium quantity demanded. And, $P_d - P_s \equiv 0$ at all competitive equilibria. Since monopoly profits (and hence P_s) are unobservable, additional information would be required to estimate this more general model[4].

There are many other limitations to the empirical quantification of the effects of research investments on societal welfare. There is the age-old problem that analysis based on past experiences with historical data only documents the past. We have faith that the past will reveal the future and hence what we have learned will be useful for making decisions for the future. But, new knowledge is a lumpy variable and new discoveries are by their very nature unique and projection is subject to these limitations. These limitations exist regardless of the method of evaluation used as long as it is based on data that have been passively generated by the economic system.

An econometric model of a market is also fraught with well known measurement problems which have essentially been ignored in this discussion. Identification problems which encompass specification problems are always present and the researcher can never be quite sure that he or she has captured the key elements of the complex interrelationships of interest. The lagged effects of evolving knowledge is also a knotty problem. As a community of scholars, we know something of most of these problems from past research efforts and will learn more as we grapple with measurement efforts. In whatever approach to measurement we take, two questions persist. What effects are we attempting to measure? And, will our methods and data permit us to measure these effects?

CONCLUDING REMARKS

Knowledge created by research and its distribution via educational processes, is a part of the capital stock that enhances the creation and distribution of wealth. The cost of research and education, at least in the public sector, is relatively easy to reckon, but defensible methods of estimating benefits are more intractable.

Marketing research, education, entrepreneurship, management-labor, capital investments in buildings and equipment, government investments in transportation systems, grades and standards, sanitary inspection, a viable monetary exchange system, computerized information systems, etc., all combine to make a wide variety of wholesome foods and kindred products readily available to most consumers, with modest buying power, most of the time. All these factors that contribute to a highly efficient food system require both private and public investment.

From an empirical estimation perspective, it is most difficult to segregate the net benefits of all the necessary investments in the food-fiber-kindred system. Private investments will be made on a continuing basis only if the returns on the investments cover opportunity costs. However, there is nearly always uncertainty surrounding investment decisions. In a monetary exchange system this includes investment of people time and talents, and monetary investments.

Basically, the greater society benefits from improved labor efficiency - both hands and brains - and the spawning of new goods and services. Certain labor efficiencies can be determined rather precisely for selected innovations -- the dolly and fork-lift for example. Even here, however, the investment becomes rather fuzzy. Innovative ideas stem from people who have acquired knowledge. The creation and diffusion of knowledge required prior investment in research and education. Investment in factories to produce the dollies and fork-lifts was also necessary.

Complex interrelationships and sequences provide little insight into wise investment decisions at the margin for administrators, legislators, and actors in the system. However, there are some things that can be reckoned satisfactorily in a monetary exchange system including direct labor (hands and brains) requirements, and value added by successive economic activities by states or other geographic delineations.

The most realistic approaches to the evaluation of marketing research is that of services created (value added), and resources saved (with emphasis on people time saved). Productivity and efficiency are enhanced via knowledge creation and technical innovation. Concurrently, new goods and services are created via resources thus saved, and further advancements in knowledge and technical innovation. Advancing knowledge and technical innovation pervade the organization, structure, management and exchange processes of the food-fiber-kindred system.

The spawning of new goods and services can be realized with resources saved in producing and delivering food - the first order of business of every economy. And, new knowledge is the great facilitator of this process. As a consequence, we assert that benefits derived from research have generally been underestimated by methods employed to date. We recognize, however, the inherent dangers from agricultural scientists measuring the productivity of agricultural science and we should encourage strong professional critique - when possible from nonagriculturalists.

FOOTNOTES

[1] Ag-food-kindred classification covers products such as cotton, wool, tobacco, industrial alcohol, and starches as well as food. Wood and wood products have, at times, also been included.

[2] However, returns to postharvest research and development activities in frozen concentrated orange juice (FCOJ) subsector of the citrus industry have been estimated at 57% (Stranahan, Shonkwiler and Stranahan) which is in the range of returns estimated for agricultural production technologies (Ruttan).

[3] Greater detail regarding the development of these equations may be found in the proposal by Ansoanuur.

[4] One might, for example, approximate $P_d - P_s$ with a function $P_s = P_d - k\,Q$ where k is a constant equal to or greater than zero and Q is the observed quantity consumed. One could estimate the model for different values of k and then choose the value k* which minimized the estimated generalized variance for the model.

REFERENCES

Anderson, James E. "A Note on Welfare Surpluses and Gains From Trade in General Equilibrium." The American Economic Review, 64(September 1974):758-62.

Ansoanuur, James S. "Evaluating Returns to Postharvest Research and Development in the Fresh Winter Tomato Industry", a dissertation proposal, University of Florida, 1986.

Freebairn, J.S., J.S. Davis, and G.W. Edwards. "Distribution of Research Gains in Multistage Production Systems." American Journal of Agricultural Economics, 64(February 1982):39-46.

Harrington, David, Gerald Schulter and Patrick O'Brien. 1986. "Agriculture's Links to the National Economy - Income and Employment." USDA, ERS. Ag Information Bulletin #504, October.

Just, Richard E. and Darrell L. Hueth. "Welfare Measures in a Multimarket Framework." The American Economic Review, 69(December 1979):947-54.

Norton, George W. and Jeffrey S. Davis. "Evaluating Returns to Agricultural Research: A Review." American Journal of Agricultural Economics, 63(November 1981):685-99.

Ruttan, Vernon W., Agricultural Research Policy. Minneapolis, University of Minnesota Press, 1982.

Shonkwiler, J.S. and H.A. Stranahan. Modeling Technical Change in the Frozen Concentrated Orange Juice Processing Industry. Bulletin 863. Agricultural Experiment Stations, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, September 1986.

Shumpeter, Joseph. The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest and the Business Cycle. Translated from the German by Redvers Opie. Cambridge: Harvard University Press, 1961.

Stranahan, Harriet A. "Evaluating the Returns to Postharvest Research in the Florida Citrus Processing Subsector." M.S. thesis, University of Florida, 1984.

FUTURE RESEARCH EVALUATION NEEDS

Vernon W. Ruttan*

It is useful to remind ourselves that we are now in the third generation of agricultural research assessment studies. During the first generation our efforts were devoted to measuring the shifts in production functions and supply curves. In this early work by Schultz, Solow, Ruttan, Griliches and Peterson, shifts in the production function or the supply curve were identified with technical change. During the second generation, efforts were made to partition productivity growth among several non-conventional factors - grouped under three broad categories - investments in human capital, advances in technology, and improvement in infrastructure. We are now well into a set of third generation studies in which analysts are making more sophisticated attempts to understand how technology influences production (e.g., the Blakeslee paper on maintenance vs. productivity enhancing research), advances in the methodology that can be used to probe the sources of change in production and productivity (the papers by Geoff Edwards and by Huffman and Evenson), and application in neglected sectors (forestry, post harvest, and social science). I will, in my summary, make comments on several areas where additional effort is needed.

Post harvest technology

I agree with Max Langham and Joe Purcell that we need to develop a much better understanding of the sources and impact of technical change in the post harvest area.

- We need the micro studies that will enable us to understand the extent to which we are underestimating output, and output growth due to improvements in quality. We also need to understand the sources and value of the utility generated by market information - including advertising. Neither of the two items are at the top of my agenda.

- We need to understand the decline in competitiveness of the U.S. food processing industry. If we abstract from the cycle in agricultural exports of the last decade and a half and compare 1970 and 1986 we see agricultural commodity exports rising as a share of agricultural production and processed food imports rising as a percent of the value of processed food.

What is going on here? There are some scraps of information that do not quite add up to a coherent picture.

- The food industry devotes a smaller share of its sales to R&D than almost any other sector (0.5% compared to 2.0 for all manufacturing and 5-10% for high technology including seed and animal drugs).

- Most of the R&D in the food industry is on the product and marketing side and very little is process technology. Process technology is done by equipment suppliers.

- An increasing share of the process technology employed in the food industry is developed abroad - particularly in Europe (dairy in Denmark and Sweden, etc). And it is first employed in Europe to produce high value added products - another name for high quality.

- I see an industry that has devoted its creativity to promotion and has neglected process and product technology in favor of market research and promotion and is losing market share as a result (hypothesis).

---

* Vernon W. Ruttan is Regents Professor, Department of Agricultural and Applied Economics, University of Minnesota.

Production research

I would like to argue that we can no longer justify expansion of the agricultural research budget - or even the present level of research - on the basis of benefit to the American consumer. Saving part of the 10% of final product value contributed by the farm sector or even the 20% contributed by the farm or input sectors simply is no longer very important to the U.S. consumer.

If we are to justify expanded production and input saving research, it must by justified in terms of maintaining our competitive position in world agriculture. The traditional manufacturing sector generated over $100 billion in trade deficit in 1986. The high technology industrial sector will show a net trade deficit when the figures are in. Agriculture will generate a $5-10 billion surplus in spite of very substantial declines from the early 1980's. The major commodity producing sectors of agriculture are among the few world class industries left in the U.S. They will remain world class only if productivity growth is sufficient to enhance our competitive position. The effect of getting the dollar "right" will show a positive effect on trade, but this is a once and for all effect. Productivity growth, if achieved, is continuous.

There is one qualification to this view. The gains from trade will depend on the kind of agricultural policy we have. If new legislation should push us in the direction of an EEC type policy - with high domestic prices and subsidized exports - the potential gains from agricultural research will be viewed by OMB, the Treasury and the Congress as a burden - a cost - rather than a benefit.

Private sector agricultural research

It is time to get a better handle on the gains from private sector agricultural research. We are continuing to employ two sloppy assumptions that do not have the research base to support them. One is that the gains from private sector research are realized entirely by the private sector firm doing the research and hence can be captured by the price of the inputs purchased from the input industry. The second is that the social rate of return to private research must be about equal to public sector and we simply discount the estimated social rate of return to public sector research by the share of private to total research. (But if the benefits of private research are caught, even partially by input prices, this discounting is overly conservative.) It is time to repair this deficiency before it discredits the whole enterprise.

Productivity growth in the input industries

Productivity growth in the manufacturing sector of the U.S. economy has been depressed - barely positive - since the early 1970's. Both the farm machinery industry and the fertilizer industry have shared this low growth in productivity. Without productivity growth there are no input cost savings to pass on to the agricultural sector. It is important that some attempt be made to understand the sources of the slowdown in productivity growth in these important suppliers of inputs.

Maintenance research

I was very excited about the Blakeslee paper on maintenance research. In my 1982 book on Agricultural Research Policy, I argued that, as partial productivity indicators (yields) or total productivity indicators rise, a higher share of a constant research budget would have to be devoted to maintenance research. Very little maintenance research is required to maintain a gross yield of 1.0 metric tons/ha. At 8.0 metric tons a much larger level of maintenance research would be required. At that time I could not find a single reference that discussed either the biology or the economics of maintenance research. Researcher managers should insist on more intensive economic research in this area.

Technology assessment

Society is insisting, and will insist even more strongly, that the agricultural and general research community provide more accurate guides to the environmental, social and economic impacts of new technology. A state research director who cannot provide his legislature with such information will stand exposed - nude - before both his friends and his critics.

Perhaps I can illustrate my point by comparing the way that California handled the "hard tomatoes" case and the way Cornell is handling the "bovine growth hormone" concerns.

California made no attempt to prepare the interest groups, either those supporting or that later opposed the new biological and mechanical technology, as to what to expect. The development of the machine harvestable tomato and the harvest machinery was an outstanding example of successful collaboration between biological scientists and engineers. But the failure to develop an adequate understanding of its potential impact resulted in a serious threat to the political credibility of agricultural research in California.

Cornell, in contrast, has maintained an active public affairs extension program to help New York dairy farmers and the general public understand the implications of the bovine growth hormone. This effort is backed up by the best set of technology assessment studies that I have seen. Cornell has also had negative feedback. But by the time the new technology reaches the market, its impact will by understood and Cornell will have maintained its political credibility.