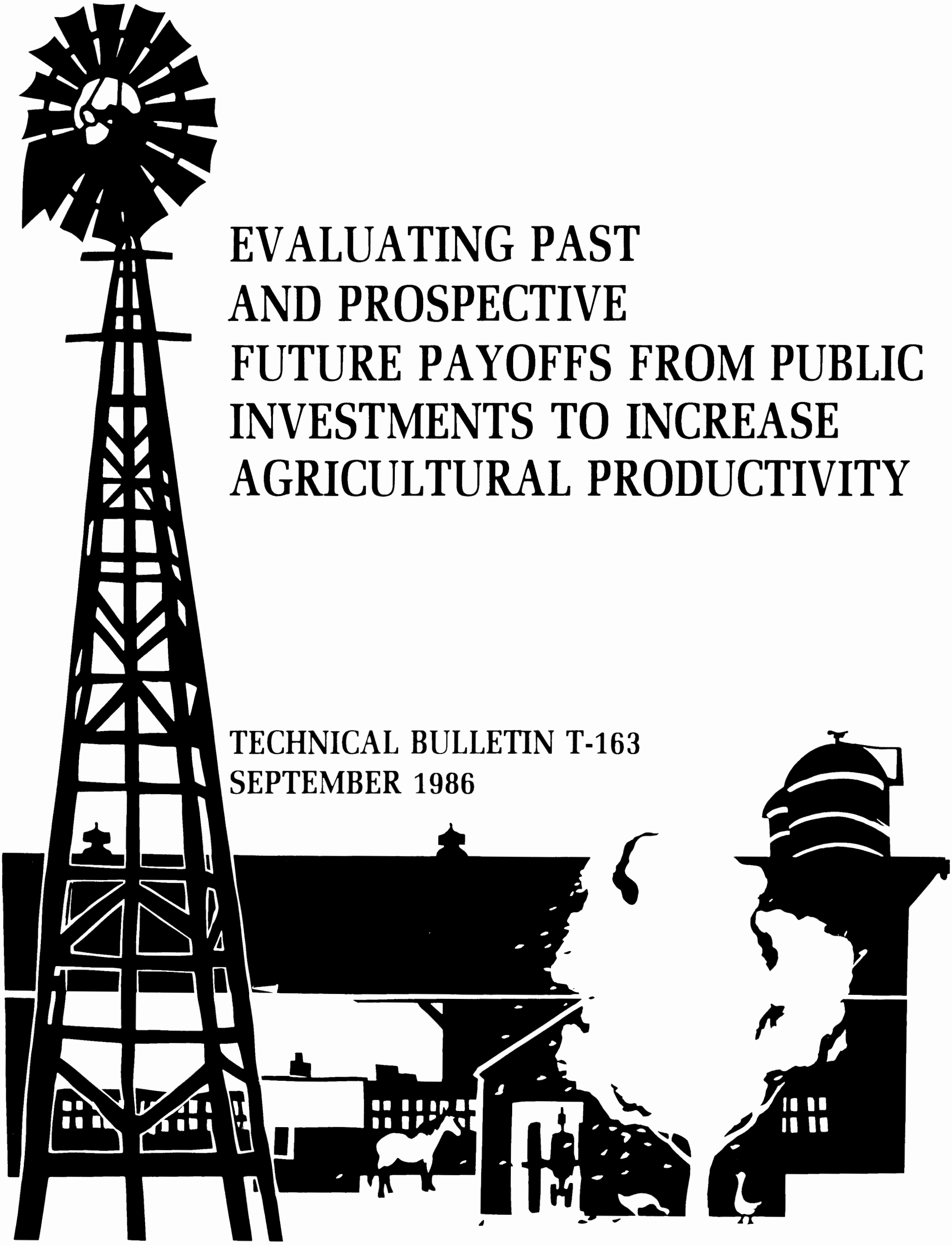

EVALUATING PAST AND PROSPECTIVE FUTURE PAYOFFS FROM PUBLIC INVESTMENTS TO INCREASE AGRICULTURAL PRODUCTIVITY

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EVALUATING PAST AND PROSPECTIVE FUTURE PAYOFFS FROM PUBLIC INVESTMENTS TO INCREASE AGRICULTURAL PRODUCTIVITY

by

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Introduction

In real terms, the annual growth of public expenditure on production-oriented research, extension, and education to increase agricultural productivity was 4.1 percent in the 1940s, 6.5 percent in the 1950s, 3.0 percent in the 1960s, and 2.2 percent in the 1970s.[1] Annual productivity gains in agriculture (total farm output/total production input) averaged 1.8 percent in the 1940s, 2.0 percent in the 1950s, 1.7 percent in the 1960s, and 1.8 percent in the 1970s. During the four decades, productivity increased at an average annual compound rate of 1.8 percent.

The relationship between public expenditures on agricultural production-oriented research, extension, and education (R and E) on one hand, and productivity growth on the other hand has been the subject of numerous investigations. The consensus of the findings is that the average and marginal rates of return to R and E are very high relative to returns on alternative investments. Conditions change, however. Reappraisal of the effect of research, extension, and education on productivity in agriculture seems appropriate.

Some Questions

Serious questions have been raised concerning the nation's investment in increasing agricultural productivity. Is productivity being measured properly? Is the rate of productivity growth and payoff declining from investments to increase productivity as some studies have indicated. Or is the rate of productivity increasing and likely to outrun prospective growth in demand? Past rates of return

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[1]Measured from 1939-49 for the 1940s decade, 1949-59 for the 1950s decade, etc.

on R and E have been higher than returns elsewhere, suggesting inefficient (too little R and E) resource use. What would be the impact on the farming economy and on productivity of more rapid or more nearly optimal rates of increase in R and E? Finally, can outlays for R and E be justified in a farming economy characterized by excess capacity?

Objectives

The general objective of this study is to estimate the contribution of research and extension to productivity in U.S. agriculture. Specific objectives are to:

(1) Estimate the past contribution of research and extension to agricultural productivity based on conventional as well as new indices of productivity.

(2) Investigate the effect of an increase in research and extension on future farm output supply and on farm prices and incomes.

(3) Determine the economically optimal levels and time path of public investments on research and extension over a specified future planning horizon.

(4) Evaluate the payoff from simultaneously investing in R and E to increase productivity while at the same time paying farmers to reduce output.

A Brief Review of Previous Analysis

Previous studies, although differing in their approaches, have consistently concluded that the contribution of research and extension to agricultural productivity has been significant. Concepts commonly employed in past studies include the value of inputs saved (Schultz, 1961; Peterson, 1967), consumer surplus (Griliches, 1958; Schmitz and Seckler, 1970), and the production function (Evenson, 1967; Griliches, 1964; Peterson, 1971; Cline, 1975; White and Havlicek, 1982; Otto and Havlicek, 1981).

Productivity evaluation studies not only differ in approaches, they also differ in their targets of inquiry. Some studies focus on aggregate levels of productivity; others focus on a specific commodity at national, regional, or state levels; and still others focus on multiproducts. Many of these studies have been reviewed elsewhere (see Davis, 1981; White, Eddleman, and Purcell, 1980; Ruttan, 1982; Braha, 1985).

In a recent paper, Fox (November 1985) questioned the validity of past findings of favorable rates of return on public R and E. His principal thesis was that private investments in R and E yielded as high a return as public R and E, hence taxes supporting public outlays had high opportunity cost and were no more productive than if used by the private sector. His thesis is flawed by the invalid assumptions that funds for public R and E come at the expense of private R and E and that private R and E would undertake worthy efforts now performed by public R and E. In another paper, Fox (October 1985) attempted to correct shortcomings of previous analysis. His results supported the conventional finding that rates of return on public R and E are higher than the opportunity cost of sources of funding and that underinvestment in public R and E has been the typical pattern.

Some conclusions and limitations of previous studies are summarized below.

(1) The studies for the most part did not investigate the macro effect of an increase in research and extension on farm prices and income, and on rates of return on R and E.

(2) Many studies relied on the USDA productivity index as the dependent variable in the production function. The USDA productivity index suffers from the usual index number problems and has other flaws (see Gardner et al., 1980).

(3) The studies emphasized past rather than prospective future rates of return. Previous studies have shown that the rate of return on past public expenditure on production oriented research and extension cluster around 50 percent. These returns are very high relative to returns on alternative investments. Other things equal, social benefit may be derived from increased public investment on research and extension to reduce the rate of return to levels for alternative investments.

(4) The studies did not account for costs of government commodity programs to restrain supply and maintain farm prices and incomes.

The present study will update and reappraise the contribution of past research and extension to productivity using three measures of productivity: USDA Index, Divisia Index, and Default Index. Compared to previous studies, more timely data on public expenditure on research and extension and other variables will be used.

The impact of increased R and E expenditure on farm output supply, farm prices, and income will be estimated employing simulation techniques. An optimal control procedure will be used to determine the appropriate level and time path of public investment on research and extension over a planning horizon with farm prices and income endogenous.

Conceptual Framework

One way to conceptualize and measure total factor productivity due to technical changes over time is to specify the production function with all the factor inputs and nonconventional inputs explicitly included:

(1) $Q_t = f(K_t, L_t, X_{1t}, X_{2t},..., X_{nt})$

where Q, K, and L are farm output, conventional capital (including land) input, conventional labor input, respectively, and X_1, X_2,..., X_n are nonconventional R and E inputs.

Ideally, this specification should be used to measure the contribution of conventional and nonconventional inputs to output of agriculture. Combined with all input and output price information from supply and demand functions, it would be possible to solve for economically optimal levels of conventional and nonconventional inputs and for optimal output. In theory, the approach can account for neutral and nonneutral technical change as well as embodied and disembodied technical change. However, problems of data and multicollinearity preclude direct estimation of (1).

An alternative used in this study is to first remove the contribution of conventional production inputs to output and use least squares to account for productivity gains in conventional inputs. This approach reduces multicollinearity among inputs but sacrifices information on interactions among conventional and nonconventional inputs. Research and extension outlays are combined in this study because they are complements; statistical procedures are incapable of separating the independent effect of each.

Other nonconventional inputs include betterment of worker health and nutrition, economies of scale and specialization, changes in product mix, and improved infrastructure such as transportation and communication (Tweeten, 1969, ch. 5; Mansfield, 1971). In this study, these sources of increasing productivity are assumed to be a product of research, extension, and education inputs or are included in farm property taxes which are a component of aggregate "production" inputs.

Should private research and extension be used as a separate explanatory variable? Without doubt, increasing productivity of the farming industry is the product of both public and private research, education, and extension. Under specified profit maximizing conditions, inputs to agricultural production purchased from the private sector reflect costs of improving inputs and are paid their value of marginal product. If prices of the conventional inputs reflect changes in the quality of the inputs, private research and extension need not be included separately in the production function. On the other hand, if prices of the conventional inputs fail to reflect the value of the marginal product, then the contribution to productivity changes of the particular input can be estimated separately using private research expenditure as an explanatory variable. Because of few and unreliable data and because of multicollinearity between public and private outlays, we were unable to estimate separately the private sector contribution. Because we were no more successful than were previous studies in quantifying the contribution of private research and extension to productivity, ad hoc procedures must be used to bracket the most likely range of outcomes under alternative conceptual models of the impact of private investment on productivity.[2]

The USDA productivity index is directly influenced by supply control. Diverted acres are included in aggregate input but only the labor and capital actually used on farms are included. No statistical association was found between diverted acres and productivity in this study and the variable is not included in subsequent analysis.

The theoretical impact of an increase in productivity of conventional farming resources is depicted in Figure 1. In the absence of supply controls, nonconventional R and E inputs shifting the supply curve from S to S' change equilibrium prices from p to p' and output from q to q'. Net social benefits are summarized as follows:

Gain to consumers	1 + 2 + 3
Loss to producers	1 - (4 + 5)
Loss to taxpayers	R + E
Net gain to society	2 + 3 + 4 + 5 - (R + E)

[2]An alternative to direct parameter estimation is to adjust the return on production oriented public research (POPR) for the private contribution. Researchers have divided the rate of return calculated from public outlays alone by a factor of 1.22 to adjust downward estimates on POPR for private outlays (Evenson, 1968; Cline, 1975). This reduces rates of return such as shown later by approximately one-fifth; other studies (Bredahl and Peterson, 1976, Table 7) make even larger adjustments.

Adjusting estimates on POPR downwards by factors such as mentioned above has been criticized on the grounds that the adjustment may bias the contribution of private investments upwards and bias downwards the contribution of POPR. It has been argued that the adjustment represents substantial double counting of private sector inputs, since inputs are also counted in the prices of the private sector inputs that enter agricultural production. In this study, the reader is encouraged to make whatever adjustments are considered to be appropriate in rates of return to compensate for bias from our inability to include private research and extension in rates of return.

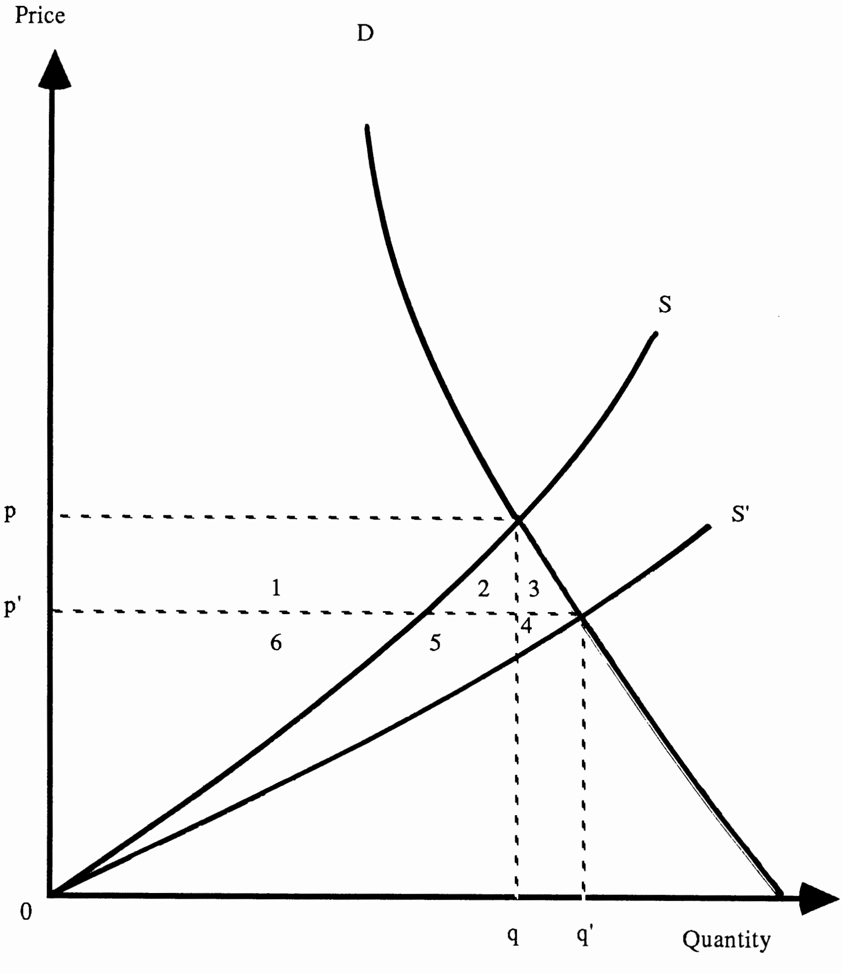

Figure 1. Hypothetical economic impact of productivity advancing the farming industry supply curve from S to S'

The loss to taxpayers occurs because of outlays for agricultural research and extension to obtain the gross gain from increased productivity 2 + 3 + 4 + 5. Of course, many individuals are both taxpayers and consumers. Producers will lose unless cost savings 4 + 5 from productivity gains exceed loss in receipts measured by area 1. A net loss to producers is most likely if demand is inelastic.

To raise revenue to producers, suppose that with increased productivity supply is controlled to bring output q and price p. Then net social benefits will be negative if 2 + 5 - (R + E) is negative in Figure 1. In such instances, it would be better to forego investment R + E in increasing productivity rather than simultaneously to invest and control output. This conceptual framework will be used later in this study to ascertain net benefits or losses with supply controls coupled with expenditures on R and E.

Empirical Econometric Model

The empirical model of productivity change used in this study is written in log form as:

$$(2)\quad \ln PIND_t = \ln A + \sum_{j=1}^{n+1} r_j \ln POPR_{t-j+1} + V_1 \ln EDI_t + V_2 \ln WI_t + \ln U_t.$$

where

$PIND_t$ = Productivity index in year t with 1977=100 (USDA index from U.S. Department of Agriculture, February 1985 and earlier issues);

$POPR_{t-j+1}$ = Production oriented public expenditure on research and extension in time t-j+1, in million 1977 dollars (U.S. Department of Agriculture, *Inventory of Agricultural Research*, annual issues, 1973-1984); data on Cooperative Extension Service expenditures for 1973-1984 from unpublished data provided by Mr. Dan Domingo of the USDA Cooperative Extension Service and for 1939-1972 from Cline (1975). Expenditures deflated by implicit deflator for government purchases of goods and services;

EDI_t = Index of educational attainment of farmers in time t, 1977=100. Educational attainment index of farmers is the level of education of farmers adjusted for age, sex, and income. Observations on EDI for the 1939-1972 period are from Cline (1975). Observations for 1973-1984 are constructed from U.S. Bureau of the Census (1980) following the methodology of Cline;

observations for which data were not available obtained by linear extrapolation;

WI_t = Weather index in time t (Stallings, 1960; and Cline, 1975); updated based on deviations from crop yield trends;

ln = Natural logarithm;

U_t = Disturbance term in time t.

The subscript j refers to the lag on POPR; V_1, V_2, and A (conglomeration of shifters) are parameters to be estimated.

The parameters in (2) in theory can be estimated with the ordinary least squares (OLS) procedure. If the classical OLS assumptions hold, and the lag lengths of POPR are known, the estimates will have the desired statistical properties (i.e., BLUE). A first-order autoregressive scheme is used to allow for autocorrelated disturbances.

Theory suggests the $PIND_t$ induced by a given increase in $POPR_{t-j}$ first increases, reaches a maximum, and declines. The polynomial lag equation seems plausible and (2) is estimated by the Almon technique (Almon, 1965). The model was estimated with and without end-point restrictions so that the choice could be made on the basis of an F-test.

Estimated Results

Equation (2) was fitted by OLS to national data for 1939-1982. The existence of autocorrelation was tested with the Durbin-Watson small sample test. The hypothesis of nonautocorrelated disturbances was rejected in favor of positive autocorrelation at the .05 percent level. The Cochrane-Orcutt method was employed to correct for autocorrelation. Simple correlations between explanatory variables were low and insignificant except between EDI and POPR where r = .98.

In estimating (2), the number of lags of POPR was varied up to 25 based on the assumption of a second degree polynomial lag structure. The model also was estimated with third and fourth degree polynomials. The latter results were inconsistent with theory and prior knowledge.

Equation (2) was estimated using the USDA, Divisia, and Default Indices as dependent variables. The estimated results are presented in Table 1. The coefficients (aggregate for POPR) are significant and the R^2 is high. The Durbin-Watson d statistic (DW) indicates that autocorrelation is not significant.

USDA Productivity Index

The sum of the lag coefficients (Σr_j) for the USDA index is .064, implying that a 1 percent increase in $POPR_t$ will increase PIND by .064 percent over time.

Table 1. Parameters for Equation (2) Estimated by Autoregressive Least Squares with Almon Lag from Annual U.S. Data for 1939-82

Explanatory Variables	Dependent Variables-Productivity Indices[a]		
	USDA Index	Divisia Index	Default Index
$lnEDI_t$	.71000	.69803	.65570
	(3.04)[b]	(1.93)	(2.05)
$lnWI_t$	.00264	.00274	.00287
	(3.62)	(4.20)	(4.30)
$lnPOPR_t$	.00126	.00147	.00162
$lnPOPR_{t-1}$	.00236	.00275	.00304
$lnPOPR_{t-2}$	.00331	.00383	.00425
$lnPOPR_{t-3}$	.00410	.00471	.00526
$lnPOPR_{t-4}$	.00473	.00540	.00607
$lnPOPR_{t-5}$	.00520	.00589	.00668
$lnPOPR_{t-6}$	.00551	.00618	.00709
$lnPOPR_{t-7}$	.00567	.00628	.00729
$lnPOPR_{t-8}$	.00567	.00618	.00729
$lnPOPR_{t-9}$	.00551	.00589	.00709
$lnPOPR_{t-10}$	.00520	.00540	.00668
$lnPOPR_{t-11}$	.00473	.00471	.00607
$lnPOPR_{t-12}$	.00410	.00383	.00527
$lnPOPR_{t-13}$	.00331	.00275	.00425
$lnPOPR_{t-14}$	.00236	.00147	.00304
$lnPOPR_{t-15}$	.00126	----	.00162
Σr_j, j=1, . . ., n+1	0.06427	0.06672	0.08260
R^2	0.97	0.97	0.97
SEE	0.02187	0.02662	0.02204
DW	2.27	2.56	2.36

[a]See Appendix for definition of Divisia and Default Indices.

[b]Figures in parenthesis are t-values; all significant at .05 probability level.
A joint F test that coefficients on $POPR_{t-j+1}$ variables are zero was rejected at 10% level of significance or better.

The increase is distributed over 16 years in the manner shown by the distributed lag weights. An F-test of the null hypothesis that the end point restrictions are appropriate was not rejected at the 1 percent level of significance. The mean lag (eight years) and the total length of lag (16 years) were determined by the minimum standard error criterion.

The other explanatory variables behave as expected. The results indicate that the elasticity of PIND with respect to EDI is .72 and with respect to the weather index is .0026.

Estimating Marginal Returns

Given that PIND = Q/X where Q is farm output and X is conventional input, it is apparent from (2) that the elasticity of the productivity index and of farm output with respect to investment on public research outlays is:

$$(3)\quad \frac{\partial \ln(Q/X)_t}{\partial \ln POPR_{t-j+1}} = \frac{\partial (\ln Q - \ln X)_t}{\partial \ln POPR_{t-j+1}} = \frac{\partial \ln Q_t}{\partial \ln POPR_{t-j+1}} = r_j$$

because aggregate input X is held constant.

The marginal product (MP_j) of $POPR_{t-j+1}$ can be approximated following Knutson and Tweeten (1979) from (3) as:

$$(4)\quad MP_j = \frac{\partial Q}{\partial POPR_{t-j+1}} = \frac{\partial PIND_t}{\partial POPR_{t-j+1}} \cong r_j \frac{PIND_t}{POPR_{t-j+1}}$$

Equation (4) indicates that MP_j is distributed over j lags in the same way the weights of the parameter on $POPR_t$ are distributed.

The stream of MP_js is used to compute the IRR on $POPR_{t-j}$ using the following equation (5) and the results from Table 1.

$$(5)\quad IRR = R\!: \sum_{j=0}^{n} VMP_j\,(1 + R)^{-j} - 1 = 0$$

where VMP_j = value of marginal product MP_jP where product price P initially is assumed to be constant with year 1977 = 1.0. Results are given in Table 2. The total marginal product and IRR on past POPR decline over time, exhibiting the law of diminishing returns from additional investment.

Comparison of Returns

Internal rates of return estimated in earlier studies are shown in Table 3 for comparison with our results in Table 2. Only studies that employed aggregate national data in the U.S. are used for comparison. Estimates of IRR on POPR cluster around 50 percent but decline through time. Peterson's estimates, for example, fell from 50 percent during 1937-1942 to 34 percent during the 1957-

Table 2. Marginal Returns and Internal Rate of Return to Past Investment in POPR Calculated for USDA Productivity Index Results from Table 1

Year	MP	IRR	Year	MP	IRR
	1977 dollars	Percent		1977 dollars	Percent
1959	21.86	56.74	1971	12.67	42.51
1960	20.41	58.22	1972	12.18	41.46
1961	19.80	54.33	1973	11.93	41.02
1962	18.40	52.27	1974	12.65	42.79
1963	17.34	50.85	1975	16.33	50.72
1964	16.41	49.64	1976	15.08	48.03
1965	15.34	47.98	1977	14.30	46.25
1966	13.78	44.93	1978	13.49	44.31
1967	14.05	45.61	1979	13.35	43.75
1968	14.13	45.88	1980	14.51	45.92
1969	13.15	43.70	1981	15.97	48.50
1970	12.55	42.25	1982	14.61	45.43

Table 3. Summary of Previously Estimated IRR Using Aggregate National Data and Production Functions

Study	Time Period	IRR
Peterson and Fitzharris, 1977	1937-1942	50
	1947-1952	51
	1957-1962	49
	1957-1972	34
Griliches, 1963	1880-1938	35
Griliches, 1964	1949-1959	35-40
Evenson, 1968	1949-1959	47
Cline, 1975	1939-1972	41-50
Knutson and Tweeten, 1979	1949-1958	39-47
	1959-1968	32-39
	1969-1972	28-35
Davis, 1979	1949-1959	66-100
	1964-1974	37

1972 period. Estimates by Knutson and Tweeten indicate that IRR fell from 39-47 percent during 1949-1958, to 32-39 percent in 1959-1968, and to 28-35 in the years 1969-1972. Our estimates in Table 2 are higher than most previous estimates. Returns to POPR have held up better than predicted from earlier analysis. This conclusion raises basic questions about the appropriateness of the Cobb-Douglas production function which implies diminishing returns from increasing POPR. Yet returns have not diminished although POPR has increased more rapidly than demand for several decades. One possible explanation for higher rates of return is that growing private sector contributions to productivity captured by the productivity index increasingly bias the index upward. The increasing rates of return cannot be explained by increasing real farm prices -- the year 1977 used as a base in Table 2 was a time of relatively low real farm prices by historic standards.

Estimates of the Divisia and Default Indices

The USDA Productivity Index is a fixed-weight Laspeyres index with weights changed periodically. The formula for the Divisia Index of total factor productivity is discussed in the Appendix. The Divisia Index is attractive as an alternative measure of productivity because the weights in the index are changed each year. The indices constructed using the formula in Appendix A are used as dependent variables to estimate equation (2). All the explanatory variables remain unchanged.

Estimated results are given in Table 1, column 2. The appropriate lag for the explanatory variable $POPR_{t-j}$ was chosen on the basis of Theil's minimum error criterion. The estimates are distributed over 15 years unlike the 16 years for the USDA Index. The sum of the lag coefficients is .067, implying that a 1 percent increase in investment in POPR raises productivity by .067 percent through time. The R^2 indicates that the independent variables account for 97 percent of variation in the dependent variable. The null hypothesis that the coefficients are jointly zero is rejected at the 1 percent level by the joint F-test.

The Default Index was formulated by Tweeten (1981) after noting that the changes in demand for farm output and in farm real prices were inconsistent with the rate of productivity growth as measured by the USDA Index. The Default Index was constructed by solving for productivity gains consistent with changes in demand and prices -- given estimates of demand parameters and the supply elasticity. The estimate of equation (2) employing the Default Index as the dependent variable, with the same independent variables as in the case of USDA and Divisia Indices, gave results shown in column 3 of Table 1. The sum of the lag coefficients is .086 which is larger than sums using the USDA and Divisia Indices. The number of lags is 16 years. The R^2 is high and the coefficients are significant.

Statistical evidence is inconclusive for selecting one index-equation over another in Table 1. However, it is of interest that the Divisia and Default Indices provide higher elasticities of production, marginal products, and internal rates of return than does the USDA Index. The marginal products essentially are proportional to the summation of r_js, hence can be interpreted for the Divisia and Default Indices from results in Tables 1 and 2. The internal rate of return calculated for 1982 for the Divisia Index is 50.86 percent and for the Default Index is 55.44 percent -- somewhat higher than the rate of 45.43 percent for the USDA Productivity Index shown in Table 2.

In subsequent analysis we use the USDA Productivity Index because it is widely available and updated annually. Some downward bias in the Index may partially compensate for omission of the private sector contribution to productivity gains. Private sector production oriented research and extension outlays to increase agricultural productivity were approximately equal to public sector outlays in recent years. If the two contributions are combined, the internal rate of return on aggregate outlays is 26.16 percent according to the USDA Productivity Index results in Table 1. This rate, although substantially biased downward and a lower limit for the return to POPR, still is favorable compared to rates on typical alternative public or private investments.

Simulation Model

Greater POPR outlays increase productivity and shift the supply curve of agricultural output to the right. A larger supply lowers farm prices and incomes, ceteris paribus. A simulation model is employed to trace the effect on productivity and aggregate supply of agricultural output from an exogenous increase in POPR. The simulation utilizes the modified SIMPAS model developed by Tweeten and Quance (1972). The SIMPAS model contains aggregate demand and supply equations with commodity prices and incomes endogenous. The demand and supply equations are assumed to be functions of Koyck type distributions of current and lagged prices in the form used by Tweeten and Quance (1972) and Yeh (1976).

The reduced form of the demand and supply equations can be written in log form as:

$$(6)\quad \ln Qd_t = \ln Ad + Bd\ln P_t + (1 - \delta d)\ln Qd_{t-1} + \delta d \sum_{i=to}^{t-1} gd_i + gd_t$$

$$(7)\quad \ln Qs_t = \ln As + Bs\ln PR_t + (1 - \delta s)\ln Qs_{t-1} + \delta s \sum_{i=to}^{t-1} gs_i + gs_t$$

where:

Qd, Qs = quantities demanded and supplied, respectively;

P, PR = prices received (deflated) and parity ratio, respectively. (In this study, P and PR move together and are represented by a single price index because PR = P/Pp where Pp, prices paid by farmers, is assumed to be constant in the absence of inflation and given a perfectly elastic input supply.);

gd, gs = annual rates of shift in demand and supply, respectively;

Bd, Bs = short-run price elasticities of demand and supply, respectively;

δd, δs = coefficients of adjustments towards equilibrium in demand and supply, respectively; and

Ad, As = constants.

The last two terms in (6) and (7) are accounting procedures which allow shifts at constant rates gd and gs unaffected by the adjustment rates of the distributed lags for prices. Supply shifts (gs) due to changes in prices of inputs, education of farmers, and productivity increases from POPR inputs. The shift in supply due to POPR investments is of major interest and is the only component of gs considered in the simulation. Productivity is assumed to respond to POPR expenditures with a distributed lag of the Almon type. Assume the lag structure of productivity response to POPR can be expressed as:

$$(8)\quad PIND_t = A \prod_{j=1}^{n+1} POPR_{t-j+1}^{r_j}.$$

where:

$PIND_t$ = USDA Productivity Index, time t;

A = conglomeration of shifters;

$POPR_{t-j+1}$ = research and extension expenditures in time t-j+1;

j = number of lags, j = 1, 2,..., 16.

Annual growth rate in the Productivity Index between two time periods is:

$$(9)\quad \ln\left(\frac{PIND_t}{PIND_{t-1}}\right) = \sum_{j=1}^{n+1} (r_j - r_{j-1})\ln POPR_{t-j+1}.$$

Substituting (9) in (7) for gs_t, we obtain a new supply function. Letting all constant terms be represented by lnC, the supply equation can be written as

$$(10)\quad \ln Qs_t = \ln C_t + Bs\ln PR_t + (1 - \delta s)\ln Qs_{t-1} + \delta s \sum_{i=to}^{t-1} \sum_{j=1}^{n+1} (r_j - r_{j-1})\ln POPR_{i-j+1}$$

$$+ \sum_{j=1}^{n+1} (r_j - r_{j-1})\ln POPR_{t-j+1}.$$

Equation (10) shows that supply shift is the cumulative effect of POPR expenditures over time. The supply shift is not constant but changes due to the lagged response of productivity to investments in POPR.

The system of equations (6) and (10) is used to simulate equilibrium price (P), quantity supplied (Qs), quantity demanded (Qd), gross farm receipts (GFR), and net farm income (NFI). The system of equations has three endogenous variables Qd_t, Qs_t, and P_t.

Parameters

The demand equation (6) has a price elasticity and a lag parameter. The price elasticity of demand for aggregate agricultural products has been estimated to range from -.2 in the short run to -1.5 in the long run (see Tweeten, 1983, p. 924). In this study a short-run elasticity of -.25 and long-run elasticity of -1.0 are used.

The shift in demand (gd) for agricultural output arises from growth in population and per capita income in the domestic market and in export demand. The yearly shift in demand to year 2025 has been projected to average between 1 percent and 2 percent (see Tweeten, 1985).

The supply equation (10) has a price elasticity parameter and a lag parameter. A short-run price elasticity of .10 and a long-run elasticity of 1.0 are used in this study (see Tweeten and Quance, 1969). The lag parameter (adjustment rate) is .10. The rate of shift in supply comes from productivity increases due to investments in POPR, as shown in equation (10).

Simulated Economic Outcomes

In the simulations, no price supports or supply controls are assumed. Four scenarios of POPR expenditures are considered: Annual growth rates of 3 percent, 5 percent, 7 percent, and 9 percent. Alternative annual demand shifts of 1.5 percent and 2.0 percent are exogenously supplied to the model. Economic outcomes for the period 1982-2025 are simulated and results are summarized in Table 4.

With a constant annual growth rate in POPR outlays of 3 percent, the productivity index (PIND) grew at the rate of 1.99 percent yearly. Because lower prices restrain output, the effect of productivity growth is to shift aggregate supply quantity by 1.86 percent annually during the simulation period given the rate of shift in demand remaining constant at 1.5 percent. The increase in supply lowers the index of prices received by .30 percent annually and increases GFR 1.56 percent annually. During the same period, NFI decreased 0.90 percent yearly.

A 9 percent annual growth in POPR outlays increases the productivity index by 2.35 percent yearly, causing supply to grow at an annual rate of 2.07 percent with an annual shift in demand of 1.5 percent throughout the period. Prices received fell by 0.51 percent yearly. GFR rose by 1.54 percent annually and NFI fell at an annual rate of 12.53 percent.

With an annual increase in demand of 2 percent, expansion in the productivity index at the rate of 1.99 percent annually from an annual growth rate in POPR expenditures of 3 percent is associated with supply quantity growth of 2.07 percent yearly. Prices received did not fall as in the case of demand shift of 1.5 percent yearly because the shift in demand exceeded the shift in supply. Thus GFR and NFI grow at an annual rate of 2.04 percent and 1.89 percent, respectively.

The maximum annual growth rate of POPR outlays of 9 percent causes the productivity index and supply to increase 2.35 percent and 2.28 percent, respectively on an annual average basis. With the demand shift less than the supply shift, prices fell by .25 percent per year. GFR rose by 2.02 percent and NFI rose by .17 percent compounded annually. It is apparent that the capacity of the farming industry to absorb productivity gains without large adjustments depends heavily on growth rates in demand.

Our projections can be compared with some previous simulation studies. Projections for 1981-1990 by White and Havlicek (1982) showed a yearly growth rate of 1.3 percent in the productivity index. Given an annual demand shift of 1.6 percent and 3.0 percent rate growth in POPR outlays, IRR fell to 15.6 percent. Prices grew at the rate of 3 to 4 percent annually.

The productivity index grew at the rate of 1.1 percent yearly to year 2000 under standard assumptions according to projections by Lu, Quance, and Liu (1978) under a 3.0 percent annual growth rate in POPR investments. Under their most optimistic assumptions, they (p. 977) projected productivity growth of 1.3 percent annually to the year 2000. The foregoing projections, although for different periods than ours, seem low in the light of our results and relative to the revised USDA data indicating an average annual productivity growth rate of 2.0 percent in the 1950-1982 period (U.S. Department of Agriculture, February 1985, p. 69).

Table 4. Annual Growth Rates of Qs, GFR, NFI, and PIND Under Alternative Growth Rates in POPR Outlays for the Period 1982-2025

Annual Growth in POPR	Variable				
	PR[a]	Qs	GFR	NFI	PIND
	Percent per year				
Shift in Demand = 1.5 percent					
3%	-0.30	1.86	1.56	-0.90	1.99
5%	-0.37	1.93	1.55	-2.61	2.12
7%	-0.44	1.99	1.55	-9.00	2.24
9%	-0.51	2.07	1.54	-12.53	2.35
Shift in Demand = 2.0 percent					
3%	0.03	2.07	2.04	1.89	1.99
5%	-0.12	2.14	2.03	1.50	2.12
7%	-0.18	2.21	2.03	0.90	2.24
9%	-0.25	2.28	2.02	0.17	2.35

[a]With assumed no inflation and constant input prices, P and PR increase at the same rate. See text for definitions of variables.

Estimating Marginal Returns

Economic decisions to invest in agriculture ideally are made at the margin. The elasticity E of output Qs_t with respect to $POPR_{t-j+1}$ is:

$$(11)\quad E = \frac{\partial Qs_t}{\partial POPR_{t-j+1}} \quad \frac{POPR_{t-j+1}}{Qs_t}.$$

Given (10) and (11), the marginal product of $POPR_{t-j+1}$ is approximated as

$$(12)\quad MP_j = \left[\frac{\delta s\,(r_j - r_{j-1})}{POPR_{t-j+1}} + \frac{(r_j - r_{j-1})}{POPR_{t-j+1}}\right] Qs_t \qquad j=0,\ 1,\ 2, \ldots,\ n.$$

Table 5 shows that the marginal products of POPR outlays decline through time. Given an annual demand shift of 1.5 percent and the historical yearly rate of growth in POPR of 3.0 percent, MP falls from $10.19 in 1982 to $3.60 in 2025. Allowing POPR to grow at a higher annual rate of 9.0 percent results in a faster decline of MP from $10.19 in the base year to $0.49 in 2025.

A similar pattern of decline in MP is also shown in Table 5 when yearly rate of demand shift is assumed to be 2.0 percent, and the rate of growth in POPR outlays is varied between 3.0 percent and 9.0 percent. As expected, the projected decline in marginal product is less in the case of a 2.0 percent shift in demand. For example, a 3.0 percent growth rate in POPR yearly resulted in the decline of MP from $10.19 in 1982 to $4.48 in 2025; while a 9.0 percent yearly increase in POPR resulted in a MP decline to $0.59 during the same period.

VMP, which is MP times product price, tends to be below MP because product prices are below 1982 product prices in all scenarios but fall the most with higher rates of growth in POPR. Because no inflation is assumed, all values are in 1982 dollars.

Estimating IRR

The distributed benefits from $POPR_{t-j+1}$ must be brought to a common time period for purposes of investment decisions and comparison with outlays. The most widely used criterion for investment decisions, its shortcomings notwithstanding, is the internal rate of return (IRR). The IRR is the highest rate of return that equates the net present value (NPV) of all future benefits to zero. The IRR (R) on $POPR_{t-j+1}$ is calculated as:

$$(13)\quad IRR = R: \left\{ \sum_{j=1}^{n+1} \left[Qs_t \left(\frac{\delta s\,(r_j - r_{j-1})}{POPR_{t-j+1}} + \frac{(r_j - r_{j-1})}{POPR_{t-j+1}} \right) \frac{P_t}{P_{to}} \right] (1+R)^{-j} \right\} -1 = 0.$$

Table 5. Economic Outcomes for Farming Industry Under Different Growth Rates of POPR and Alternative Yearly Demand Shifts, 1982-2025

Year and POPR Growth	Variable							
	PR	Qs	GFR	NFI	POPR	MP	VMP	IRR
	1910-14= 100	Bil. 1982 $	$ Bil.	$ Bil.	$ Bil.	1982$	$	%
<u>Actual</u>								
1982	60.67	142.40	142.40	24.57	1.74	10.19	10.19	45.43
<u>Projected</u>:	**Annual Shift in Demand = 1.5%**							
<u>3%</u>								
1995	58.12	186.95	179.10	25.01	2.60	5.55	5.31	25.51
2010	55.65	245.09	224.82	22.62	3.99	4.35	3.99	19.83
2025	53.20	320.86	281.40	16.50	6.21	3.60	3.15	15.66
<u>5%</u>								
1995	57.73	187.83	178.73	23.91	3.35	4.88	4.64	21.73
2010	54.63	249.05	224.27	18.80	6.96	2.88	2.59	12.02
2025	51.50	330.51	280.59	7.68	14.48	1.80	1.52	4.88
<u>7%</u>								
1995	57.35	188.69	178.37	22.84	4.36	4.33	4.09	18.66
2010	53.65	252.99	223.74	14.50	12.04	1.93	1.71	6.10
2025	49.88	340.25	279.75	1.20	33.21	0.93	0.75	-2.88
<u>9%</u>								
1995	56.98	189.54	178.14	21.78	5.65	3.88	3.64	16.12
2010	52.70	256.93	223.21	11.22	20.60	1.32	1.14	-1.40
2025	48.34	350.09	278.95	-10.13	75.02	0.49	0.38	-8.93
<u>Projected</u>:	**Annual Shift in Demand = 2.0%**							
<u>3%</u>								
1995	60.51	190.40	189.90	32.96	2.59	6.29	6.27	29.22
2010	60.20	258.67	256.70	43.26	3.99	5.22	5.18	24.98
2025	59.70	351.53	346.29	56.02	6.12	4.48	4.41	21.73
<u>5%</u>								
1995	60.10	191.28	189.51	31.83	3.35	5.52	5.47	24.91
2010	59.10	262.85	256.07	39.18	6.96	3.43	3.34	15.98
2025	57.85	362.09	345.26	46.25	14.48	2.22	2.11	9.16
<u>7%</u>								
1995	59.71	193.03	189.13	30.22	4.36	4.88	4.80	21.43
2010	58.04	267.01	250.43	35.12	12.04	2.29	2.19	9.31
2025	56.03	372.76	344.26	36.43	33.21	1.13	1.04	0.44
<u>9%</u>								
1995	59.32	193.03	188.75	29.62	5.65	4.36	4.26	18.58
2010	57.02	271.16	254.86	31.08	20.60	1.56	1.46	4.13
2025	54.30	383.55	343.28	26.51	75.02	0.59	0.52	-6.18

where:

The expression inside the square brackets is the VMP_j of POPR and

P_t = prices received by farmers at time t,

P_{to} = prices received by farmers at time t = 0, the latter assumed to be 1982.

The VMP of POPR declines with increased POPR outlay in the same pattern as MP, except that the magnitude of VMP is less due to declining prices caused by productivity increases, ceteris paribus.

As shown in Table 5 for a demand shift of 1.5 percent annually, the IRR for a 3 percent annual increase in POPR starts at 45.43 percent in 1982 and falls to 25.51 percent in 1995, to 19.83 percent in 2010, and to 15.66 percent in 2025. The IRR becomes negative in time with higher rates of growth in research and extension outlays. Annual demand shift of 2.0 percent results in IRR decline from 45.43 percent in 1982, to 29.22 in 1995, 24.98 in 2010, and 21.73 in 2025 for a 3 percent annual growth in POPR. The decline is to 18.58 percent in 1995, 4.13 in 2010, and -6.18 in 2025 for a 9 percent annual growth in public research and extension outlays. Diminishing returns are apparent.

Table 5 shows that investing in POPR at the historical rate of 3 percent yearly results in an IRR that is higher than returns are likely to be on alternative investments in the future. Economically efficient allocation of resources requires that investments continue until returns are equal among resources committed to various undertakings of similar risk. This indicates that net benefits can be generated from increasing investment in POPR. The following section elaborates on this issue.

Optimal Control Model

Assume that policymakers have identified a long-run desired target rate of return (IRR_d) and wish to allocate public resources efficiently through control of POPR expenditures over time. We express POPR outlays, the control variable, as a function of time t: The objective is to influence the economic system by adjusting investments in the control variable POPR through time to keep the target variable (IRR_t) as close to the desired level (IRR_d) as possible. From the previous equations, the optimal expenditure and its time path can be sought. The performance of the system can be measured by the deviations of the actual (IRR_t) from the target (IRR_d). The performance measure can be specified as a quadratic cost minimization function:

$$(14)\ J = \sum_{t=1}^{T} (IRR_t - IRR_d)^2.$$

IRR_t is the actual return derived from the investment in POPR through time, t=1, 2,..., T as expressed by (13). IRR_d (which need not be constant but may vary with time) is exogenously determined by policy makers. Knutson and Tweeten (1979) have detailed that there are other social and political considerations that could enter the objective function of policy makers. Indeed, if these were known and quantifiable, they could be included in (14). For purposes here, IRR is assumed to be the sole criterion in the investment decision.

The marginal benefits from POPR are distributed over time and influence the rate of return as shown earlier in (13). IRR_t will change with alternative levels of the control variable POPR. In successive simulation model iterations, the new IRR_t is compared against the target IRR_d, until a value is found for IRR_t which minimizes (14).

To limit the number of possible paths of the control variable, the growth rate in investment in POPR per year is specified to be within a range of 3 percent to 10 percent. The minimum growth rate of 3 percent is the historical yearly increase in POPR outlays for the last five decades. The 10 percent maximum limit is imposed due to several reasons. The research and extension institutional system may be unable to absorb real investment growth in POPR beyond 10 percent without strain and sharply diminishing returns at least in the short run. The existing infrastructure including scientists, supporting personnel, and laboratories may be inadequate. Even if this were surmountable, the technology forthcoming might unduly dislocate farmers through increased output and depressed prices and incomes. The social costs associated with such a decision may be judged unacceptable. Too, in times of budget stringency, investments beyond real growth rates of 10 percent may not be feasible.

Given the boundary constraints of 3 percent and 10 percent, an infinite number of investments within the constraints can be made that would eventually stabilize the achieved rate of return (IRR_d) at the desired level. The problem thus becomes one of selecting an optimal time path of expenditures on $POPR_t$ (t=1, 2,..., T) that minimizes the performance measure (14). We employ the sequential search algorithm of Box Complex (Box, 1965). The procedure minimizes the criterion function subject to constraints on the control variables.

Optimal Control Results

The optimal simulation control model considered the period 1982-2025. For given POPR expenditures through time, equilibrium demand and supply conditions for aggregate agricultural products are simulated in the absence of price supports or production controls. Weather conditions and educational levels of farmers are assumed to be average. Demand and supply shifts and parameters are as assumed earlier. The target variable, IRR_d, is assumed to be 10 percent in real value throughout the simulation period. That value is arbitrary and could be changed but in real terms is well above historic real interest rates. The functional forms of the control variable were as follows:

(a) Exponential growth function with a single optimal growth rate of POPR for the entire period.

(b) Step function - The growth rate in POPR expenditure is divided into segments. Initially, investment is allowed to grow somewhat rapidly followed by a transition or deceleration period and a constant growth rate thereafter.

Exponential Growth Function

Given the exponential growth form of the control variable POPR, the parameters on the supply and demand equations, and an annual shift in demand at 1.5 percent, then a 4.03 percent annual growth in POPR outlays minimized the performance measure. Table 6 shows the impact of the optimal value of the control variable on the endogenous variables. From 1982 to 2025 the productivity index grew at a yearly rate of 2.05 percent, Qs grew at an average rate of 1.94 percent, and PR declined at the rate of .34 percent per year. GFR grew modestly at the rate of 1.59 percent per annum. The equilibrium value of NFI fell at the rate 1.64 percent per annum.

The equilibrium values of the variables in the model are quite different when the rate of annual shift in demand is assumed to be 2.0 percent. The annual rate of growth in POPR that minimizes the performance measure (14) averaged 4.91 percent per year throughout the period under study. The equilibrium value of Qs grew at the rate of 2.19 percent and GFR rose by 2.08 percent yearly while NFI increased at an annual rate of 1.47 percent. The productivity index rose at an annually compounded rate of 2.11 percent. Prices received showed a modest decline of about .11 percent yearly. The higher shift in demand (2.0 percent versus 1.5 percent) helped prices received to remain relatively stable, thereby making GFR and NFI also relatively higher than with slower growth in demand.

The Step Function

In optimizing the step function, we divided the simulation period into segments. POPR was allowed to grow relatively fast in the initial segment of the period followed by decreasing growth rates in the subsequent three period segments. If the annual shift in demand is 1.5 percent throughout the simulation period, the optimal time path is an annual increase in POPR of 10 percent for the period 1982-1990, a drop in the growth rate by 1 percentage point per year for 1991-1995 to a growth rate of 5.1 percent each year for the 1996-2005 period, and a drop in the growth rate by 1.8 percentage points during each year 2006-2010 to an annual rate of growth of 3.0 percent for the remaining years 2011-2025. The result is a 10 percent IRR in year 2025. Translated into actual expenditure, the pattern is that spending starts at $1.74 billion in 1982, grows to

Table 6. Equilibrium Values of Variables Using Single Exponential Growth Rate of the Control Variable Under Alternative Yearly Demand Shifts, 1982-2025

Year and POPR Growth	Variable							
	PR	Qs	GFR	NFI	POPR	MP	VMP	IRR
	1910-14= 100	Bil. 1982 $	$ Bil.	$ Bil.	$ Bil.	1982$	$	%
Actual								
1982	60.67	142.40	142.40	24.57	1.74	10.19	10.19	45.43
Annual Shift in Demand = 1.5%								
1995	57.92	187.39	178.92	22.48	2.82	5.19	4.96	23.52
2010	55.14	247.07	224.55	20.71	5.28	3.53	3.29	16.60
2025	52.34	325.67	280.98	12.10	9.50	2.54	2.19	9.90
Annual Shift in Demand = 2.0%								
1995	60.13	191.28	189.54	31.90	3.39	5.57	5.52	25.18
2010	59.18	262.56	256.12	39.46	6.70	3.54	3.45	16.57
2025	57.98	361.35	345.33	45.93	13.66	2.33	2.23	9.88

\$3.45 billion in 1995 and \$5.55 billion in 2010, and is \$8.78 billion in year 2025. Results are given in Table 7.

This pattern of expenditures would increase aggregate agricultural productivity at the average rate of 2.07 percent yearly through 2025. If demand increases only 1.5 percent annually throughout the period under consideration, supply quantity increased 1.95 per annum and prices received declined at an annual rate of 0.35 percent. GFR grew by 1.59 percent while NFI declined by 1.87 percent annually from 1982 to 2025.

Optimal results (criteria function minimized) assuming a 2.0 percent annual demand shift in Table 7 are for POPR outlays to grow at 9 percent annually during 1982-1990. The growth rate declines by .34 percentage points each year from 1991 to 1995 to a 7.4 percent yearly growth rate during 1996-2005. Then the growth rate falls by .38 percentage points each year for 2006-2010 to an annual growth rate of 4.7 percent during the 2011-2025 period.

The net social cost in foregone output is less for the step than for the exponential function because the former moves POPR more quickly to the optimal level. However, the particular step function for the 1.5 percent annual rate of growth in demand causes a rate of growth in productivity requiring adjustments not easily borne by farmers as apparent from income data in Table 7.

Investment in Agricultural Research and Extension in the Presence of Excess Capacity

Can continued investment in technology to raise agricultural productivity be justified when excess capacity already exists in agriculture? Several considerations support continuing investments even if excess capacity exists. Analysis is based on the conceptual framework developed earlier in Figure 1.

According to the foregoing estimates, each dollar invested in agricultural production research and extension returns approximately \$10 undiscounted or \$4.74 discounted to the present at a 10 percent rate in 1982. Thus the \$1.74 billion annual investment in POPR produces a net discounted social gain or addition to national income of (\$4.74 x \$1.74 billion) \$8.25 billion. This is a measure of area 2 + 3 + 4 + 5 in Figure 1.

The \$15 billion spent on commodity programs on average in recent years are mostly transfer payments rather than a net social cost as measured by foregone national income. Given national farm output of approximately \$142 billion in 1982, net social cost (NSC) in billion dollars is calculated from the following formula

$$(15)\quad NSC = \frac{GFR}{2}\left(\frac{1}{Bs} - \frac{1}{Bd}\right)\left(\frac{\Delta Q}{Q}\right)^2$$

Table 7. Equilibrium Values of Variables Using Step Function Growth of the Control Variable Under Alternative Yearly Demand Shifts, 1982-2025

Year and POPR Growth	Variable							
	PR	Qs	GFR	NFI	POPR	MP	VMP	IRR
	1910-14= 100	Bil. 1982 $	$ Bil.	$ Bil.	$ Bil.	1982$	$	%
<u>Actual</u>								
1982	60.67	142.40	142.40	24.57	1.74	10.19	10.19	45.43
<u>Annual Shift in Demand = 1.5%</u>								
1995	57.19	189.33	178.50	21.83	3.45	3.98	3.75	17.58
2010	54.66	249.27	224.58	8.32	5.55	2.91	2.62	12.59
2025	52.23	326.58	281.15	10.92	8.78	2.60	2.23	10.24
<u>Annual Shift in Demand = 1.5%</u>								
1995	59.66	196.70	189.34	30.04	3.31	4.48	4.59	21.36
2010	58.84	269.61	256.06	33.61	6.46	3.14	3.05	14.64
2025	57.96	361.42	345.31	46.25	12.89	2.46	2.34	10.10

where Bs is the farm output supply elasticity, Bd is the farm level demand elasticity for farm output, GFR is gross farm receipts, and $\Delta Q/Q$ is excess capacity as a proportion (not percent) of farm output (Tweeten, 1979, p. 485). In 1982, excess capacity, defined as output that needed removal by the government programs from the market to maintain politically acceptable prices to farmers, was approximately 4 percent of expected farm output with normal weather and stocks (Tweeten, April 1984, p. 31). If Bs is .1 in the short run and 1.0 in the long run, and if Bd is -.25 in the short run and -1.0 in the long run, then the net social cost of 4 percent excess capacity is $1.59 billion in the short run and $.23 billion in the long run. Social cost is less in the long run as producers adjust to avoid economic inefficiency of supply control.

If the actual price is within the range p - p' in Figure 1 as expected, the area 2 + 5 in the figure is approximately $8.25 billion - $1.59 billion = $6.66 billion in the short run and $8.25 billion - $.23 billion = $8.02 billion in the long run when resources and markets have had an opportunity to adjust. The net social gain (addition to national income) when simultaneously investing in POPR and controlling production is area 2 + 5 less POPR, or approximately $6.66 billion - $1.74 billion = $4.92 billion under short-run assumptions and $8.02 billion - $1.74 billion = $6.28 billion under long-run assumptions.

By 1985, excess capacity was 7 percent of normal output at existing prices. NSC computed from (15) was $4.87 billion in the short run and $.70 billion in the long run under these conditions, or triple 1982 levels. These social costs would nearly offset the net benefits of POPR, $6.51 billion, in the short run but not in the long run.

Net farm income may be defined as (PR)Q - (Pp)X where PR and Pp are respectively prices received and paid by farmers and Q and X are respectively aggregate output and input. Rearranging terms, it is apparent that (Q/X) = (PR/Pp). In a well-functioning economy, an increase in productivity reduces the parity ratio, other things equal. Net farm earnings per unit of resources will be maintained after resource adjustments because greater productivity enables farmers to cover all resource costs at a lower ratio of prices received to prices paid by farmers. Thus the lower real farm prices and net farm income shown in earlier tables resulting from productivity gains exceeding growth in demand do not necessarily mean that farming resources are earning lower returns than like resources elsewhere. Farm resource adjustments to high levels of productivity growth may be traumatic for many farmers, however, and some type of adjustment assistance in the form of direct payments and training and other preparation for alternative employment may be warranted. The foregoing analysis indicates that a growth dividend (net social gain) is available out of which to compensate for losses.

Excess capacity in 1985 does not trace solely to productivity gains. In fact, the foregoing analysis suggests that farm resources are capable of adjusting to productivity gains at rates experienced in recent years. Much of the excess capacity in agriculture in 1985 stems from high real interest and exchange rates induced by an unanticipated federal fiscal policy of large full-employment deficits. A reversal of current fiscal policy will not retrieve all lost markets but will reduce excess capacity in agriculture. Current excess capacity is transitory unless commodity programs provide incentives to maintain excess farming resources and commodity stocks.

Research and extension resources cannot be readily turned on and off to influence output and productivity. As noted earlier, POPR typically has its greatest impact on farm productivity and output eight years after initial investment and is not obsolete on the average until 16 years after initial investment. Thus POPR decisions made today must be designed for expected supply-demand conditions to year 2000.

Our nation's standard of living and ability to compete in international markets depends on productivity of resources. American farmers cannot compete with developing-country farm commodities produced by low cost labor if productivity is no greater in the U.S. than in such countries. An overvalued dollar may temporarily sacrifice comparative advantage in farm exports to competitors. In long-term perspective, however, the nation has little choice but to continue to increase productivity (by investing in high payoff activities such as agricultural research and extension) to be able to compete in international markets and improve standards of living. A significant cutback in POPR outlays would sacrifice a major source of future economic progress.

Summary

The summary briefly reviews findings regarding each of the objectives of this study.

(1) Production-oriented public research and extension (POPR) has had a high payoff according to results of this study. Internal rates of return have remained high and averaged 45 percent in 1982 based on estimates shown in Table 2. The U.S. Department of Agriculture's aggregate multifactor productivity index gave lower estimates of returns than did alternative estimates of productivity constructed for this study. However, the U.S. Department of Agriculture index was used in much of the analysis because possible downward bias in estimates may somewhat offset bias from failure to include contributions of the private sector to productivity gains in agriculture.

(2) Projected impacts in Tables 4 and 5 of greater rates of increase in production-oriented public agricultural research and extension indicate that continuation of past rates of increase in POPR of 3 percent per year will slightly lower future real prices for farmers (and also food ingredients for consumers) if demand grows at 1.5 percent per year but real farm prices will increase if demand grows by 2.0 percent per year. POPR rising at 5 percent or more per year reduces

real farm prices even if demand for farm output grows at 2.0 percent per year. Net farm income, a measure of adjustments required by farmers, holds up well even with growth in POPR up to 9 percent per year if demand grows at 2.0 percent annually. If demand grows only 1.5 percent annually, net farm income becomes negative by year 2025 for a 9 percent rate of future growth in POPR. It is apparent that optimal rates of increase in public research and extension outlays depend heavily on future growth in demand.

(3) Optimal growth in POPR to bring rates of return to 10 percent by year 2025 also depends heavily on assumptions. If POPR must be increased at one rate from 1982 to 2025, results of this study suggest a 4 percent real rate is optimal if demand increases 1.5 percent per year (Table 6). If demand growth is 2.0 percent per year, the optimal single growth rate for POPR is 5 percent per year. Net social benefits (additions to national income) are greater if POPR is increased at a more rapid rate initially and at a slower rate later as indicated by the "step" function for optimal POPR in Table 7. If "optimal" considers adjustments required in farming as well as internal rates of return, other conclusions could be reached.

(4) Finally, this study found that continuing investment in POPR economically is justified even if supply is controlled to raise farm prices and incomes -- within historic bounds for excess capacity. The favorable payoff from POPR even with supply controls results from the high productivity of production-oriented agricultural research and extension. This conclusion does not hold for public inducements (through tax credits or other incentives) to raise conventional farm input use, however, because conventional inputs have much lower rates of return than POPR.

This study has many limitations. Parameter estimates and data need continuing refinement. Disaggregation by commodity, state, and type of investment in research and extension would be useful. Failure to develop an adequate procedure to account for contributions of the private sector to agricultural productivity is a serious shortcoming of this and previous studies. However, even if rather generous estimates of the contribution of the private sector to productivity are assumed, results of this study suggest that POPR has had a favorable payoff relative to alternative uses of public funds. A more complete accounting for impacts of alternative levels of POPR on rural communities and farm family well-being would be desirable but is beyond the scope of this study.

APPENDIX

Division and Default Indices

A modified Laspeyres formula used to construct the USDA Productivity Index employs base period price weights to aggregate the outputs and the inputs. The assumption is that the base period weights will remain constant over time. But some outputs or inputs may be replaced by new, more profitable outputs and inputs. Changes in factor price ratios may occur; producers substitute cheaper and more productive inputs for more costly and less productive inputs. The Laspeyres formula fails to account for these changes over time.

Derivation of the Divisia Index

An advantage of the Divisia Index as a measure of multiple-factor productivity is that the output share and input share weights change continuously so that changes in the output mix and input mix are accounted for.

The problem with Divisia Index in its continuous form is that it requires continuous price and quantity data. However, a discrete approximation can be made as follows:

$$\text{(A-1)}\qquad \frac{MFP_{t+1}}{MFP_t} = \frac{\sum_{i=1}^{n} \frac{1}{2}(\beta_{it} + \beta_{i(t+1)})\log \dfrac{Q_{i(t+1)}}{Q_{it}}}{\sum_{j=1}^{m} \frac{1}{2}(\alpha_{jt} + \alpha_{j(t+1)})\log \dfrac{X_{j(t+1)}}{X_{jt}}}$$

where b_i is the value share of the i^{th} output Q_i in total output value and a_j is the cost share of the j^{th} input X_j in the total input value. All outputs 1, 2,..., n and inputs 1, 2,..., m are combined to form the multifactor productivity index (MFP). Expression (A-1) is used in this study to compute the Divisia Index of U.S. agricultural productivity.

In computing the Divisia Index, the output categories are meat products, dairy products, poultry and eggs, livestock products, food grains, feed grains, cotton, tobacco, oil bearing plants, vegetables, fruits, miscellaneous crops, and nuts. The input categories are labor, real estate capital, depreciation of capital stock, repair and operation of machinery, seeds, fertilizer, feed, livestock, and miscellaneous inputs.

The data on output categories are taken from the U.S. Department of Agriculture's *Economic Indicators of the Farm Sector: Income and Balance Sheet Statistics* (September 1984 and earlier issues). Output is the sum of cash receipts, government payments, home consumption, and inventory changes (less rental value of farm dwellings) deflated by their respective price indexes. Price deflators for all outputs have the same name as the output except for the fruits and nuts value which is deflated by the index for "all crops." All price deflators are taken from the U.S. Department of Agriculture's *Agricultural Statistics* (1984 and earlier issues).

Expenditure data for input categories except land and labor are from *Economic Indicators of the Farm Sector: Income and Balance Sheet Statistics*. The expenditure estimates are deflated by their respective price indexes. The index of motor supply prices is used to deflate expenditures on repair and operation of machinery. Depreciation is deflated by the average of motor vehicles price index and machinery price index; and miscellaneous inputs expense is deflated by the index of prices of all commodities bought for production.

To find the service flow from land, land area adjusted for quality is multiplied by the average cash rent per acre taken from U.S. Department of Agriculture statistics. The labor input is total person hours of labor multiplied by the hired labor wage rate based on data from the U.S. Department of Agriculture.

Derivation of the Default Index

The Default Index of factor productivity was also used as the dependent variable to estimate the contribution of POPR to productivity. For the 1970s, the published U.S. Department of Agriculture's measures appeared to underestimate the gains in productivity consistent with the increase in demand and price changes. Tweeten (1981) derived a procedure to solve for a productivity index consistent with shifts in demand and prices that occurred from year to year.

The Default Index is constructed by assuming equilibrium in a base year and that demand and supply for farm output can be described by the following:

$$\text{(A-2)}\quad Qd_t = AdP_t^{Bd}\, Y_t^{v} N_t + E_t$$

$$\text{(A-3)}\quad Qs_t = AsPR_t^{Bs}\,(1 - w)Qs_{t-1}T$$

where:

Qd_t, Qs_t = demand and supply quantities, respectively;

Ad, As = intercept terms of demand and supply, respectively;

P_t, PR_{t-1} = prices received and parity ratio, respectively;

Y_t = real disposable income per capita;

N_t = domestic population in millions;

E_t = exports;

Bd = short-run and long-run price elasticity of domestic demand;

v = income elasticity of demand;

Bs = short-run price elasticity of supply;

w = rate of adjustment of supply to prices; and

T = default Productivity Index.

Intercept terms are chosen so that demand and supply quantity in the base year, 1972=100. Then equation (A-2) and (A-3) are solved for T over time.

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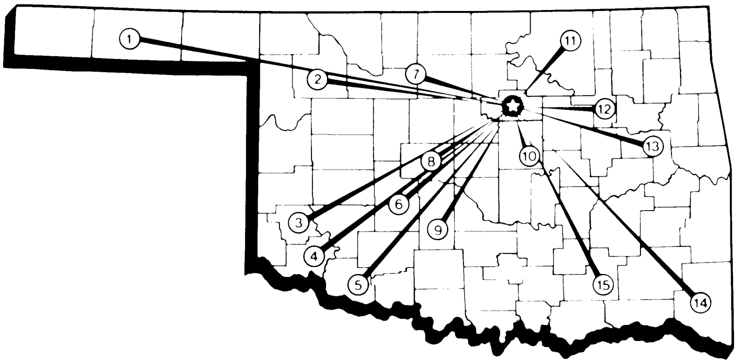

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