EVALUATION OF PAST AND OPTIMAL FUTURE INVESTMENTS IN RESEARCH AND EXTENSION TO INCREASE AGRICULTURAL PRODUCTIVITY

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CHAPTER I

INTRODUCTION

The contribution of technology to economic growth has long been recognized in national and sectorial studies (Solow, Salter, Fabricant, Kendrick). In agriculture, a considerable body of literature relates productivity increases to technological change induced by research, extension, and education (Schultz, Griliches, Evenson, Cline, Tweeten). Creation of technology through such means has become an integral part of public policy in the U.S. agriculture sector. Essentially, investment in research, extension, and education is an indirect public policy instrument to increase productivity in agriculture and achieve national objectives such as making food and fiber available to consumers at reasonable prices.

Outlays to expand farming productivity through public education predate specific attempts to fund farming productivity gains through research and extension aimed directly at farmers. Direct publicly supported efforts to improve farming productivity began with the Morrill Act of 1862 which established the land grant colleges, followed by the Hatch Act of 1887 that created the State Agricultural Experiment Stations (SAES). In 1906 the Adams Act increased funding for the SAES. The Smith-Lever Act of 1913 established the Agricultural Extension Service, and the Smith-Hughes Act of 1917 established federal support for teaching of vocational agriculture in

TABLE I

PUBLIC RESEARCH AND EXTENSION EXPENDITURES 1939-1984 (IN MILLIONS OF CURRENT DOLLARS)

YEAR	PRODUCTION ORIENTED	NONPRODUCTION ORIENTED	TOTAL
1939	64	41	105
1940	66	43	109
1941	63	43	106
1942	65	46	113
1943	66	40	106
1944	68	42	110
1945	76	43	120
1946	91	46	137
1947	113	72	186
1948	120	90	210
1949	140	68	206
1950	157	121	279
1951	162	84	247
1952	174	89	263
1953	180	98	278
1954	190	101	291
1955	202	104	306
1956	224	137	361
1957	250	146	395
1958	282	184	466
1959	296	189	485
1960	312	191	503
1961	334	204	538
1962	361	206	568
1963	381	228	609
1964	413	245	659
1965	456	255	711
1966	498	248	746
1967	520	267	787
1968	566	283	849
1969	597	299	896
1970	645	354	999
1971	710	372	1082
1972	779	456	1235
1973	841	621	1462
1974	904	652	1556
1975	1034	714	1748
1976	1145	782	1927
1977	1248	782	2030
1978	1379	680	2059
1979	1493	724	2217
1980	1646	787	2433
1981	1652	856	2508
1982	1741	901	2642
1983	1864	965	2829
1984	1856	1031	2887

Sources: Cline, Phillip L., "Sources of Productivity Change in U.S. Agriculture", Ph.D. Thesis, Oklahoma State University, Stillwater, OK, 1975 and U.S. Department of Commerce: Combined Statement of Budgets, Government Printing Press, Various Issues, Washington, D.C.

high schools. These Acts and other legislation (Tweeten, 1979) effectively created institutions to generate and disseminate technology and increase productivity of the farming sector.

The evidence of this public commitment can be gleaned from Table 1. Public expenditure on research, extension and education increased from $105,492 to $2,433,712 during the three decades of 1940-1980. The annual growth was 6.97 percent in the 1939-49 decade; 8.94 percent in the 1949-59 decade; 6.33 percent in the 1959-69 decade; and, 10.5 percent in the 1969-79 decade.

In real terms, the annual growth of public expenditure on production-oriented research, extension, and education was 41 percent in the 1939-49 decade, 6.5 percent in the 1949-59 decade, 3.0 percent in the 1959-69 decade and 2.2 percent in the 1969-79 decade.

During the same four decades productivity in agriculture (total. output/total input) increased by 18 percent during 1940-1950, 26 percent during 1950-1960, 13.3 percent in the 1960-1970 and 12.7 percent during the 1970 decade. During the four decades total productivity increased 92.0 percent.

The relationship between public expenditures on research, extension, and education on one hand, and productivity growth on the other hand has been the subject of numerous investigations (Schultz 1957, Griliches 1958, Peterson 1967, Evenson 1968, Cline 1975, White and Havlicek 1982). The consensus of the findings is that the average and marginal rates of return to production-oriented public expenditure on research and extension are very high relative to returns on alternative investments. Other things being equal, it appears that net social benefits would accrue from increased investment in research, extension, and education. Efficient allocation of scarce public resources requires an increase in allocation to high-return investments until rates of return are equal for investments of similar risk.

Conditions are rapidly changing, however. The findings of the previous studies notwithstanding, reappraisal of the effect of research, extension and education on productivity in agriculture seems necessary for reasons discussed below.

Need for Reappraisal

Evidence from the 1960-1970 and 1970-1980 decades suggests rates of gain in productivity are declining, while expenditures on research and extension continue to grow at least in nominal terms. This slow-down in the rate of productivity has caused some to raise questions concerning the payoff from public expenditure on agricultural research, extension and education.

Some have attributed the decline in the growth rate of productivity to the fact that redundant labor no longer exists in farming to provide increase productivity when it is replaced by more productive inputs. Also most farm output comes from farm firms which have reached their economic size--their minimum long-run average cost (Cline, 1975). Therefore, new breakthroughs in technology are necessary to shift this cost function and/or increase productivity.

Low-cost sources of future farm output are certainly needed now as much as ever before. The disparate growth rates between population and production of food and fiber in many developing nations has potentially chilling consequences. The U.S. has become the breadbasket of the world, providing about one-fifth of the agricultural commodities that enter the world markets (USDA, 1984). Foreign exchange earnings from the export of agricultural products help the nation's balance of payments. Annual net U.S. foreign exchange earnings from the agricultural commodities amounts to $37-44 billion. Increasing productivity helps to maintain and/or improve this nation's competitive position in world markets.

Past studies have failed to estimate the contribution of the private input supply sector to research, extension, and to productivity change in agriculture. The agriculture sector is increasingly dependent on the nonfarm sector for its inputs and these inputs are frequently improved in productivity and profitability by efforts of private firms producing and marketing the inputs. Costs of improving these inputs may not be charged to farmers in higher inputs prices. Estimates of the contribution of private firms to farming productivity are elusive and unreliable. If the contribution of the private sector to productivity has been underestimated, then the estimated contribution of the public sector to productivity may have been overestimated.

Technical change increases supply of agricultural products, ceteris paribus. An increase in supply impacts on prices of output and incomes of farmers. In determining economic feasibility of expanding productivity through research, extension, and education, the impact of increased output on farm prices and rates of return must be accounted for.

Finally, questions persist concerning the conceptual foundations of conventional productivity indices. For example, is the Laspeyres productivity index used by the USDA adequate as a measure of multifactor productivity (MFP) in agriculture? Among other shortcomings, this index does not account for substitution of cheaper for expensive inputs as prices change. Furthermore, the USDA agricultural productivity index underestimates some inputs and overestimates others. For example, soil erosion is underestimated, causing the land input to be overestimated and the productivity index underestimated, ceteris paribus.

Divisia and Default indices (see Appendices A and B) are other measures of MFP. Divisia index of TFP is theoretically appealing in that it accounts for changes in factor shares through time. Default index is a crude measure of productivity constructed by working backwards assumingly a base year. Both Divisia and Default indices can be used to estimate the contribution of research, extension and education to productivity.

Objectives

The general objective of this study is to reappraise the contribution of research and extension to productivity in U.S. agriculture and determine the optimal levels and time path of public investment in research and extension over a planning horizon. The specific objectives are to:

(1) Evaluate, ex post, the contribution of research and extension to agricultural productivity using an econometric model and three measures of productivity as dependent variables: USDA index, Divisia index, and Default index.

(2) Estimate the private sector's investment in research and extension and its contribution to productivity in agriculture.

(3) Estimate the length of lag for productivity to respond to investments in research and extension.

(4) Determine the optimal levels and time path of public investments in research and extension over a specified future planning horizon with farm prices and incomes endogenous.

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

Definitions and Limitations

Production is a physical process by which factor inputs are transformed into goods and services. In a static sense, the technology in use determines the efficiency with which the factor inputs are transformed into goods and services. This efficiency maybe measured by partial productivity (ratio of total output to an input in the case of a single input) or total factor productivity (the ratio of total output to total production inputs in the case of multifactor inputs). The interest of this study lies in the latter.

In agricultural production, there are many heterogenous inputs and outputs which cannot readily be combined to measure aggregate physical input or output. To compute multifactor productivity, the "price" of each output and each input is used to aggregate quantities. This raises the usual index number problem of what weights to use and how to account for changes over time, where some inputs are discarded and others introduced.

More will be said later on index numbers. For now suffice it to say that an increase in productivity over time may be measured by the ratio of value of output to input in the comparison period to value of output to input in the base period where quantities are weighted by constant base period prices. An increase in the ratio implies an increase in productivity. At issue is how this productivity change came about.

An increase in productivity over time implies that the production process produces more output of goods and services with the same quantity of inputs or the same output with less inputs. Technology is usually credited as the major source of the change in productivity in agriculture (Griliches, 1957). The term "technology" is a catchall for what is in most cases merely a substitution of a more productive and profitable input, practice or technique for a less profitable and productive one. It is helpful to identify the underlying factors rather than the generic name "technology" in explaining productivity changes for purposes of making public policy.

In broad terms, technology has many dimensions. It includes (a) improved quality of inputs, such as better trained, skilled, experienced labor and improved machinery and crop varieties; (b) better management practices such as integrated pest management or minimum tillage; and (c) new techniques of organization, marketing systems and administration (Mansfield, 1968). Some authors make the distinction between technology and technical change: defining technology as society's stock of knowledge (including the state of the arts) and technical change as the adoption of new techniques. This implies that the latter is the realized source of productivity changes while the former is the potential for future productivity. The terms technical change and technology are used herein interchangeably to mean sources of productivity increase.

New inputs may be identified from proper time series data but the measurement of quality improvements in them require separate data series which are not available (Heady and Dillon). In our empirical study, separating quality improvements from input value is virtually impossible (Cline, 1975). The assumption is that productivity gains arise from changes in quality of inputs that are not reflected in input prices but are caused by public education, research, and extension inputs. It is assumed that this relationship between output and nonconventional inputs can be correctly quantified and specified empirically in equation form.

Another limitation is the unavailability of any data series showing total factor inputs. The existing USDA productivity index measures output per unit of conventional inputs and does not measure productivity of total factor inputs: it leaves out nonconventional inputs.

Reliable, extended data on the private sector expenditure on productivity increasing research and extension are not available. The availability of only a few years of data give rise to estimation problems. Several years of data are required to quantify the lag effect of research and extension on productivity. Various approaches will be used to bracket the most likely range of outcomes under alternative conceptual models of the impact of private investment in greater productivity of the farming industry.

CHAPTER II

LITERATURE REVIEW

A considerable number of studies relate research and extension to agricultural productivity increases. Although differing in their approaches, these studies conclude that the contribution of research and extension to productivity has been significant. The studies can be categorized as ex post and ex ante approaches. Concepts commonly used in ex post studies include: (1) the value of inputs saved, (2) consumer surplus, (3) production function, (4) national income, and (5) nutritional impact. The ex ante studies have used: (1) a scoring approach, (2) ex ante benefit-cost analysis, (3) simulation models, and (4) mathematical programming.

Productivity evaluation studies differ in approaches, as well as in their targets of inquiry. Some studies focus on aggregate levels of productivity, while others focus on a specific commodity at national, regional, or state levels, and still others focus on multiproducts. Some of these studies are reviewed in this section with emphasis on methodology and empirical results.

Ex Post Studies

Inputs Saved Approach

Schultz (1957) pioneered work to quantify the contribution of research and extension to agricultural productivity. In his ex post evaluation of the contribution of research and extension, he used values of inputs saved in 1950 as compared to 1910. He found that agricultural output was 32 percent higher in 1950 than in 1910. He reasoned that use of 1910 techniques to produce the 1950 output would have required \$39.6 billion instead of \$30 billion actually used (using 1910-14 prices), and attributed the difference of \$9.6 billion (\$39.6 - \$30.0) to the improved techniques used in 1950.

He also estimated value of inputs saved using 1946-48 price weights. In 1950, input of \$30.0 billion was 14 percent higher than in 1910, whereas output in 1950 (using 1946-48 prices) was 75 percent higher than 1910 and productivity increased by 54 percent. The dollar value of the 1950 level of output using 1910 techniques would have been \$16.2 billion (.54 X \$30) in additional inputs. Thus, in 1950 alone, \$16.2 billion worth of inputs were saved by productivity gains since 1910.

Schultz (1953) warned against attributing all the estimated gains from public investment to public research and extension because: (1) public expenditures on research and extension may partly finance nonproduction oriented research. Therefore attributing all of the above estimated effect to production oriented public research and extension may give biased results; (2) the estimates may include gains from private sector research, thus bias upward the contribution of production oriented public research. In addition, the estimates may be biased upwards since education, public roads, television, magazines, and newspapers had some effect in raising farm productivity that is not accounted for in conventional inputs.

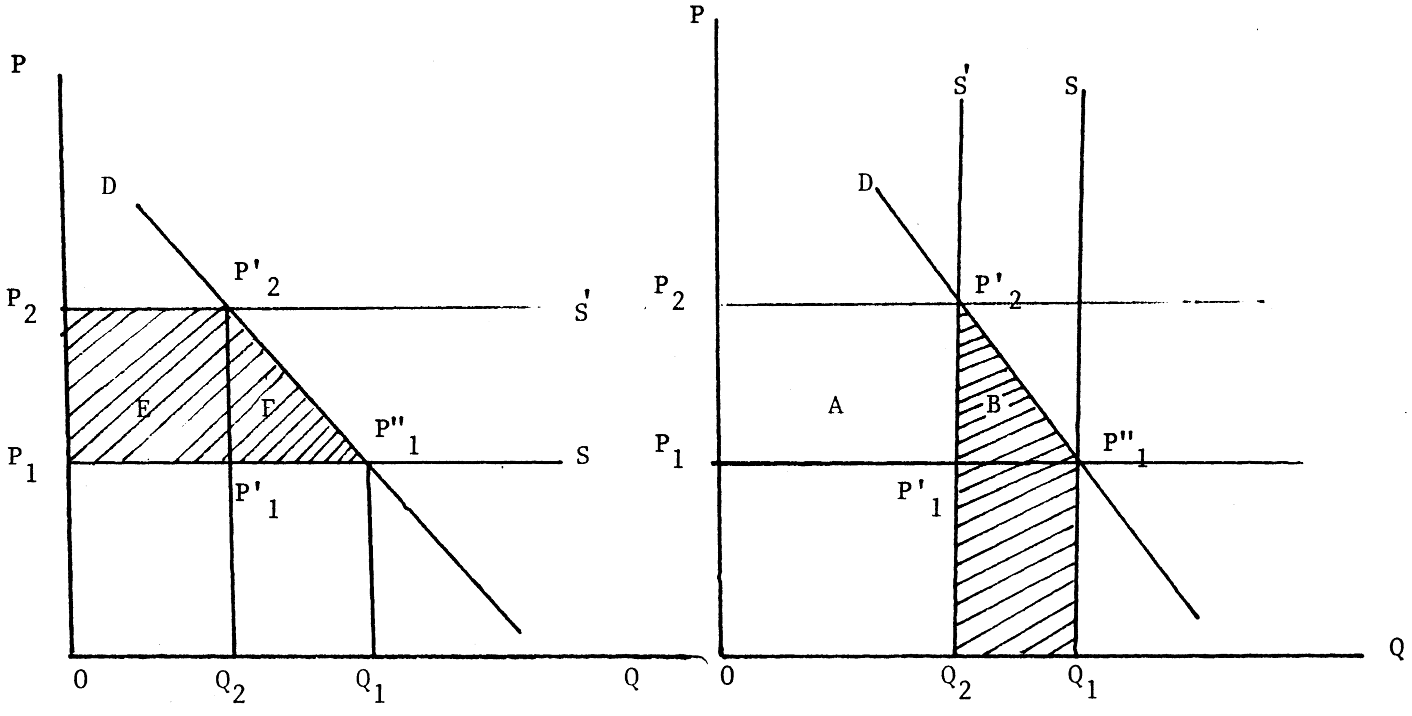
Peterson (1967), using a similar approach and updated data (1950-1967), reported that annual value of inputs saved increased from about \$10 billion in 1950 to about \$26 billion in 1967 (constant 1957-59 prices). Using data for 1950-1967 Peterson also estimated a marginal internal rate of return to research and extension of 42 percent.

Consumer Surplus Approach

The consumer surplus approach places a value on extra output resulting from more efficient resources and techniques induced by research and extension. Research and extension shifts the supply curve to the right, ceteris paribus, creating "economic surplus". Theoretical controversy notwithstanding (Currie, Murphy and Schmidt, 1971), the concept of economic surplus has been widely used to evaluate the contribution of research and extension to productivity.

Griliches (1958) was the first to apply the consumer surplus approach in his study of the economic payoff from hybrid corn. He assumed parallel shift of the supply curve as shown in Figure 1a and 1b, and thus implicitly assumes unitary elasticity of demand.

Griliches estimated the loss in social surplus if hybrid-corn (new technology) were to disappear. This would shift the supply curve upwards from S to S' in (1a) and to the left from S to S' in (1b). The resultant loss in consumer surplus is the area under the demand curve between the old and the new supply curves. Assuming a perfectly elastic supply curve (1a) the welfare loss is represented by $P_2P_2'P_1''P_1$, while under the assumption of an perfectly



(a)

(b)

Figure 1. Griliches' Approach to Estimatin Returns to Research and Extension.

inelastic supply curve (1b) the welfare loss is represented by $P_2'P_1''Q_1Q_2$. The consumer surplus S is estimated using the following formulas:

$S_1 = KP_2Q_1\ (1 - 1/2\ Kn)$ in Figure 1a

$S_2 = KP_2Q_1\ (1 + 1/2\ K/n)$ in Figure 1b

where:

K = percentage change in yield caused by hybrid corn

P_1 and Q_1 = original equilibrium price and supply quantity of corn, respectively.

n = absolute value of the price elasticity of demand for corn.

Griliches estimated the lower limit of consumer surplus from (1a) and the upper limit from (1b) and reported the widely quoted "external" rate of return of 743 percent, using the cash flow technique where research and extension costs are outflows and annual values of consumer surplus are inflows. An interest rate assumed to reflect the opportunity cost of capital in the economy is used to discount both the outflow of research costs and the inflow of consumer surplus (considered perpetual) to a point in time where development of technology is closed. The 743 percent "external" rate of return is computed assuming 5 percent as the opportunity cost of capital in the economy. The interpretation of this rate of return is that, on the average, hybrid corn returned 743 percent annually on investment in the discounted (at 5 percent) value of its development.

A preferred approach to discount costs and returns of research is to compute that internal rate of return which equates the present value of flow of costs with the present value of flow of the returns over the entire life of the investment. The internal rate of return

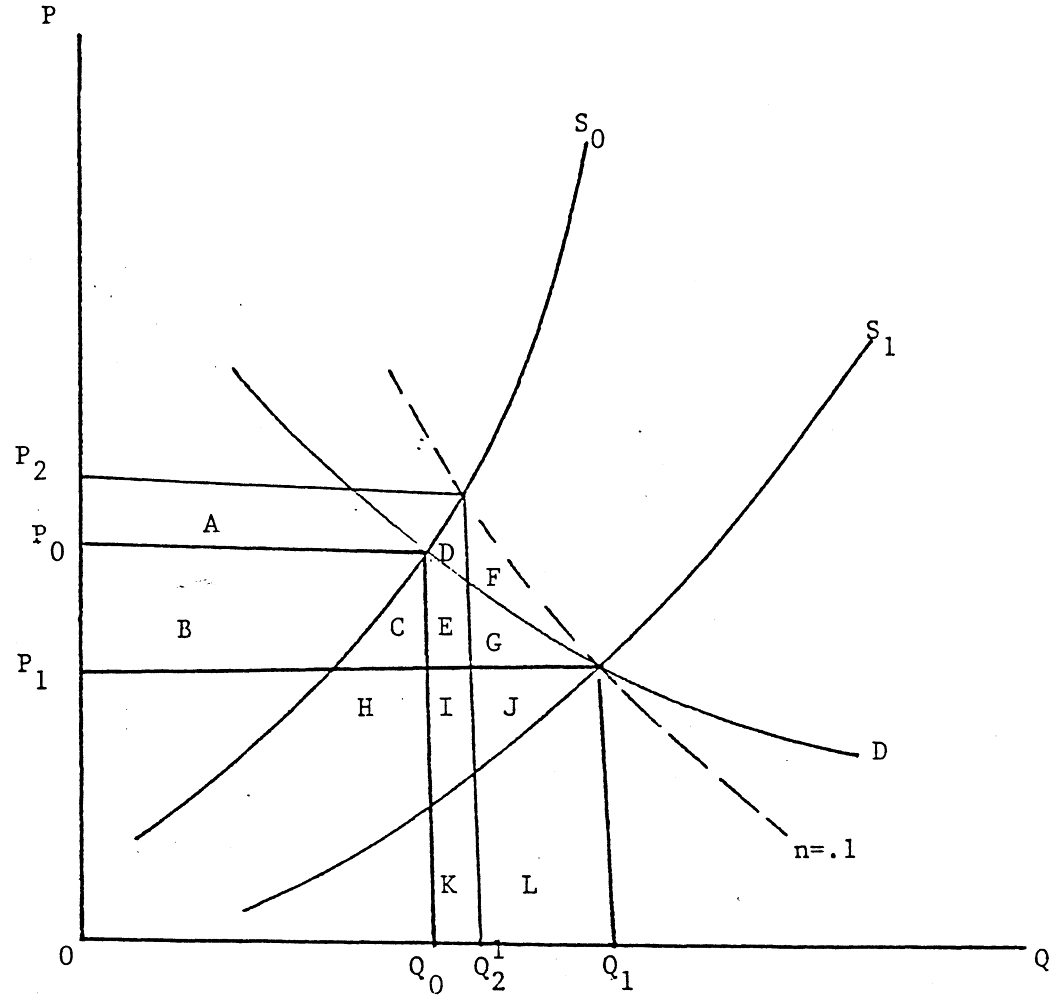


Figure 2: Peterson's Approach to Estimating Returns to Research and Extension.

on hybrid corn according to the Griliches study is about 37 percent. On the average, each dollar invested on research on hybrid corn returned about 37 percent annually from the time it was invested to perpetuity.

Peterson (1967) employed the consumer surplus approach to estimate the rate of return to investment on poultry research. Unlike

Griliches, Peterson eliminated the assumption of unitary elasticity of supply and demand curves by assuming proportional supply shifts (Figure 2). Under the assumption of no new technology, the poultry supply function shifts from S_1 to S_0, and P_1 and Q_1 shift to P_0 and Q_0 respectively. Then, the net change in economic surplus becomes:

$$CS = A+B+C+E+G+(-A-B+H+I+J) = C+E+G+H+I+J$$

Peterson approximates this area by

$$KQ_1P_1 + 1/2\ K^2P_1Q_1/n - 1/2\ Q_2K^2P_1\ (P_1/P_0)$$
$$(en\ /\ n+e)\ (n-1\ /\ n)^2$$

where:

n = absolute value of the demand elasticity

e = supply elasticity

K = percentage shift in supply curve $(Q_1 - Q_2/Q_1)$

If n = 1 or e = 0, the above equation can be reduced to

$$KQ_1P_1\ (\ 1 + K\ /\ 2n)$$

Equating the estimated annual net social returns and the annual poultry research and extension expenditures, Peterson found an internal rate of return of 18 percent. This magnitude is quite different from other estimates from his work as reviewed under the production function approach.

Schmitz and Seckler (1970) estimated the social benefits and social costs of the tomato harvester, accounting for the effect of the new technology as apparent in displaced farm workers. They estimated gross social rates of return on investment of 929 to 1,282 percent, ignoring distributional effects and without compensation for displaced farm workers. Where compensation for the displaced workers was considered, and as the amount of compensation varies from 0 percent to 100 percent of the displaced wage bill, the net social rate of return varied from 1,288 percent to -345 percent.

Hertford and Schmitz (1977) assumed that demand and supply curves are linear and that the supply shift due to technical change is parallel and that the net social surplus can be approximated by the following:

Change in total net social surplus = KP_1Q_1 (1+1/2K/n+E)

Change in consumer surplus = KP_1Q_1 / n+e (1 - 1/2 Kn / n+e)

Change in producer surplus = KP_1Q_1 (1 - 1 / n+e)

[1 - 1/2 K (2n+e / n+e)]

K = Horizontal distance between S_1 and S_0.

Ayer and Schuh (1972) estimated the social returns to cotton breeding programs in southern Brazil. They assumed that demand for cotton from southern Brazil is dependent on current year's prices and supply is dependent on previous year's price, and that supply shifts to the right due to the difference of yield between improved and unimproved cotton seed. Then, using a price elasticity of demand (-.188) and a price elasticity of supply (.944) of cotton from prior studies, the authors estimated the social rate of return to be 90 percent. The distribution of the benefits was 60 percent to producers and 40 percent to consumers. Land owners and managers received large portions of the benefits. Labor benefited through greater employment without an increase in wages.

Akino and Hayami (1975) followed an approach similar to Ayer and Schuh and estimated social benefits from rice breeding research in Japan. Consider d and S_0 as actual market demand and supply curves in figure 3. S_n supply curve would exist if improved rice were not developed. Assuming closed economy market equilibrium, a shift in the supply curve from S_n to S_o increases consumer surplus by the area ABC + BP_nP_0C; producer surplus by the area ACO - BP_nP_0C and social benefit by area ABC + ACO.

If the public policy is to maintain a sufficient supply of rice to prevent a rise in cost of living, i.e. maintain price at P_o, and if domestic production of rice could not meet the demand, i.e. supply does not shift from S_n to S_0, the difference $Q_n{}' \, Q_0$ must be imported. This reduces producers surplus by BP_nP_0C without being compensated by area ACO. Under the assumed conditions, they found that consumers were sole beneficiaries of research; producers were worse off. When they used low price elasticities of demand and supply, their estimated rate of return ranges between 18 percent and 75 percent - - estimates in line with those of Griliches and Peterson in the United States, Ayer and Schuh in Brazil.

Scobie and Posada (1978) studied the impact of the Columbian national rice research program. They also investigated the incidence of research costs and the resultant benefits among upland producers, irrigated land producers and consumers in various income groups. They concluded that the national research program benefited consumers the most, while producers suffered overall. The small producers lost the most.

National Income Approach

Tweeten and Hines (1965) point to the increase in agricultural productivity even as the aggregate volume of conventional inputs

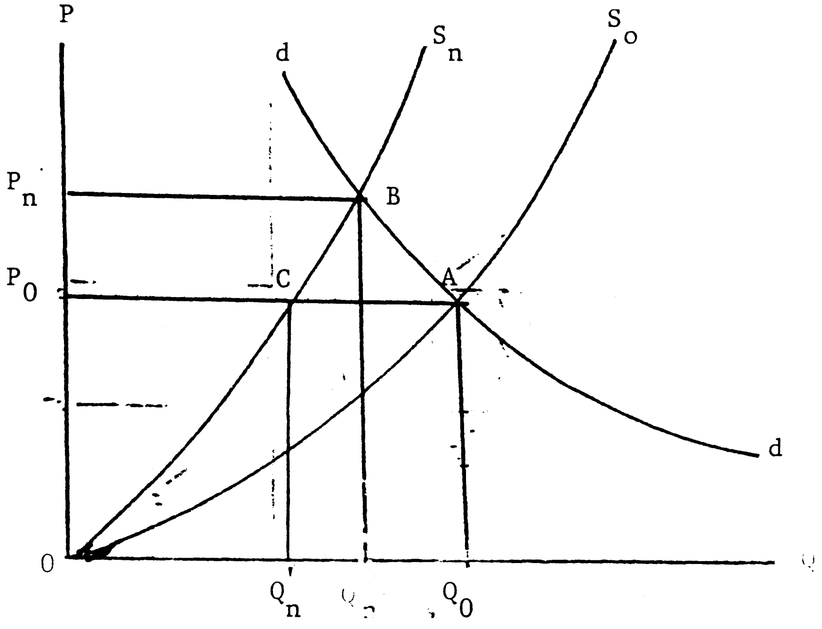


Figure 3. Akino and Hayami Model of Estimating Returns to Research.

remained the same since 1950. Because the farm sector adopted machinery, fertilizers, seeds, pesticides, feeds and management techniques made more productive and profitable by education and research, the conventional inputs yielded more output through application of nonconventional inputs. The authors employed the notion that national income increased due to agricultural productivity which made possible outmigration of human resources to the nonfarm sector where the value of their marginal product is higher.

For the 1910-1963 period, they estimated national income of $247 billion if the percentage of farming population in 1963 were the same as in 1910 and if everyone were paid the 1963 per capita income prevailing in the farming sector, and $500 billion if payment is computed using 1963 per capita income prevailing in the nonfarm sector. National income would have been $482 Billion if everyone in each sector were paid the 1963 per capita income prevailing in their respective sectors. They calculate a benefit-cost ratio of 2.0.

The authors also reported that, if productivity in agriculture had not released human resources to more productive jobs, the national income in 1963 would have been $411 billion lower than actual national income. According to these authors, the higher the gap in per capita income between the farm and nonfarm sectors, the more outmigration of human resource from farming and therefore the higher the returns to agricultural research and extension.

Production Function Approach

In addition to the inputs saved and consumer surplus approaches, another frequently used approach to estimate the contribution of research, extension and education is the production function approach.

Theoretical problems arise in measuring the research and extension variables. Evenson (1974) has suggested use of the number of publications in scientific journals as a proxy to specify research and extension output. An alternative specification is the use of some measure of adoption of technological innovation resulting from research to specify the research variable. Sim and Araji (1980) used the acreage harvested of wheat varieties bred by western agricultural experiment station systems to measure output due to adopted innovation. The problem is that it is applicable only to limited types of research for which the output can be measured in this way.

Griliches (1964) was the first to specify research and education as independent variables in a production function. Research and extension were defined as expenditures of state and agricultural experiment stations and extension services. He introduced a crude intuitive method of providing for the lagged effect of research and extension on productivity by constructing observations on research and extension using average expenditures of the previous year and the level of six years previously (e.g. average of 1953 and 1958 expenditures is used as the observation for 1959). He then fitted cross sectional data across states for 1949, 1954, and 1959 to a Cobb-Douglas production function and reported a marginal product for research and extension of about $13, which when adjusted for private sector's share was $6.50, i.e. every dollar invested in research and extension increases output by $6.50.

Peterson converted this estimated marginal product of research and extension to an internal rate of return. He assumed a 6-year lag between expenditure and initial return and found that the undiscounted marginal product of $6.50 converts to an internal rate of return of 53 percent if the return continues to perpetuity; 36 percent if the return is realized in the sixth year.

Peterson (1971) also used a similar specification and estimated the rate of return to investment on poultry research. He used two alternative measures of productivity gains: Gains in feed efficiency and the decline in prices of poultry products relative to those of poultry inputs. He fitted cross-sectional data across states (1959) including experiment station research on poultry as a separate variable to a Cobb-Douglas production function and reported an undiscounted marginal product of research of about $6.00 adjusted for the contribution of private research. By assuming a 10-year lag for the effect of research to influence output, he estimated a marginal internal rate of return of 33 percent.

Evenson (1967) employed a production function to measure the effect of research on productivity and the mean length of the lag between research expenditures and inflow of benefits. He fitted time series data for the U.S. (1938-1963) and cross-section data for states in estimating the effect of research and extension on productivity. A productivity index is employed as the dependent variable and current values of public research and extension expenditures, weather index and an index of educational attainment as independent variables. Evenson found a marginal product for public research and extension of $10.80 and a marginal internal rate of return of 57 percent. Adjusting the coefficient for private research reduces this rate of return to 48 percent. He also assumed that research and extension expenditures have an inverted V time form and estimated the mean lag of state supported research to be about 5 1/2 years and for federally supported research to be about 8 1/2 years when productivity resulting from research and extension reaches its maximum.

Evenson admitted the V shape hypothesis of the contribution of research to productivity is inelegant and unwieldy for empirical estimation and statistical treatment (p. 34). He then proceeded to let the data determine the form of lag. Alternative lengths (n) of lag to total technological obsolescence were tried in an iterative fashion to estimate the parameter (average lag) n/2; the R^2 criteria is then used to determine the best estimate of n/2.

Cline (1975) followed Evenson and fitted a Cobb Douglas production function to national data for the years 1939-72 using an Almon distributed lag model. Cline found that a 1 percent increase in research and extension causes .037 percent increase in productivity over its lifetime. This amounted to marginal physical product of $4.30 and marginal internal rate of return of 26 percent. After adjusting for private sector contribution, the marginal internal rate of return to public investment on research and extension was 22 percent. His estimate of the length of lag between investment and the beginning of return was about six years. He also found a 13-year lag between research and extension investment and obsolescence of the new technology.

Cline also estimated the regional impact of public research and extension, computing internal rates of return to investments, and other productivity parameters in each of the 10 production regions in the U.S. The lag between research and extension investment and obsolescence of output therefrom ranged from 9 years in the Pacific region to 14 years in the Great Lakes region. The marginal internal rate of return without adjustment for the private sector expenditures also varied among regions ranging from 54 percent in the Pacific to 17.5 percent in the Southern Plains.

Other studies also have focused on the impact of research and extension at state or regional levels. Latimer and Paarlberg (1965) attempted to determine whether state differences in creation and distribution of technology by public institutions affected average productivity of farms among states. They tested the hypothesis that differences in public inputs of agricultural research and education are not significantly related to differences in gross income per farm from state to state, after taking into account the effects of other inputs. They found that a state does not capture for its own farmers all the benefits of research and extension work done in that state and concluded that agricultural knowledge is pervasive. Spillover occurs because information produced by public research agencies is freely available to all without regard to state boarders.

Bauer and Hannock (1975) performing similar analysis found that every dollar invested on research and extension increased farm output by $5.84 in 9 years. But they could not find statistically significant coefficients on the research and extension expenditures within the state, implying that there is a tendency for research results generated in one region to spill over to another region. Evenson (p. 173) made similar conclusions.

Brehdal and Peterson (1976) estimated the marginal product and internal rate of return to investment in research and extension on specific commodities (cash grains, poultry, dairy and livestock). They fitted a cross-section of national and state data (1969) to a Cobb-Douglas production function and found internal rates of return on the national level ranging from 46 percent to 36 percent for the various commodities.

The authors also found substantial differences in marginal products of and rates of return to investment in research and extension on each of the four commodities -- both among states and within states. They concluded that there may be spillover of research and extension results between states and that states with larger research departments are net exporters of research results. It is possible that the estimated marginal products of investments for the larger states is biased downwards and that for the small states biased upwards.

To isolate the separate effects of research and extension investments within and outside the region, White and Havlicek (1979) estimated two production function models for the southern region of the U.S. In the first model, output per farm was regressed on conventional inputs and current and lagged value of research and extension expenditures within the southern region. In the second model, a variable to account for the effects on productivity in the southern region resulting from investments on research and extension outside the region was explicitly recognized as a separate variable in addition to the explanatory variables in the first model.

Both models were estimated using time series data and Almon (1965) distributed lag procedure, yielding marginal products of research and extension of $11.56 for the first and $7.99 for the second model. Internal rates of return to investment on research and extension were 50.8 percent and 39.8 percent for the first and second models, respectively.

The authors concluded that increases in productivity in a region result from investments on research and extension within the region and outside the region, and that interregional transfer of research results is pervasive. They also reported that the rate of return on research and extension in the southern region is 72 percent if all productivity increases are attributed to investments within the region

(Model I). Accounting for interregional transfer of research and extension results, the rate of return to investment on research and extension in the southern region is 20 percent (Model II).

In a related study, White and Havlicek (1980) regressed output per farm on crop acreage per farm, capital input per farm, and lagged value of research and extension expenditures. Time series data for 1929-77 were divided into three periods: 1929-1941, 1942-1957, and 1958-1977 to test for differential effects of research and extension expenditures during the subperiods. They found that the regression coefficient on research and extension, 0.20 during 1929-1941; declined to 0.185 during 1942-1957 and 0.193 during the 1958-1977 period. They also found marginal products of $10.21, $8.47 and $6.89 during the three periods, respectively. The internal rates of return to investments on research and extension during the three time segments were 54.80 percent, 48.30 percent and 41.70 percent. The authors concluded, among other things, that the rate of return to investment on research and extension was highest when there was a greater potential of substituting improved capital for labor.

Otto and Havlicek (1981) investigated the response of individual crops (corn, wheat, soybeans and sorghum) to research and extension expenditures within a state and outside the state. They estimated a supply response model using time series (1967-77) and cross section data, and reported internal rate of return to research expenditures within the state on the basis of a 12-year total lag of 177.7 percent for corn, 81.0 percent for wheat, 176.4 percent for soybeans and 101.2 percent for sorghum. Likewise, the rates of return for extension were 63.1 percent for corn, 62.7 percent for wheat and 47.00 percent for sorghum on the basis of the 12-year lag. These estimated results did not account for private research, however.

Ex Ante Studies

Benefit-Cost Analysis

The ex ante benefit-cost approach of evaluating agricultural research is conceptually analogous to the consumer surplus approach. The main difference is that in an ex ante benefit-cost analysis, the effects of research and extension on productivity are predicted on the basis of subjective judgments of research scientists on such questions as probabilities of research success and adoption of resulting technology, size of costs and benefits of research projects. This information is used to calculate expected or predicted benefit-cost ratios and rates of return on projects. The major criticism of this approach is its heavy dependence on subjective judgments of research scientists and other experts.

Using a probabilistic model, Araji, Sim and Gardner (1978) made an ex ante estimate of the costs and benefits of research and extension directed to sheep, lettuce, tomatoes, grapes, apples, citrus fruits, potatoes, cotton and rice for the western region. The benefits estimated were dependent on the probability of research success and probability of adoption of the results. Costs were the expected outlays on research. Based on the expected benefits and costs, they estimated the internal rate of return to investment on research and extension. Their results are given in the Table II.

The authors also reported that without extension activities, one-fourth to two-thirds of the expected rates of return to investment on research will not be realized, depending on the commodity.

Lindner and Jarret (1978) argue that previous consumer surplus techniques of measuring gross annual research benefits have paid insufficient attention to the manner in which the supply curve shifts in response to the adoption of innovation. They argue that total benefits will differ in magnitude as innovations generate divergent, convergent or parallel shifts in supply (their exposition is shown by figure below). The authors developed a formula for measuring the size of research benefits generally applicable to all types of supply shifts.

TABLE II

EX ANTE RATE OF RETURN (PERCENT) TO PUBLIC INVESTMENT
IN AGRICULTURAL RESEARCH AND EXTENSION
IN THE WESTERN REGION

Commodity	13-Year Lag	18-Year Lag
Sheep	33.28	34.75
Lettuce	35.83	83.28
Tomatoes	45.63	47.58
Grapes	39.85	41.70
Apples	47.73	48.69
Citrus Fruits	0	25.17
Potatoes	104.43	104.18
Cotton	42.38	42.38
Rice	33.83	35.59

Assuming that the current supply situation is known and demand-supply curves are linear S_0 and D_0, they made an ex ante estimate of the impact of investment on research on supply and hence the social benefits from research and extension. Adopting new technology would shift supply from S_0 to S_1. The gross annual research benefit is $A_1M_1M_0A_0$. Their generalized formula is:

(1) $A_1M_1M_0A_o = 1/2(P_oQ_1 - P_1Q_o + Q_oA_o - Q_1A_1)$

(2) Change in producer benefits = $1/2(Q_oA_o - Q_1A_1 - P_oQ_o + P_1Q_1)$,

(3) Change in consumer benefits = $1/2(Q_oQ_1 - P_1Q_o + P_oQ_o - P_1Q_1)$

where P_o and Q_o are current price and quantity.

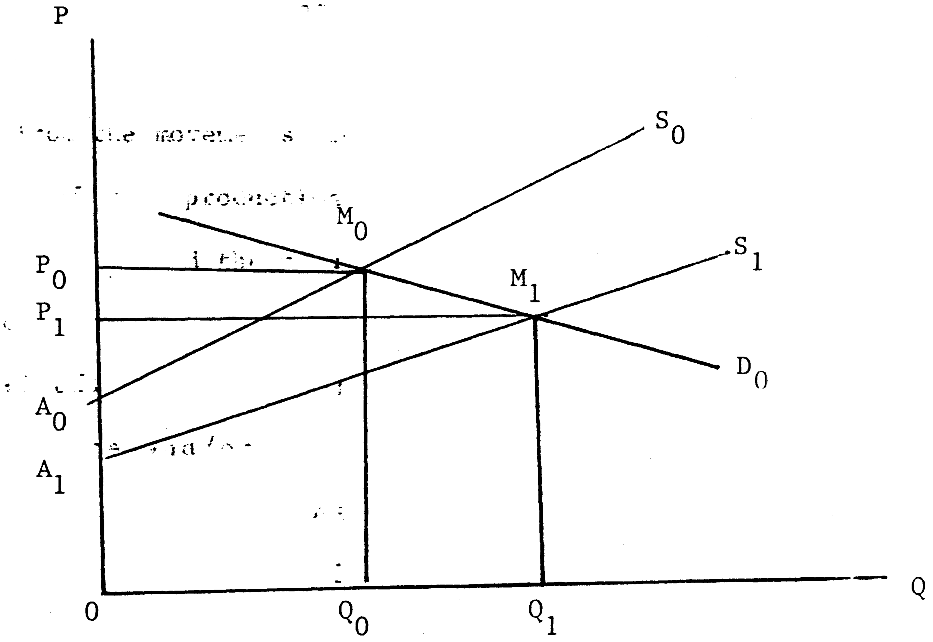


Figure 4. Lindager and Jarrett Model of Estimating Returns to Research and Extension

In summary, the numerous studies using the consumer surplus approach have assumed that the supply shifts to the right as a result of technical change induced by research and extension. These shifts have been assumed to be parallel (Griliches, Hertford, Schmitz); proportional (Peterson); pivotal (Akimo and Hayami, Ayer and Schuh); and parallel, convergent, divergent, or pivotal (Lindner and Jarret). The distributional effects between consumers and producers differ significantly depending on the nature of the supply shifts.

In spite of the controversy surrounding the nature of supply shifts, the consumer surplus approach has been used widely to estimate economic surplus, average product and average rate of return resulting from investments on research and extension. In agriculture, decisions to invest in research and extension are made on the margin, often with no specific technology development in mind at the time of funding. Knowledge of the marginal product and marginal rate of return for aggregated research and extension outlays are relevant in this decision process.

Simulation Approach

Yao-Chi Lu, Leroy Quance and Chun Liu (1978) estimated the parameter on research and extension and its lagged effect on productivity using the Cline (1975) production function model. They fitted national aggregate time series data for 1939-72 using an Almon distributed lag model. They found that a 1 percent increase in research and extension expenditure will increase productivity gradually with peak impact after 6-7 years.

The parameter estimates were used to simulate ex ante productivity growth, and to compute benefit-cost ratios, and rate of return to public research and extension. Growth rates of research and extension expenditure of zero percent, 3 percent, and 7 percent were assumed to result in low level, baseline (historical level), and high level technologies respectively. Ex ante projections based on the three technological scenarios show productivity index increases from 112 in the base year (1974-76) to 144 under the low-level technology, 146 under the baseline technology and 156 in the case of high level technology by the year 2000 with attendant annual growth rates of 1.0 percent, 1.1 percent, and 1.3 percent, respectively.

The authors incorporate the impacts of emerging new technologies in the projections using probability of innovation and adoption. Under the most optimistic conditions they report productivity index increases from 112 in the base year to 168 by the year 2000; an average of 1.3 percent which is less than the historical average of 1.5 percent of the past 50 years. Comparing productivity increases between baseline and high technology scenarios, they predicted that in the one year 2000 productivity would grow by 1.8 percent. Given the demand for food, under the high-technology scenario prices received by farmers would fall, consumer surplus would increase by 27.9 billion in constant 1974 dollars, producer surplus would fall by $11.1 billion and social benefits would increase by $16.8 billion. Their estimates resulted in a benefit-cost ratio of 3.3 and internal rate of return of 15 percent.

Knutson and Tweeten (1979) followed up on the production function estimated by Cline (1975) and made further analysis and ex ante projections. They selected 16 years as the lag required for research and extension to stop influencing agricultural productivity (p. 71). Based on 16-year lag, they computed the internal rate of return on research and extension.

White and Havlicek (1982) regressed the productivity index of U.S. agriculture on the index of educational attainment of farmers, weather index and lagged value of production-oriented public investment on research and extension, using time series data and the Almon distributed lag procedure with second degree polynomial. They found that the sum of the regression coefficients (production elasticities) on research and extension was 0.0381 for the 14-year lag, implying a 1 percent increase in research and extension expenditure would increase productivity by 0.0381 percent in its lifetime. This result concurs with the findings by Evenson (1967).

The authors also used quadratic programming to determine the optimal pattern of investment on research and extension for given a rate of increase in farm prices under selected conditions. Increasing expenditures on research and extension from $695.8 million to $3,649.4 million during the 1981-1990 period was estimated to reduce the rate of real increase in farm prices from .7 percent to .2 percent and also the rate of return on investment on research and extension from 36 percent to 6.9 percent. Finally, they examined the effects of reduced research funding on consumer food expenditure and on taxes. If the government underfunds research and extension by 10 percent of the optimal level for three years during 1981-1990 period, each dollar saved will cost the government in making it up in later years $2.56 ($1.50 discounted at 6 percent). Assuming no make up for the low level of investment in later years, the cost to the consumer is $4.39 ($3.07 discounted by 6 percent). Research along the same lines was done later by White, Havlicek and Otto (1978).

Critical Evaluation of Previous Research

We have reviewed past studies with emphasis on methodology and empirical results. The methodologies can be classified as ex post and ex ante. The ex post studies used value of inputs saved, consumer surplus, national income and production function approaches. The ex ante studies are consumer surplus, benefit-cost and simulation approaches.

Most of the ex post studies (inputs saved, consumer surplus, national income) and the ex ante studies (consumer surplus, benefit-cost) are suited to estimate the average rate of return and are of little use for investment decision purposes. The production function approach is best suited to evaluate the contribution of past research and extension to agricultural productivity.

Numerous studies using the production function approach have explicitly recognized the research and extension variable. In contrast to the consumer surplus studies that estimated the average rate of return, these studies could directly estimate the marginal internal rate of return of research and extension.

The two distinct advantages of the approach are therefore (1) estimation of the marginal product of research, and (2) ability to estimate the lag structure of research and extension effect on productivity.

A number of conclusions are summarized below.

(1) The studies reviewed did not estimate the private sector's investment on research and extension and its contribution to productivity in agriculture,

(2) The studies did not investigate the effect of an increase in research and extension on farm output supply and on farm prices and income,

(3) In terms of data, the use of the USDA productivity index as the dependent variable in the production function leaves much to be desired. The USDA productivity index suffers from the usual index number problems. It does not fully account for substitution of cheaper for expensive inputs as prices change.

(4) Empirically, the 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, it appears that there is social benefit to be derived form increased public investment on research and extension to reduce the rate of return to levels of alternative investments. Past estimates are of little use in judging the payoff from future expenditures, however.

The present study will reappraise the contribution of past research and extension to productivity using three measures of productivity: USDA Index, Divisia Index, and Default Index as dependent variables. More timely data on public expenditure on research and extension and other variables will be used. Also, an attempt will be made to estimate the private sector's expenditure on research and extension and its contribution to productivity in agriculture.

Appropriate investment to overcome the apparent public underinvestment in research and extension will be calculated. An optimal control procedure will be used to determine the optimal levels and time path of public investment on research and extension over a planning horizon with farm prices and income endogenous. The impact of increased research and extension expenditure on farm output supply, farm prices and income will be investigated employing simulation techniques.

CHAPTER III

CONCEPTUAL FRAMEWORK

The purpose of this chapter is to conceptualize the sources of productivity changes in agriculture. Of special interest is the effect on productivity of investment in nonconventional agricultural inputs. Issues to be discussed include time lags and measurement problems in tracing the effect on agricultural productivity of expenditures on research, extension and education.

Measuring productivity via the production function approach requires specification of an aggregate production function describing the U.S. agriculture. Traditionally, agricultural output has been expressed as a function of conventional inputs - land, capital and labor. Estimated partial and total factor productivities of these inputs display the usual economic behavior - the law of diminishing returns. Increases in productivity from conventional inputs are attainable up to a point where they are optimally combined and are paid the value of marginal product for a given level of technology. But in a more general equilibrium context, nonconventional inputs come into play. These nonconventional inputs (often assumed to be held constant) emanate not only from the knowledge industry (research, education and extension) but also from sources that alter the physical and/or economic environment such as weather and agricultural commodity price support programs (Cline 1975). In fact, the production process is much broader than just conventional inputs and includes as inputs research, extension and education related to agriculture.

Two approaches are possible to specify the effect of technical change on productivity. Technological change incorporated in new inputs and/or improvements of existing inputs is embodied. Technical change can be embodied in new capital goods or in quality improvements in other inputs such as labor, pesticides or seeds (Peterson and Hayami). Alternatively, disembodied technical change affects output-input relationships through changes in technique of combining inputs or know-how (Solow, 1957; Salter, 1970). Examples in agriculture of such changes include cultural practices such as plant spacing or timing of activities.

Either embodied or disembodied technical change may result from investments in research and development and from extension and education promoting adoption (Jorgenson 1966). Embodied or disembodied, the following conditions are necessary for technological change to affect productivity:

(a) Returns to new inputs, to improved quality of existing inputs and/or to new techniques of combining inputs must exceed costs.

(b) Farmers must adopt the new inputs, improved quality inputs and/or new techniques of combining existing inputs.

Improved and/or new inputs shift the level of the production function, enabling the farmer to produce more output for given inputs or a given output for less inputs. If the productivity of one input is increased relative to another (marginal rates of substitution change), then technical change is said to be biased or non-neutral. If the shift in the production function occurs because productivity of all inputs increase uniformly or because of factors not associated with any included conventional inputs so that factor substitutions remain unchanged, then technical change is said to be neutral.

Productivity has broadly been defined as the change in total farm output that results from a given set of production inputs. In theory, an aggregate production function that describes U.S. agriculture requires homogenous outputs and inputs. But agricultural outputs and inputs are heterogenous. The numerous outputs must be aggregated using prices. Likewise, labor and capital are combined using constant prices. The use of constant prices to aggregate heterogenous outputs and inputs causes the usual index number problems. Constant-price aggregation does not account for factor substitutions as prices change [see Appendix for index number problems].

Given the production function, variations in output due to shifts in the function may be confounded with movements along the same function. To measure productivity, the shift of the function must be separated from the movements along the function. Such separation can be attained if the production function is homogenous of degree one, and all factors are paid their value of marginal products.

Some or all of these assumptions do not hold. Inputs are not always used efficiently. Equilibrium is continually disturbed by changes in price and/or supply conditions in the factor market. Continuous technological changes destabilize equilibrium. These assumptions may not be so violated that useful results cannot be obtained.

Specifying the production function with the labor and capital as the only input variables results in much unexplained output. Correct specification of the production function, including the nonconventional inputs, is necessary to explain productivity. In the final analysis, measuring productivity depends on the functional form of the production function and on the proper measurement of inputs and outputs. Misspecification of an aggregate production function, errors in estimating the parameters, or omitted variables will spill over to the measure of total factor productivity.

Measuring Productivity

As mentioned in the introduction, technology at a point in time influences the manner in which resources are combined to produce goods and services. Given the level of technology, a statically optimal combination of resources is obtained when factor inputs are paid their VMP. Over time technical change causes shifts in the production function. Some use a time trend to measure productivity. This simplistic approach does not account for the underlying factors that cause productivity changes nor for the magnitude of the contribution of each factor. Another way to measure productivity is to assume that the production function of U.S. agriculture can be described by

(1) $Q_t = A_t K_t^{\alpha} L_t^{\beta}$

where:

Q_t = Total physical output in time t

L_t = Total labor input in time t

K_t = Total capital input in time t

A_t = Cumulative effect of productivity

α and β are parameters of the explanatory variables.

On the assumption that equation (1) is homogenous of degree one in conventional inputs, total factor productivity of the conventional inputs (labor and capital) can be measured by the ratio of total output to total conventional inputs; i.e.

$$(2)\quad A_t = \frac{Q_t}{K_t^{\alpha}\, L_t^{\beta}}$$

Two problems become immediately apparent from equation (1). On the input side, labor and capital cannot be aggregated because they are measured in heterogenous physical units. Even within the same class (e.g. labor), heterogeneity exists because of quality differences. Some workers are more educated, more skilled or more dependable than others. In the case of capital, machine hours, fertilizers and pesticides must be aggregated. These differences within and among classes preclude aggregation in physical units to measure productivity. The numerous outputs also have quality and physical measurement differences and so cannot be aggregated directly to form Q_t.

Constant dollar values of the inputs are used to aggregate inputs and outputs in equation (1). Reliance on prices to aggregate inputs and outputs over time gives rise to index number problems.

By definition productivity over time is the ratio of productivity of the comparison period to the productivity in the base period. Equation (1) in time t=0 can be expressed as:

$$(3)\quad Q_o = A_o K_o^{\alpha} L_o^{\beta}$$

where:

Q_o = Value of total output in time t = 0,

L_o = Value of total labor input in time t = 0,

K_o = Value of total capital input in time t = 0, and

A_o = Cumulative effect of productivity in time t = 0

α and β are the parameters of the explanatory variables.

Total factor productivity in time t = 0 can be measured by

$$(4)\quad A_o = \frac{Q_o}{K_o^{\alpha}\ L_o^{\beta}}$$

Productivity changes can now be measured by productivity index $\dot{P}_t | P_t$ defined as the ratio of productivity in time t (comparison period) to productivity in the base period (time t = 0). Thus,

$$(5)\quad \dot{P}_t | P_t = \dot{A}_t / A_o.$$

The rate of change of productivity per unit of time is defined as $\dot{A}_t / A_t$. Following Solow (1957), U.S. agriculture can be described by a Cobb-Douglas production function:

$$(6)\quad Q_t = A_t K_t^{\alpha} L_t^{\beta}$$

where Q, K, L, and A are as defined in equation (1) for time period t. Taking the derivative of equation (6) with respect to time and dividing by Q, the following equation to measure productivity is obtained.

$$(7)\quad \frac{\dot{A}_t}{A_t} = \frac{\dot{Q}_t}{Q_t} - \left[\alpha \frac{\dot{K}}{K} + \beta \frac{\dot{L}}{L} \right]$$

Equation (7) implies that productivity increase is the difference between the rate of change of output and the weighted sum of the rate of change of factor inputs. In other words, the equation measures productivity as the residual of output changes unexplained by increases in conventional inputs and therefore attributes all increases to neutral technical change. Measuring productivity as the residual in this manner is a measure of "ignorance" since nothing is known of the underlying factors that cause productivity (Abramovic, 1951). In addition, this approach incorporates input measurement errors into the residual term.

An improved way to conceptualize and measure total factor productivity due to technical changes over time is to specify the production function where all the factor inputs and nonconventional inputs are explicitly included.

$$(9) \quad Q_t = [K_t, L_t, X_{1t}, X_{2t}, \ldots, X_{nt}]$$

where Q, K, L are as defined in (1) and X_1, X_2, ..., X_n are nonconventional inputs.

Ideally this specification should be used to measure total factor productivity and compute the productivity index of the U.S. agriculture. The advantages are that it is suited to neutral and non neutral technical change as well as embodied and disembodied technical change. Parameters in (9) could in theory be measured with least squares procedure. But problems of multicollinearity preclude direct estimation. How then can we quantify the contribution of technical change to productivity?

Quantifying Technical Change

Two approaches are possible when a production function is specified to study productivity increases over time: Adjusting inputs for quality differences; and explicitly recognizing nonconventional inputs as explanatory variables.

Adjusting Inputs for Quality

Technological change has been quantified by adjusting conventional inputs for changing quality (Denison, 1962). The assumption is that productivity gains are attributable to the conventional inputs of capital and labor adjusted for quality (Peterson and Hayami, 1977).

Changes in quality of the conventional inputs can occur in many ways. Education, training and experience may improve the quality of labor inputs. Through experience labor may learn a more efficient way of combining existing inputs in the production process. Labor may learn new techniques of management and organization that improve productivity. The improvement in quality of labor is equivalent to a larger quantity of conventional labor used in the production process.

Likewise, quality improvements with respect to the capital input could occur over time with impact on productivity. A tractor can be made more energy efficient, consuming less energy to plow the same quantity of land. Pesticides that are more effective with the same or less quantity applied on a given farm may replace an existing pesticide.

Quantifying productivity by adjusting conventional inputs for quality improvements implies that all the technical change is embodied. This embodied technical change may in fact be the result of nonconventional inputs. Quantifying productivity in this manner makes it difficult to show the benefits and costs of public and private undertaking (the creation and dissemination of knowledge) purported to increase productivity.

Nonconventional Inputs as Variables

Explicitly recognizing nonconventional inputs as separate variables in the production function is the second approach to explain productivity gains. The nonconventional inputs create quality improvements in the conventional inputs and/or create entirely new inputs as discussed above. Assuming quality improvements are the result of research, extension and education, the production function can be estimated without adjustment of conventional inputs for quality and by including nonconventional inputs as separate variables. This implies that technical change (i.e. output unexplained by conventional inputs) is the result of quality improvements in inputs which have not been reflected in the conventional input measures. The problem here is the difficulty of identifying all nonconventional inputs that impact on productivity in agriculture.

Sources of Productivity (Nonconventional Inputs)

Previous studies have identified productivity enhancing nonconventional inputs: research, extension and education (Schultz, 1957; Griliches, 1958; Evenson, 1967; Tweeten, 1979; Cline, 1975); weather (Evenson, 1967; Cline, 1975; Havlicek, 1982; Tweeten, 1979). Other nonconventional inputs include: betterment of worker health and nutrition, economies of scale and specialization, changes in product mix, improved transportation and communication, and a more nearly optimal allocation of resources (Mansfied, 1971).

Many investigators have alluded to, and some have imputed, the contribution to agricultural productivity of expenditures on research and dissemination of information by the private sector (Schultz, 1953; Griliches, 1958; Peterson, 1977). But none has explicitly recognized this as an independent variable. Since private sector expenditure for this purpose is significant as shown in Table II (NSF, 1975), and the agriculture sector is becoming increasingly dependent on the input purchased from the nonfarm sector (Tweeten, 1979), it is possible that the private sector is a significant source of technical change in agriculture.

TABLE III

PRODUCTIVITY ORIENTED AGRICULTURAL RESEARCH
EXPENDITURE BY PRIVATE SECTOR
(IN MILLIONS OF CONSTANT DOLLARS)

YEAR	EXPENDITURE	YEAR	EXPENDITURE
1963	121		
1964	127	1970	215
1965	160	1971	220
1966	177	1972	231
1967	194	1973	200
1968	195	1974	264
1969	203	1975	310

Source: National Academy of Sciences. Agricultural Production Efficiency, National Academy of Sciences, Washington, D.C., 1975.

A conceptual problem is whether or not private research and extension should be used as a separate explanatory variable. It can be argued that under competitive profit maximizing conditions inputs to agricultural production purchased from the private sector are paid their value of marginal product (Evenson, 1967). If so, prices of the conventional inputs reflect changes in the quality of the inputs. On the other hand, if price of the conventional input fails 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 expenditures as an explanatory variable.

The above reasoning could be complicated by the manner of pricing followed by the private firms that produce the improved or new inputs. The theory of the product life cycle (Kotler, 1974) suggests alternatives of pricing new and/or improved quality products. New and/or improved quality products may be initially under-priced or over-priced depending on the competitive, technological and economic environment (Berglas and Jones, 1977).

Assume for example, the private firms wish to recover the value of their research expenditures quickly and charge high prices. This implies some time is required for competitors to come up with a competing product and the first producers will capitalize on the situation. This may give less incentive for farmers to adopt the new/or improved technology, because productivity gains may be offset by high-priced inputs.

If private firms under-price their product at the initial stages to undercut possible competitors, the incentive for farmers to adopt the technology is increased. An under-priced input in the farming sector would mean that the difference between prices of inputs and marginal value product of the inputs would appear as a source of productivity increase resulting from new and/or improved technology adopted by farmers.

The private sector could incorporate public research results to produce new or improved agricultural inputs. While the new or improved input may increase productivity, the price charged by the private sector may reflect only its share of the cost. If this happens, the difference between the productivity of the input and its price due to public research will appear in productivity attributable to public research. If the private sector embodies all the improvements and prices the product accordingly, the conventional measure will reflect the output increase in agriculture. The contribution of the public research will disappear.

Conceptually, where the final input is the result of research efforts by both public and private sectors, the final impact of the new or improved input on productivity should be attributed to the two sectors on a pro-rata basis. Practically, it may be difficult to isolate the portions that belong to the public and private sectors.

Weather

Weather affects productivity by altering the physical environment in which production takes place (Suieth, 1957; Thompson, 1961; Evenson, 1968; Cline, 1975). Most important elements of weather are temperature and precipitation. Both elements fluctuate in a random fashion (Murray, 1964). Weather and technology are not easily separated in measuring productivity changes.

Weather can influence productivity in different ways. It is reasonable to expect regions with little rain to be best suited for the adoption of irrigation technology. Likewise regions with marshy land are best suited to adopt drainage technology. In regions where weather variation is high, farmers may be cautious and inhibited from the full use of a new technology well suited to stable weather patterns.

"Normal" weather seldom prevails anywhere. Farmers sometime experience too much precipitation; other times draught. This variation and uncertainty affects productivity. When productivity increases due to favorable weather in one region, productivity may fall in another region due to unfavorable weather. Within the framework of this study, variations in productivity among regions due to weather may be offsetting and weather is assumed to be random from year to year.

Classification of Sources of Productivity

The sources of productivity (i.e. research, extension, education, weather) can be categorized as production-oriented and nonproduction-oriented (Cline, 1975). Production-oriented sources have as their ultimate aim the improvement of agricultural productivity by enhancing technology and its application. Alternatively, nonproduction oriented sources seek to improve agricultural productivity by favorably altering the social and economic environment in which agricultural production decisions are made.

Research and Extension Expenditures

Research is conducted on production-oriented as well as nonproduction-oriented activities. Research on improved crop varieties is production-oriented. Expenditures on improved infrastructure and communication, sociology and efficiency of the marketing system are nonproduction-oriented. These areas of research have indirect rather than direct impact on productivity.

Similarly, research and development expenditures by the private sector could be divided into production-oriented and nonproduction-oriented expenditures. Research and development expenditures to make a tractor energy-efficient are production-oriented expenditures. On the other hand, research expenditures to improve the appearance, comfort and convenience of farm machinery increase productivity indirectly and are mainly nonproduction-oriented.

Extension expenditures can be viewed similarly. Some extension expenditures to improve community services and the environment, to enhance consumer health, nutrition and well-being and to raise the standard of living and the quality of life are nonproduction-oriented. They only indirectly influence productivity.

Some public and private sector extension activities disseminate input specific information to farmers that increase the rate of adoption of improved inputs. Also, extension activities disseminate information to improve labor and management skills. These extension activities are considered production-oriented.

Theoretically, prices of the inputs would reflect quality improvements caused by extension activity of the private sector, assuming competitive market conditions and profit maximizing producers. However, input quality improvements resulting from public sector extension activities may appear as technical change unrelated directly to conventional inputs.

Education

Education has long been identified as a source of productivity in agriculture (Griliches, 1964). There are two ways in which this variable contributes to productivity. The impact of education on productivity is felt primarily through better labor input. Better educated labor combines other resources more efficiently. Therefore, expenditure on education that improves labor quality is production oriented.

Education may make farmers more profit conscious, seeking cost-reducing inputs such as machinery and yield-increasing inputs such as hybrid varieties. It also improves their allocative skills in the employment of resources and combination of enterprises.

Education also contributes to productivity indirectly. Better educated management could minimize resistance to change, adopt new technologies faster and choose better technologies. Education also makes the creation of new technologies possible by providing scientists, technicians, etc. for society in general. The spillover to agricultural science and technology from other segments is increased through education.

Other Variables

Agricultural price support programs may have influenced productivity changes over the years. Such programs reduce the inherent business risk of price fluctuations in the free market. The security and capital provided by public price support programs may provide an economic environment encouraging farmers to produce a given output more efficiently and to adopt new/improved technologies. Public policy of supply management through acreage restrictions may reduce output and induce an inefficient combination of land and non-land resources. But the policy may have contributed to the intensity of farming and the search for improved technology.

Policies designed to encourage capital investment through tax credits and deductions on new investments could serve as incentives to adopt new technology that increases productivity. Inflation gives rise to cash-flow problems that may have influenced productivity.

Having discussed the sources of productivity change, which are by no means exhaustive, it is now time to summarize the sources under the two categories. Following (Cline, 1975), the production-oriented technological change is brought about by changes in:

1. Resources used to produce direct inputs into the agricultural production process.

2. Production-oriented public research activities.

3. Production-oriented private research activities.

4. Production-oriented public extension activities.

5. Production-oriented private extension activities.

6. The level of educational attainment of farmers.

7. Long-run improvements in transportation, communication, and other factors which indirectly influence the quality of agricultural input.

The second category, i.e. nonproduction-oriented, of sources of productivity that alter the physical and/or economic environment could be summarized as follows (Evenson, Cline):

1. Utilization and development to expand the demand for farm products.

2. Nutrition and consumer use research aimed to determine nutrient requirements and how foods can best supply these requirements.

3. Marketing research to improve market outlook and to reduce costs and maintain product quality in moving products from farmer to consumer.

4. Plant and animal disease and pest control program designed to keep out of this country harmful diseases and pests from abroad.

5. Extension activities related to child development, community development, health, food preparation and selection, home furnishings, and utilization of farm output.

These two groups of variables are by no means exhaustive. It is hypothesized that the observed productivity changes in the U.S. agriculture can be explained by production-oriented research and extension carried out by the public and private sector, the level of educational attainment of farmers, weather, and nonproduction-oriented research and extension by private and public sectors.

Based on the sources of productivity increase discussed thus far, equation (9) depicts agricultural productivity as a function of several variables as defined below:

(9) $P_t = f(X_{1t}, X_{2t}, \ldots X_{10t})$

where:

P_t = Productivity index at time t

X_{1t} = Production-oriented public sector expenditure in research at time t

X_{2t} = Production-oriented private sector expenditure in research at time t

X_{3t} = Production-oriented public sector expenditure in extension at time t

X_{4t} = Production-oriented private sector expenditure in extension at time t

X_{5t} = Nonproduction-oriented public sector expenditure in research at time t

X_{6t} = Nonproduction-oriented private sector expenditure in research at time t

X_{7t} = Nonproduction-oriented public sector expenditure in extension at time t

X_{8t} = Nonproduction-oriented private sector expenditure in extension at time t

X_{9t} = Educational attainment of farmers at time t

X_{10t} = Weather index at time t

The next step is to consider the time shape of the effects of the explanatory variable on the independent variable.

The explanatory variables enumerated have different impacts on productivity over time. Expenditures for research and extension create productivity gains that are spread over several years. The hypothesized time lag for research can be explained by reference to Figure 5.

Research expenditures made in time period t will first produce new technology in time period t + m. The time lag m is spent in inquiring and searching for new knowledge. The time period can be viewed as invention lag and commercialization lag (Marschak, 1968). Conceptually, these lags could vary in length depending on the complexity of the research, intensity of effort and resource commitment and amount of the technical change sought. Greater expenditures for research and extension on a given technology may shorten the time between initial outlays and productivity gains. This lag is shown by the lag t to t + m' in the figure. On the other hand, if research effort is less, the time lag required for invention and commercialization of new knowledge is longer as shown by the distance t to t + m in the figure.

The variation of the lag structure of the innovation process implies that policy makers can manipulate the instrument variable -- investment on research -- to achieve the desired goal of an improved or new agricultural input.

Assume that investment on research made in time t produces innovation after a total time lag of m (or m') with greater research commitment. At this point in time, the new technology is available to

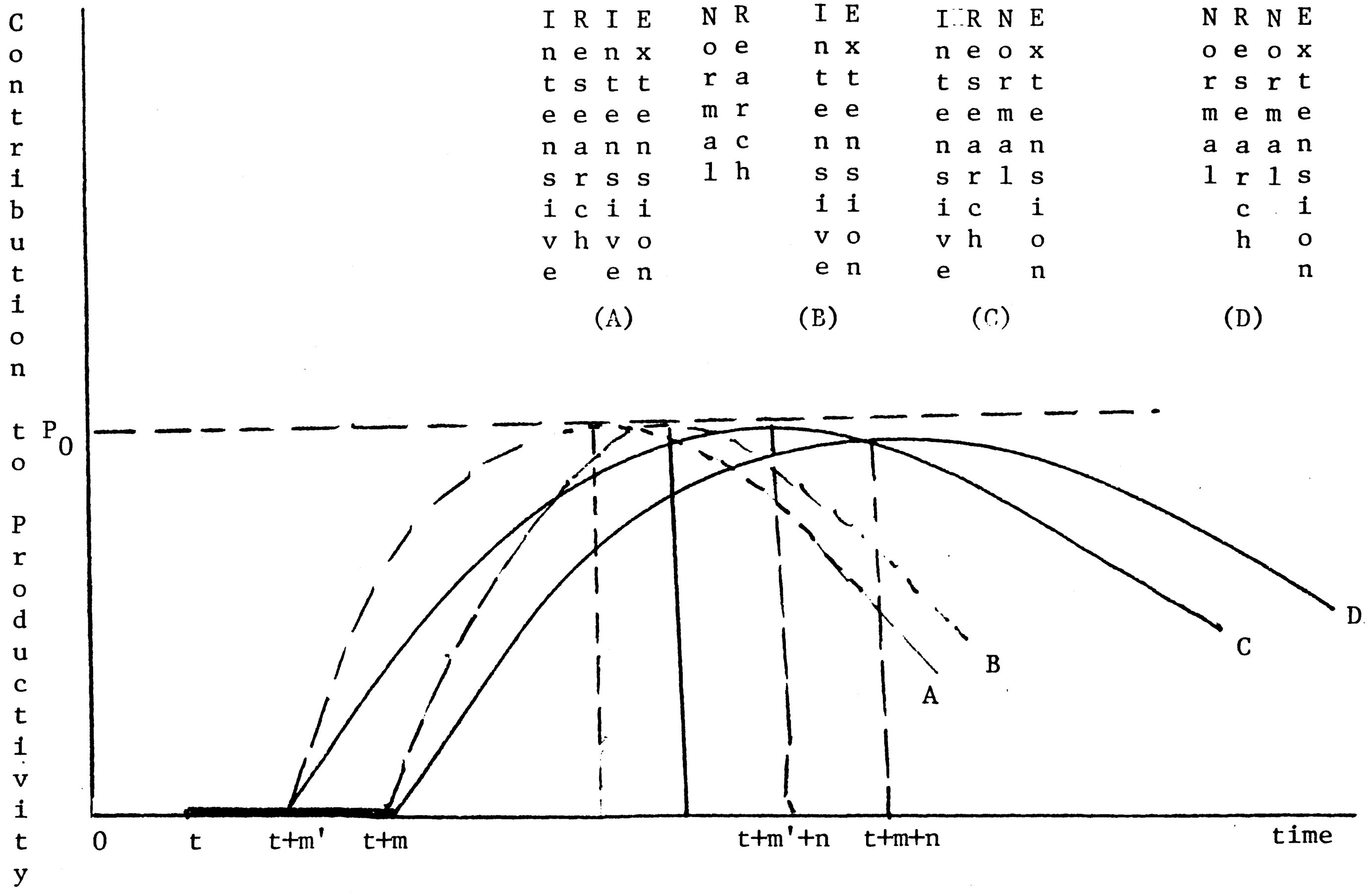


Figure 5. Effect of Production Oriented Research and Extension on Productivity.

potential users and extension is in a position to promote the diffusion of the new technology to farmers.

Extension

The research results impact on agricultural productivity as the new inputs are adopted by part or all potential users (Evenson, 1968). Extension expedites the adoption process of the technological change. Extension activity may start in time t + m or t + m', although in some cases extension activities might be initiated earlier in anticipation of the technology being made available.

The time structure of the adoption process can vary. Intensive extension effort and resource outlays make faster adoption of the innovation possible as will higher level of educational attainment of farmers. The rate of adoption is a function not only of extension and education but also of the complexity of the innovation, resistance to change by potential users, perception of risk and profitability of the new input, cost and availability of credit, and the size of the unamortized investment on existing inputs (Salter, 1970).

Productivity Gains

Technical change begins impacting on productivity in time t + m or t + m' as some potential users adopt the innovation. Initially, productivity increases slowly as few users adopt the technical change. As early adopters benefit from the technical change and gain experience in the effective use of the new input (Evenson), other farmers adopt. This adoption coupled with corrections, modifications and adjustments in the technology (Nabseth) causes productivity gains to rise. When all or most potential users have adopted and gained experience about the technical change, productivity increases reach a maximum at P_0 and then decline.

The decline in productivity can be attributed to depreciation of the value of past research and extension for various reasons: Some technology may become obsolete and be replaced by superior or improved inputs, others may depreciate due to biological decay as in the case of insects building resistance to certain insecticides. Still other technical changes (inputs) could become economically obsolete due to the changes in relative prices (Evenson, 1968; Cline, 1975). The depreciation in the value of the technical change causes the productivity curve to slope downwards in Figure 5.

The discussion thus far shows that research and extension activities are complementary; research results would increase productivity only when extended and adopted by farmers. Conversely, extension activity is most successful when new technology is available from research. It is conceptually possible to consider extension and research as separate variables and estimate their effect on productivity and respective lag structures. But there are statistical problems associated with estimating the variables separately due to intercorrelations as discussed in the next chapter.

Instead research and extension inputs are combined to form a combination of the individual lag responses of each in a procedure following (Evenson, 1968; Cline, 1975). Since extension activity enters the process of producing technical change with a lag of M or M' (Figure 5), the joint observation on production-oriented research and extension following Cline and Evenson can be written as:

$X_{11} = (X_1)_t + (X_3)_{t+m}$

$X_{12} = (X_2)_t + (X_4)_{t+m}$

$X_{13} = (X_5)_t + (X_7)_{t+m}$

$X_{14} = (X_6)_t + (X_8)_{t+m}$

where:

X_{11} = Public expenditure in production oriented research and extension,

X_{12} = Private expenditure in production oriented research and extension,

X_{13} = Nonproduction-oriented public expenditure in research and extension, and

X_{14} = Nonproduction-oriented private expenditure in research and extension.

Given the convoluted distributed lag function of production oriented research and extension, Equation (9) can be rewritten as:

(10) $P_t = f(X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14})$

Before leaving the topic of the time form of the explanatory variables, it is appropriate to mention the timing of the effect of weather and educational attainment variables. Following Cline (1975), weather in the current period is assumed to affect productivity in the same period. Educational attainment of farmers enables them to discriminate information and make current decisions, and therefore its impact on productivity also is immediate.

Our discussion of the conceptual framework of productivity change in agriculture has identified the main sources of productivity growth. What remains is a specification of the functional form. Productivity change may be specified as:

$$PIND_t = A_t \prod_{j=0}^{n} POPR_{t-j+1}^{rj} \prod_{i=0}^{m} PVPR_{t-i}^{ki} NPVPR_t^{vo} NPOPR_t^{v1} EDI_t^{v2} e^{v3WI_t} U_t$$

Where:

$PIND$ = Productivity index at time t.

$POPR_{t-j}$ = Productivity oriented public expenditure in research and extension at time t-j.

$PVPR_{t-i}$ = Productivity oriented private sector expenditure in research and extension at time t-i.

$NPVPR_t$ = Nonproductivity oriented private sector expenditure in research and extension at time t.

$NPOPR_t$ = Nonproductivity oriented public expenditure in research and extension at time t.

EDI_t = Index of educational attainment of farmers at time t.

WI_t = Weather index at time t.

A_t = A conglomeration of shifters

r_j, $j=0,1,2,\ldots, N$; K_i; $i=0,1,2,\ldots, M$; and V_0, V_1, V_2, V_3 are parameters to be estimated.

U_t = Disturbance term at time t.

Given the above specification of the productivity model, the next chapter discusses the estimation procedures, econometric problems and suggested remedies.

CHAPTER IV

EMPIRICAL ECONOMETRIC MODEL

The theoretical model of productivity change discussed in Chapter III can be written in log form as:

$$\begin{aligned} \ln PIND_t &= \ln A_t + \sum_{j=1}^{n+1} r_j \ln POPR_{t-j+1} + \sum_{i=1}^{m+1} k_i \ln PVPR_{t-i+1} \\ &\quad + V_0 \ln NPVPR_t + V_1 \ln NPOPR_t \\ &\quad + V_2 \ln EDI_t + V_3 WI_t + U_t \qquad [4.1] \end{aligned}$$

where

$PIND_t$ = Productivity index at time t

$POPR_{t-j+1}$ = Productivity oriented public expenditure in research and extension at time t-j+1

$PVRR_{t-i+1}$ = Productivity oriented private sector expenditure in research and extension at time t-i+1

$NPOPR_t$ = Nonproductivity oriented public expenditure in research and extension at time t

$NPVPR_t$ = Nonproductivity oriented private sector expenditure in research and extension at time t

EDI_t = Index of educational attainment of farmers at time t

WI = Weather index at time t

ln = Natural logarithm

U_t = Disturbance term at time t

$_j(j=1,2,\ldots,n+1)$; $_i(i=1,2,\ldots,m+1)$; V_1, V_2, V_3; V_4 are parameters to be estimated

A = Conglomeration of shifters.

The parameters in (4.1) can, in theory, be estimated with the OLS procedure. If the classical OLS assumptions hold, and the lag lengths of $POPR_{t-j}$ and $POVR_{t-i}$ are known, the estimates will have all the desired statistical properties (i.e., BLUE). But the classical OLS assumptions may not hold, and the lag lengths of POPR and $PVPR_{t-i}$ are unknown apriori, causing estimation problems of intercorrelated explanatory variables and autocorrelated disturbances [Johnston, 1972].

Multicollinearity

The model 4.1 may violate the assumption of the independence of the explanatory variables. Collinear variables produce estimators with usually high variances. Coefficients become sensitive to changes in the data and specification.

The presence of multicollinearity in 4.2 is almost certain because lagged values of POPR and $PVPR_t$ are regressants. Also variables $POPR_t$, $PVPR_t$, $NPOR_t$, EDI_t tend to move in the same direction. Estimating (4.1) directly with OLS procedures would result in imprecise estimates. Under the circumstances, tests of hypotheses become invalid [Johnston, 1972]. Suggested remedies include increasing sample size and or imposing apriori restrictions.

The variable $PVPR_{t-i+1}$ causes a special problem. While the contribution of private sector research and extension to productivity in agriculture is almost axiomatic, sufficient time series data to estimate the parameters on $PVPR_{t-i+1}$ are lacking. On the other hand, even if data are available, separate specification of the variable with its numerous lags would only add to the already collinear exogenous variables in the model. For these reasons, the variable $PVPR_{t-i+1}$ and $NPVR_t$ are dropped from the (4.1) to be handled later. The modified model can now be written as:

$$\ln PIND_t = \ln A_t + \sum_{j=1}^{n+1} r_j \ln POPR_{t-j+1} + V_1 \ln NPOPR_t + V_2 \ln EDI_t + V_4 WI_t + U_t \qquad [4.2]$$

Almon Technique (Polynomial Distributed Lag-PDL)

The problem of estimating the PDL in (4.2) can be minimized by employing the Almon technique (Almon, 1965). Digressing for a moment, the PDL is discussed briefly. Consider the variable $POPR_{t-j}$ and the PDL model:

$$PIND_t = r_o POPR_t + r_1 POPR_{t-1} + r_2 POPR_{t-2} + \ldots + r_n POPR_{t-n} + e_t \qquad [4.2.1]$$

where variables are as defined in (4.1) , $r_o \ldots, r_n$ are parameters to be estimated and e_t is the disturbance term.

The coefficients in (4.2.1) can be estimated with OLS and estimates will have all the desired properties if the classical OLS assumptions are not violated. The estimates are imprecise if the assumption of zero covariance of the disturbance terms (e_t) is violated and the explanatory variables and lag values of the explanatory variables ($POPR_{t-j}$) are intercorrelated.

The essence of the Almon technique is to estimate models of the type in (4.2.1) by introducing apriori restriction. Assume, as Almon did, that the weights on the parameters (rj's) can be approximated by a suitable polynomial in j and there exist parameters such that:

$$r_j = C_0 + C_{1j} + C_{2j}^{2} + \ldots + C_{pj}^{p} \qquad [4.2.2]$$

$$j = 0, 1, 2, \ldots, n; \ p<n$$

where p is the degree of polynomial and $p < n$. If $p = 2$, for example, substituting (4.2.2) into (4.2.1), we obtain:

$$PIND_t = r_o + C_o \sum_{j=0}^{n} POPR_t + C_1 \sum_{j=0}^{n} iPOPR_{t-j} + C_2$$

$$\sum_{i=0}^{n+1} j^2 POPR_{t-j} + U_t \qquad [4.2.3]$$

Defining

$$Z_{ot} = \sum_{j=0}^{n} POPR_{t-j}$$

$$Z_{1t} = \sum_{j=0}^{n} jPOPR_{t-j} \qquad [4.2.4]$$

$$Z_{2t} = \sum_{j=0}^{n} j^2 POPR_{t-j}$$

The model to be estimated can be written as:

$$PIND_t = r_0 + C_0 Z_{0t} + C_1 Z_{1t} + C_2 Z_{2t} + e_t \qquad [4.2.5]$$

Equation (4.2.5) reduces the number of parameters to be estimated from $n + 1$ to $p + 1$ and can be estimated with OLS procedure. If the classical OLS assumptions hold, and the restrictions imposed are true, the estimates (Cj's) will have all the desired statistical properties. From the estimated Cj's, the original parameters (rj's) can be computed [Schmidt and Waud, 1973].

Determination of Lags

The determination of the lag length of the POPR variable is another problem. One way to determine the lag length is to estimate the model by increasing the number of lags each time by one and terminate the estimation when the last lag is statistically insignificant. It is possible to obtain statistically significant coefficient well beyond the true termination point, however. Also, the lag length cannot be chosen on the basis of t-tests, since these tests are invalid when the lag length is chosen incorrectly [Schmidt and Waud, 1972]. An alternative is to estimate the model with numerous lags and choose the one with Theil's $\bar{R}^2$ (minimum standard error) criteria [Theil, 1961], an approach followed in this study.

End Point Restrictions

A related issue is the end point restrictions. Almon (1965) suggests end point restrictions be imposed. Trivedi (1970) recommends that such restrictions not be used indiscriminately. The controversy can be minimized by reverting to the theory underlying the model to be estimated.

The theory chapter suggested that $PIND_t$ induced by a given increase in $POPR_{t-j}$ first increases, reaches a maximum and declines.

This is shown in figure (5). The polynomial equation (4.2) described seems plausible. It is desirable, however, that the model be estimated with and without restrictions so that the choice could be made on the basis of an F test that the end point restrictions are appropriate (Toro-Vizcarrondo and T. D. Wallace, 1968).

Autocorrelated Disturbances

Estimating 4.1 as specified may violate the assumption of the independence of each disturbance terms. Time series data in economics cause disturbance term of successive periods to be correlated. Thus the classical OLS assumption of zero covariance of the disturbances could be violated, resulting in autocorrelated disturbances. Parameter estimates will be unbiased even with autocorrelation, but variances are no longer minimum.

The presence of autocorrelation can be tested with the Durbin-Watson d statistic. If the test shows autocorrelated disturbances, the model (4.1) can be transformed to an autoregressive model (4.3) assuming that the disturbance term (U_t) follows a first-order autoregressive scheme.

$$\begin{aligned} \ln PIND_t - \rho \ln PIND_{t-1} &= \sum_{j=1}^{n+1} r_j (\ln POPR_{t-j} - \rho \ln POPR_{t-j-1} \\ &+ V_1(\ln NPOPR_t - \rho \ln NPOPR_{t-1}) \\ &+ V_2(\ln EDI_t - \rho \ln EDI_{t-1}) \\ &+ V_3(WI_t - \rho WI_{t-1}) + e_t \end{aligned} \qquad [4.3]$$

where

$e_t \quad = \quad (U_t - \rho U_{t-1})$

$\rho \quad = \quad$ coefficient of autocorrelation $(0<\rho<1)$

(4.3) would produce preferable estimates by removing the effect of autocorrelation [Kamenta, 1970].

In this section, we have discussed the empirical framework and the measures to be taken to correct for multicollinearity by imposing apriori restrictions, and to correct autocorrelation by transforming the model. The next section presents discussion of the estimated results.

Estimated Results

The productivity change model was estimated directly with the OLS procedure. Equation 4.1 was fitted to the national data. The number of lags of POPR was varied from 1-25. The estimates were unstable and imprecise. Multicollinearity became apparent as can be gleaned from Table (IV). The explanatory variables POPR, NPOR, EDI are highly correlated violating the assumption of nondependence of the explanatory variables. In the presence of multicollinearity, tests of the hypotheses become invalid.

Estimating (4.1) with OLS also resulted in large estimated variances. 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. With autocorrelation, estimates may be unbiased but are no longer efficient. The Cochrane-Orcutt method [Kamenta, 1980] was employed to correct for autocorrelation.

TABLE IV

CORRELATION COEFFICIENTS

	EDI	WI	POPR	NPOPR
EDI	1.00000 0.0000	0.08023 0.6519	0.97728 0.0001	0.86898 0.0001
WI		1.00000 0.00000	0.06204 0.7274	0.13663 0.4410
POPR			1.00000 0.0000	0.91490 0.0001
NPOPR				1.00000 0.0000

Multicollinearity is minimized by the use of the Almon technique (PDL). As discussed in the empirical framework, we imposed the apriori restriction on the model (4.3) that the weights on $POPR_{t-j}$ lie on a polynomial of degree p

$$r_j = C_o + C_{1j} + C_{2j}^2 + . . . + C_{pj}^p$$

The restriction reduced the number of parameters to be estimated from n + 1 to p + 1. Having corrected for both autocorrelation and multicollinearity, we estimated the model (4.3). We also imposed constraints that end points approximate to zero. In estimating (4.3) the number of lags of POPR were varied form 1-25 based on the assumption of second degree polynomial[1]. The results obtained from fitting (4.4) to the national data were contrary to expectation. The coefficients on NPOPR were statistically insignificant. This is consistent with previous findings (Cline, 1975), suggesting that NPOPR does not impact productivity in a significant way. Moreover, some of the lag coefficients on POPR showed negative signs. While it is possible for some individuals to lose, it is improbable for the whole farm sector to lose due to new technology. The negative coefficients did not, therefore, make sense. Consequently, the NPOPR is dropped. As mentioned in our objectives, we estimated the model 4.4 below using the USDA, Divisia and Default indices as dependent variables.

$$\begin{aligned} \ln PIND_t - \rho \ln PIND_{t-1} = {} & \sum_{j=1}^{n+1} r_j (\ln POPR_{t-j+1} - \rho \ln POPR_{t-j}) \\ & + V_2(\ln EDI_t - \rho \ln EDI_{t-1}) \\ & + V_3(WI_t - \rho WI_{t-1}) + e_t \end{aligned} \qquad (4.4a)$$

$$\begin{aligned} \ln DVSA_t - \rho \ln DVSA_{t-1} = {} & \sum_{j=1}^{n+1} r_j (\ln POPR_{t-j+1} - \rho \ln POPR_{t-j}) \\ & + V_2(\ln EDI_t - \rho \ln EDI_{t-1}) \\ & + V_3(WI_t - \rho WI_{t-1}) + e_t \end{aligned} \qquad (4.4b)$$

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[1] We attempted to estimate the model with third and fourth degree polynomials. The results were inconsistent with theory discussed in Chapter III and prior knowledge.

TABLE V

PARAMETER ESTIMATES USING MODEL 4.3

Explanatory Variables	Dependent Variables-Productivity Indices		
	USDA INDEX	DIVISIA INDEX	DEFAULT INDEX
$\ln EDI_t - \rho \ln EDI_{t-1}$	.71000	.69803	.65570
	(3.04)	(1.93)	(2.05)
$WI_t - \rho WI_{t-1}$	.00264	.00274	.00287
	(3.62)	(4.20)	(4.30)
$\ln POPR_t - \rho \ln POPR_{t-1}$	.00126	.00147	.00162
$\ln POPR_{t-1} - \rho \ln POPR_{t-2}$	.00236	.00275	.00304
$\ln POPR_{t-2} - \rho \ln POPR_{t-3}$	.00331	.00383	.00425
$\ln POPR_{t-3} - \rho \ln POPR_{t-4}$	.00410	.00471	.00526
$\ln POPR_{t-4} - \rho \ln POPR_{t-5}$	.00473	.00540	.00607
$\ln POPR_{t-5} - \rho \ln POPR_{t-6}$	.00520	.00589	.00668
$\ln POPR_{t-6} - \rho \ln POPR_{t-7}$	.00551	.00618	.00709
$\ln POPR_{t-7} - \rho \ln POPR_{t-8}$	.00567	.00628	.00729
$\ln POPR_{t-8} - \rho \ln POPR_{t-9}$	.00567	.00618	.00729
$\ln POPR_{t-9} - \rho \ln POPR_{t-10}$	.00551	.00589	.00709
$\ln POPR_{t-10} - \rho \ln POPR_{t-11}$	.00520	.00540	.00668
$\ln POPR_{t-11} - \rho \ln POPR_{t-12}$	.00473	.00471	.00607
$\ln POPR_{t-12} - \rho \ln POPR_{t-13}$	.00410	.00383	.00527
$\ln POPR_{t-13} - \rho \ln POPR_{t-14}$	.00331	.00275	.00425
$\ln POPR_{t-14} - \rho \ln POPR_{t-15}$	.00236	.00147	.00304
$\ln POPR_{t-15} - \rho \ln POPR_{t-16}$	.00126	--	.00162

TABLE V (Continued)

Explanatory Variables	Dependent Variables-Productivity Indices		
	USDA INDEX	DIVISIA INDEX	DEFAULT INDEX
n+1			
r_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
ρ	0.52	0.68	0.61

Figures in parenthesis are t-values
coefficients are significant at .05 level

Joint F test that coefficients on $POPR_{t-j+1}$ variables are zero was rejected at 1% level of significance.

$$(\ln DFLT_t - \rho \ln DFLT_{t-1}) = \sum_{j=1}^{n+1} r_j (\ln POPR_{t-j+1} - \rho \ln POPR_{t-j}$$

$$+ V_2(\ln EDI_t - \rho \ln EDI_{t-1})$$

$$+ V_3(\ln WI_t - \rho \ln WI_{t-1}) + e_t \qquad (4.4c)$$

where:

PIND is as defined above, DVSA is Divisia productivity index and DFLT is Default productivity index.

The estimated results are presented in Table V and highlighted below:

USDA Productivity Index:

The table shows estimates for three different dependent variables. Column 1 is the estimate of the USDA index, columns two and three are for Divisia and Default indices, respectively. We first discuss estimates on the USDA index. The coefficients are significant. The R^2 is high. The Durbin-Watson d statistics indicate that positive autocorrelation is not a significant problem.

The model estimated being in log form, the coefficients are elasticities. The sum of the lag coefficients $(\sum_{j=1}^{n+1} r_j)$ is .064, implying that a one percent increase in $POPR_t$ will increase PIND by .064 percent over time. The increase is distributed over 16 years in the manner shown by the distributed lag weights, i.e., increasing at first, reaching a maximum after eight years (mean lag) and then declining as shown in figure 6. The mean lag (eight years) and the total length of lag (16 years) are determined by minimum standard error criteria.

However, (4.4) was also estimated without the end point constraints in order to test the hypothesis that the end point constraints are appropriate. An F-test of the type:

$$F_{m,\ T-K} = (ESS_R - ESS_{UR}) \Big/ (ESS_{UR})\ T-K \qquad [4.5]$$

was used to test the hypothesis, where:

m = number of restrictions imposed on the model

ESS_R = error sum of squares in the restricted model

ESS_{UR} = error sum of squares in the unrestricted model

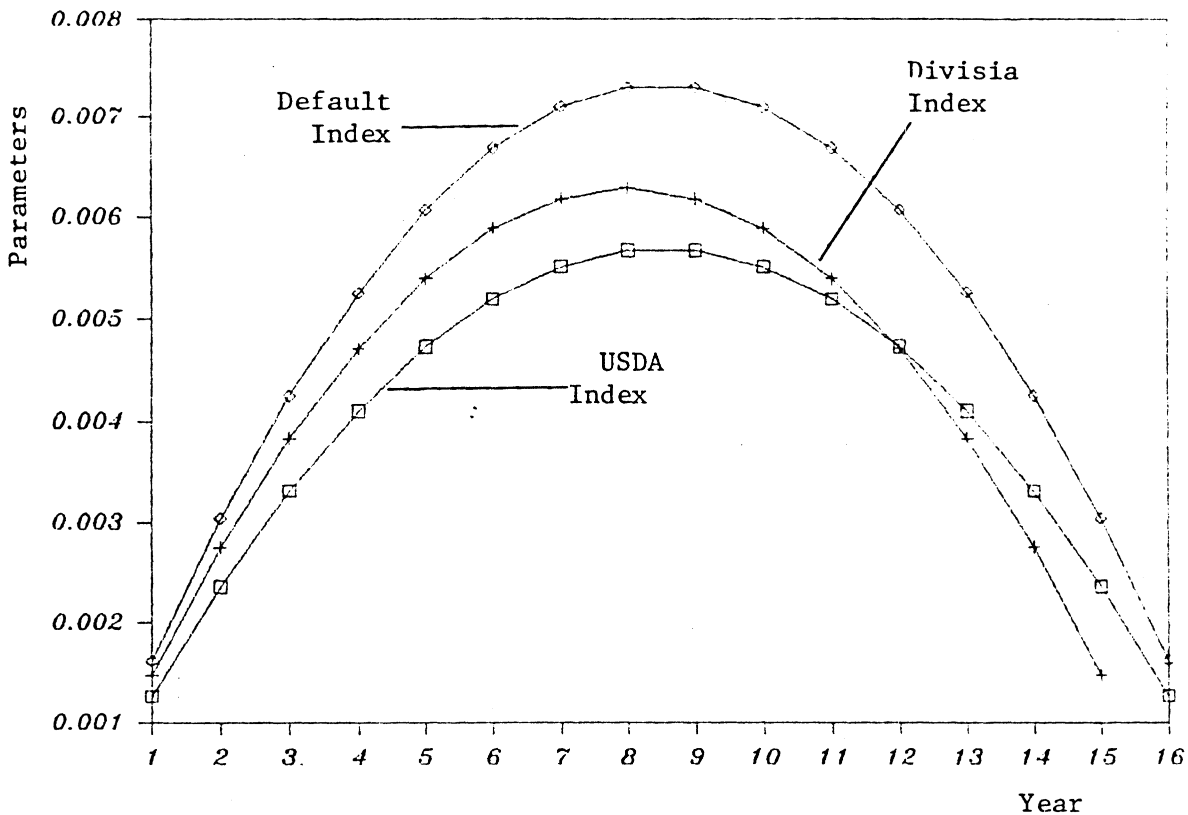

Figure 6. Estimated Parameters on POPR

T = the number of observations

K = the number of independent variables.

The null hypothesis that the end point restrictions are appropriate was not rejected at the one percent level of significance.

The other explanatory variables including EDI and WI also behave as expected. The coefficients on both variables are significant. The results indicate that the elasticity of PIND with respect to EDI is .72 and the elasticity of PIND with respect to weather index is .0026. The interpretation is that a 1 percent increase in EDI increases PIND by .72 percent and a 1 percent increase in weather index increases PIND by .0026 percent.

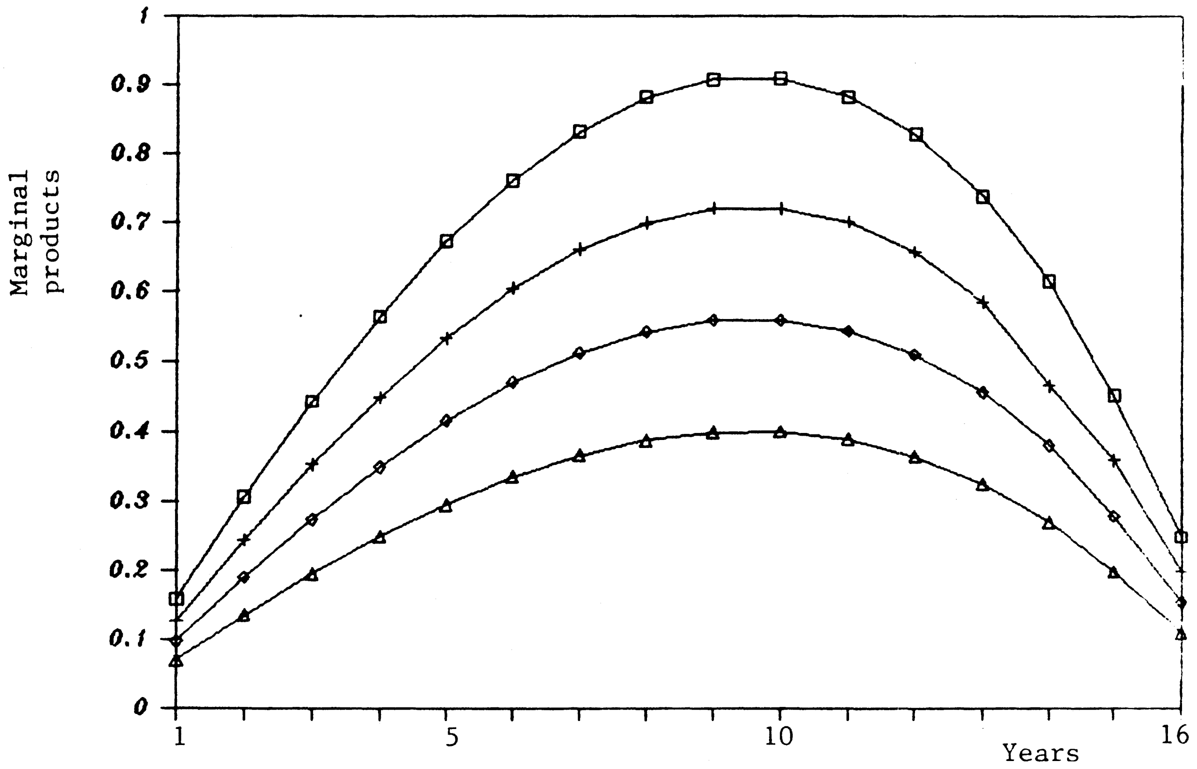

Figure 7. Estimated Marginal Products of POPR

Estimating Marginal Returns:

It is apparent from (4.2) that the elasticity of the productivity index with respect to investment on public research outlays is:

$$\frac{\partial \ln PIND_t}{\partial \ln POPR_{t-j+1}} = \frac{\partial PIND_t}{\partial POPR_{t-j+1}} \; \frac{POPR_{t-j+1}}{PIND_t} = r_j \qquad [4.5]$$

by definition

$$MP_j = \frac{\partial Qs}{\partial \; POPR_{t-j+1}} \qquad [4.7$$

The marginal product (MP_j) of $POPR_{t-j+1}$ can be approximated following (Knutson and Tweeten, 1979) from (4.2), (4.6) and (4.7).

$$MP_j = \frac{\partial Qs_t}{\partial POPR_{t-j+1}} \simeq \frac{\partial PIND_t}{\partial POPR_{t-j+1}} \quad \frac{\partial Qs_t}{\partial PIND_t} \qquad [4.8]$$

from (4.6)

$$\frac{\partial PIND_t}{\partial POPR_{t-j+1}} = \frac{r_j PIND_t}{POPR_{t-j+1}} \qquad [4.9]$$

substituting (4.9) into (4.8) we obtain

$$MP_j = \frac{r_j PIND_t}{POPR_{t-j+1}} \cdot \frac{\partial Qs_t}{\partial PIND_t} \qquad [4.10]$$

$$j=1,2,\ldots, n+1$$

Equation (4.10) indicates that MPj is distributed over j number of lags in the same way the weights of the parameter on $POPR_t$ are distributed. The MP_j starts low at first increases, reaches a maximum and then falls. Figure (7) shows the inverted U shape of the MP_js of POPR over the lag period.

The stream of the inflow of the MP_js is used to compute the IRR on $POPR_{t-j}$ using equation (4.10)

$$IRR = R: \sum_{j=0}^{n}[VMP_j \ (1+R)^{-j}]-1 = 0 \qquad [4.11]$$

where VMP_j = value marginal product in computed as $MP_j \frac{P_t}{P_{to}}$. R is the rate of return that equates the net present value of future flows to zero. The results are given in Table (VI). The table shows that

Table VI

MARGINAL RETURNS TO PAST INVESTMENT IN POPR

YEAR	MP	Adjusted MP	IRR	Adjusted IRR	YEAR	MP	Adjusted MP	IRR	Adjusted IRR
1959	21.86	17.58	56.74	45.61	1971	12.67	10.19	42.51	34.18
1960	20.41	16.41	58.22	46.81	1972	12.18	9.79	41.46	33.33
1961	19.80	15.20	54.33	43.68	1973	11.93	9.59	41.02	32.98
1962	18.40	14.79	52.27	42.03	1974	12.65	10.17	42.79	34.40
1963	17.34	13.94	50.85	40.88	1975	16.33	13.13	50.72	40.78
1964	16.41	13.19	49.64	39.91	1976	15.08	12.12	48.03	38.62
1965	15.34	12.33	47.98	38.58	1977	14.30	11.50	46.25	37.18
1966	13.78	11.79	44.93	36.12	1978	13.49	10.85	44.31	35.62
1967	14.05	11.30	45.61	36.67	1979	13.35	10.73	43.75	35.18
1968	14.13	11.36	45.88	36.88	1980	14.51	11.67	45.92	39.92
1969	13.15	10.58	43.70	35.13	1981	15.97	12.84	48.50	38.99
1970	12.55	10.09	42.25	33.97	1982	14.61	11.75	45.43	36.53

both the total marginal product and IRR on past POPR continue to decline, exhibiting the law of diminishing return.

Comparison of Returns

We have discussed the marginal returns from past investments in POPR within the framework of our models. It is now time to compare our results against results of previous studies. Notice, however, that differences in methodologies and time span covered by different studies make direct comparison of results a little difficult. A case in point is the difference in the length of lag on POPR, even among the studies that used the production function approach. For example, we estimate a 16 years lag, which is apparently consistent with the general view of experts in the field [Tweeten, 1979], while [Cline, 1975] estimates a lag on POPR of 14 years. However, these differences are not too great to make a meaningful comparison of the marginal returns to investments in POPR unwarranted.

We choose studies that employed aggregate national data in the U.S. for our comparison. The Table VII below shows that IRR on POPR cluster around 50 percent. A closer look also reveals that IRR declines through time. Peterson's estimate, for example, fell from 50 percent during 1937-1942 to 34 percent during 1957-1972 periods. The same is true of the estimates by Knutson and Tweeten where IRR falls from 39-47 percent during 1949-1958, to 32-39 percent in 1959-1968 and 28-35 in the years 1969-1972, while our estimates given in Table VII are higher than most estimates, the trend of diminishing returns can be observed.

Estimates of the Divisia Index

We now discuss estimates of the Divisia and Default indices in that order. The theoretical aspects of the Divisia index of total factor productivity is discussed in the Appendix. The indices constructed using formula (Appendix A) are used as dependent variables 7 to estimate the model 4.4. All the explanatory variables remain unchanged. The steps taken in estimation are similar to the steps taken for estimating the USDA productivity index.

The estimated results are given in Table V column 2. The best time form of the explanatory variable $POPR_{t-j}$ was chosen on the basis of Theil's minimum error criteria. The estimates are distributed over 15 years unlike the 16 years for the USDA index. The sum of the lag coefficients is .067. This implies that a one percent increase in investment in POPR would increase productivity by .067 through time. These increases are distributed in a manner shown by Figure (6). The R^2 is high showing that the independent variables explain 99 percent of variation in the dependent variable. A joint F

TABLE VII

SUMMARY OF ESTIMATED IRR USING AGGREGATE NATIONAL DATA AND PRODUCTION FUNCTION

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	1949-59	47
Cline, 1975	1939-1972	41-50
Knutson and Tweeten, 1979	1939-1958	39-47
	1959-1968	32-39
	1969-1972	28-35
Davis, 1979	1949-1959	66-100
	1964-1974	37
Evenson, 1979	1868-1926	65

Source: Ruttan, V. W. Bureaucratic Productivity: The Case of Agricultural Research", Public Choice. 35(1980):533.

test on the coefficients showed that the null hypothesis that the coefficients are jointly zero is rejected at the 1 percent level.

The table shows that the number of lags for the USDA productivity index is longer than the number of lags for the Divisia index. As alluded to in the introduction, the Divisia index is theoretically attractive as a measure of productivity because the weights in the index are changed constantly. The difference in the magnitude of the parameters and the associated length of lag may be due to that fact.

Estimates of the Default Index:

The default indices are constructed on the basis of discussion in the Appendix B. The estimation of 4.4 employing default indices as the dependent variables, leaving the independent variables the same as in the case of USDA and Divisia indices, resulted in statistics given by column 3 in Table V. The sum of the lag coefficients is .086 which is larger than sums using the USDA and Divisia indices as can be observed from Figure 7. The number of lags is 16 years, similar to the lags associated with the USDA index. The mean lag is eight years. Again, the best lag is chosen on the basis of Theil's minimum error criteria. The R^2 is high and the coefficients are significant. Having discussed the estimates, we now move to rationalize the contribution of PVPR to productivity.

PVPR and Productivity

The difficulty of handling the contribution of PVPR to agricultural productivity was mentioned earlier. Time series data long enough to be analyzed within our framework and make meaningful inference are unavailable. The 13 years data at our disposal are inadequate to be fitted into the polynomial lag model (4.3) employed in this study.

It has been asserted (Ruttan, 1980) that investments on private research are larger than public research (POPR). After adjusting for proportion of private sector expenditure that is nonproduction-oriented, we observe that about 47 percent of expenditures are for nonproduction-oriented research and extension.

This study failed to estimate econometrically the parameters of PVPR investments due to inadequacy of time series data. An alternative approach is to approximate the contribution of PVPR. Some previous studies have adjusted downwards estimates of benefits from POPR by 30 percent [White and Havlicek, 1980]. The assumption is that, of the total expenditure on agricultural research and extension, a third is invested by the private sector. A factor of 1.22 has also been used to adjust downwards estimates on POPR (Evenson, 1968; Cline, 1975).

Adjusting estimates on POPR downwards by factors such as mentioned above has been criticized [Ruttan, 1980] on the grounds that the adjustment may bias the contribution of PVPR investments upwards and bias downward the contribution of POPR. Alternatively, 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.

Under the circumstances, we are left with the alternative of seeking some approximation, knowing too well that the final result would be crude. Using the available data on PVPR, we computed the ratio of PVPR investments to the total productivity oriented research and extension expenditures in agriculture to find a factor and adjust downwards the estimates on POPR. The adjustment factor is calculated as the 13 years average of the ratio of productivity oriented private sector expenditure to the sum of public and private sector research and extension expenditures. The adjustment factor so computed is .196 and the adjusted rates of return are given by Table VI. This is a crude estimate; the reader may wish to adjust estimates herein by factors specified by other researchers noted above.

In conclusion, this chapter reported estimates of an autorregressive PDL model. The estimates in Table V were discussed. We also showed the marginal products and internal rates of return to past POPR investments. The next section deals with the future impact of POPR on productivity, shifts in supply of aggregate agricultural outputs and subsequent transmission to demand, prices and income. The parameters estimated are used in a simulation model.

CHAPTER V

SIMULATION MODEL

The theory chapter suggested that an increase in POPR outlays increases productivity and shifts the supply curve of agricultural output to the right. Increases in supply lower prices and incomes, ceteris paribus. We employ a simulation model to trace the effect on productivity and aggregate supply of agricultural output of an exogenous increase in POPR. The simulation model employed is a modified SIMPAS developed by Tweeten and Quance (1970). The SIMPAS model uses a simultaneous formulation of aggregate demand and supply equations with prices and incomes endogenous. Both the demand and supply equations are assumed to be functions of Koyck type distributions of current and lagged prices in a formation similar to those used by Tweeten (1970) and Yeh (1976). The equations and the model are shown below:

$$Qd_t = AdP_t^{\gamma\beta d} P_{t-1}^{\gamma^1\beta d} P_{t-2}^{\gamma^2\beta d}, \ldots, P_{t-\infty}^{\gamma^\infty\beta d} e^{\sum_{i=to}^{t} gd_i} \qquad [5.1]$$

$$Qs_t = AsPR_t^{\mu\beta s} PR_{t-1}^{\mu^1\beta s} PR_{t-2}^{\mu^2\beta s}, \ldots, PR_{t-\infty}^{\mu^\infty\beta s} e^{\sum_{i=to}^{t} gs_i} \qquad [5.2]$$

where:

Qd, Qs = Quantities demanded and supplied respectively.

P, PR = Prices received (deflated) and parity ratio respectively.

gd, gs = Rates of shift in demand and supply respectively.

βd, βs = Short-run price elasticities of demand and supply respectively.

γ, μ = Weights related to the speed of adjustment towards equilibrium, $\delta d = 1-\gamma$ and $\delta s = 1-\mu$

Ad, As = constants

By introducing the lagged values and with some manipulation, the reduced form of the demand and supply equations can be written in log form as follows:

$$\ln Qd_t = \ln Ad + \beta d \ln P_t + (1-\delta d)\ln Qd_{t-1} + \delta d\sum_{i=to}^{t-1} gd_i + gd_t \qquad [5.1.1]$$

$$\ln Qs_t = \ln As + \beta s \ln PR_t + (1-\delta s)\ln Qs_{t-1} \quad \delta s\sum_{i=to}^{t-1} gs_i + gs_t \qquad [5.2.1]$$

The shift in demand (gd_t) for agricultural output arises from growth in population and per capita income in the domestic market and export demand. The shift in demand has been discussed in detail by Tweeten (1969). The average yearly shift in demand to year 2025 has been estimated to range between 1 percent per year to 2 percent per year.

Supply shifts (gs_t), due to changes in prices of inputs, education of farmers, weather and, above all, due to productivity increases from POPR inputs. The shift in supply due to POPR investments is of major interest. Productivity is assumed to respond to POPR expenditures with a distributed lag of Almon type. Assume the lag structure of productivity response to POPR can be expressed as:

$$PIND_t = a_t \prod_{j=1}^{n+1} POPR_{t-j+1}^{r_j} \qquad [5.2.2]$$

where:

$PIND_t$ = Productivity index time t

a_t = Conglomeration of shifters

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

j = Number of lags, $j = 1, 2, \ldots, n$

Annual growth rate in the productivity index between two time periods is:

$$\ln\left(\frac{PIND_t}{PIND_{t-1}}\right) = \ln\left(\frac{a_t}{a_{t-1}}\right) + \sum_{j=1}^{n+1} (r_j - r_{j-1}) \ln POPR_{t-j+1} \qquad [5.2.3]$$

The annual productivity change (5.2.3) due to POPR enters the supply function (5.2.1) through the exponential component (g_{st}). substituting (5.2.3) in (5.2.1) for g_{st}, we obtain the new supply function:

$$\begin{aligned} \ln Qs_t = {} & \ln A_t + Bs \ln PR_t (1-\delta s) \ln Qs_{t-1} \\ & + \delta s\Big[\sum_{i=to}^{t-1} (\ln a_i - \ln a_{i-1}) \\ & + \sum_{j=1}^{n+1} (r_j - r_{j-1}) \ln POPR_{i-j+1}\Big] + (\ln a_t - \ln a_{t-1}] \\ & + \sum_{j=1}^{n+1} (r_j - r_{j-1}) \ln POPR_{t-j+1} \end{aligned} \qquad [5.2.4]$$

$$\text{Let } \hat{A}_t = \ln A_t + \delta s \sum_{i=to}^{n+1} (\ln a_i - \ln a_{i-1}) + \ln a_t - \ln a_{t-1} \qquad [5.2.5]$$

Substitute (5.2.5) into (5.2.6) and obtain

$$\begin{aligned} \ln Qs_t = {} & \ln\hat{A}_t + \beta s \ln PR_t + (1-\delta s)\ln Qs_{t-1} \\ & + \delta s \sum_{i=to}^{t-1} \sum_{j=1}^{n+1} (r_j - r_{j-1}) \ln POPR_{i-j+1} \\ & + \sum_{j=1}^{n+1} (r_j - r_{j-1}) \ln POPR_{t-j+1} \end{aligned} \qquad [5.2.6]$$

Equation (5.2.6) shows that supply shift is the cumulative effect of POPR expenditures over the time horizon to t-1 plus the last (t^{th}) period investment. Unlike previous studies that assumed supply grows at a fixed rate due to productivity of POPR, equation (5.2.6) shows that supply shift due to productivity of POPR is variable. The equation traces the lagged response of productivity due to investments in POPR.

The system of equations (5.1) and (5.2.6) is used to simulate equilibrium prices (P), quantity supplied (Qs), quantities demanded (Qd), gross farm income (GFI), 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 reduced form demand equation (5.1) has a price elasticity and a lag parameter. The price elasticity of demand for aggregate agricultural products has been estimated to be between -.3 and -1.5. In this study a short-run elasticity of -.25 and long-run elasticity of -1.0 are used.

The shift in demand (gd) has two components: The domestic component and foreign component. The shift in demand due to the domestic component comes from population growth and increases in per capita income. The shift in demand due to foreign component comes from the growth in exports. Tweeten (1970) has shown that, while the domestic component can be estimated fairly accurately using income elasticity of demand and population growth, the foreign component is difficult to predict. Nevertheless, Tweeten and others have estimated that the total shift in demand to year 2025 is likely to average between 1 percent and 2 percent yearly.

The supply equation (5.2.6) has a price elasticity parameter and a lag parameter. Short-run price elasticity of .10 and long-run elasticity of 1.0 are used in this study. 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 (5.2.6).

Scenarios

The reduced system of equations (5.2) and (5.2.6) together with the parameters discussed are used to simulate and optimize equilibrium Q_{dt}, Q_{st}, prices, GFR, production expenses and NFI. Four scenarios of POPR expenditures are considered in the simulation model. Annual growth rates of POPR expenditure of 3 percent, 5 percent, 7 percent, and 9 percent are used to simulate productivity and supply shifts and the impact thereof on equilibrium prices, GFR, Qd_t, Qs_t, PE, NFI. Alternative demand shifts of 1.5 percent and 2 percent are exogenously supplied to the model. The results are analyzed below.

Simulated Economic Outcomes

Many scenarios are considered in this analysis. The only variable parameter is the shift in supply due to productivity gains from growth in POPR endogenously determined. Economic outcomes for the period 1982-2025 are simulated based on the parameters discussed and exogenously determined growth rate in POPR. The results are summarized in Table VIII. Actual results for the base year are included in each table as reference points.

An annual growth rate in POPR outlays of 3 percent is one of the scenarios considered. During the simulation period, the productivity index grew at the rate of 1.99 percent yearly. The effect of productivity growth is to shift aggregate supply 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 and increases GFR at a yearly rate of 1.56 percent. During the same period, NFI decreased at the rate of 0.90 percent yearly.

The result of 5 percent rate of annual growth in POPR expenditures is presented in Table VIII. The productivity index grew at a yearly rate of 2.12 percent and aggregate output increased by 1.93 percent yearly. Prices received declined at an annual rate of 0.37 percent due to an increase in supply relative to demand. GFR and NFI increased by 1.55 percent and -2.61 percent, respectively, because additional output due to productivity growth offset the fall in price.

Table VIII

ANNUAL GROWTH RATES OF Qs, GFR, NFI UNDER ALTERNATIVE GROWTH RATES IN POPR OUTLAYS FOR THE PERIOD 1982-2025

Shift in Demand = 1.5 percent

	3%	5%	7%	9%
Qst	1.86	1.93	1.99	2.07
GFR	1.56	1.55	1.55	1.54
NFI	-0.90	-2.61	-9.00	-12.53
PR	-0.30	-0.37	-0.44	- 0.51
P	-0.30	-0.37	-0.44	- 0.51
PIND	1.99	2.12	2.24	2.35

Shift in Demand = 2.0 percent

Qst	2.07	2.14	2.21	2.28
GFR	2.04	2.03	2.03	2.02
NFI	1.89	1.50	0.90	0.17
PR	-0.03	-0.12	-0.18	-0.25
P	-0.03	-0.11	-0.18	-0.25
PIND	1.99	2.12	2.24	2.36

Table VIII shows an annual growth rate of 2.24 percent in productivity and 1.99 percent in aggregate supply due to a 7 percent growth rate in POPR assuming demand shifts at the rate of 1.5 percent yearly. The shift in supply by 1.99 percent depressed prices received by .44 percent and consequently GFR grew only by 1.55 while NFI fell at the rate of 9.00 percent yearly.

The projected outcome due to a 9 percent growth in POPR outlays annually is given in Table VIII. The Productivity index increased by 2.35 percent yearly. Supply quantity grew at an annual rate of 2.07 percent. The annual shift in demand remaining at 1.5 percent throughout the study period, prices received fell by 0.51 yearly. GFR rose by 1.54 percent annually and NFI fell at an annual rate of 2.53 percent.

The results discussed are based on annual shift in demand at the rate of 1.5 percent. An annual shift in demand of 2 percent changes the results as can be noted from Table VIII. A look at the Table indicates the productivity index increased at the rate of 1.99 per cent annually from an annual growth rate in POPR expenditures of 3 percent. Supply quantity increased at the rate of 2.07 percent yearly. Supply increases notwithstanding, prices received did not fall as in the case of demand shift of 1.5 percent yearly. GFR and NFI grow at an annual rate of 2.04 percent and 1.89 percent respectively.

Table VIII also shows the projected economic outcomes from an annual increase in POPR of 5.0 percent and a constant yearly demand shift of 2.0 percent. The productivity index and supply grew at a 2.14 percent rate yearly. Because the demand shift rate is close to the supply shift rate, prices fell modestly by a rate of .11 percent yearly, GFR grew at the rate of 2.03 percent and NFI increased at an annual rate of 1.5 percent.

With an annual investment rate of increase in POPR of 7.0 percent, productivity and supply increase of 2.24 percent per year. Because the supply shift is greater than the demand shift (2.2 vs 2.0 percent), simulated prices fell at the rate of .17 percent and GFR rose by 1.01 percent annually.

The maximum annual growth rate of POPR outlays of 9.0 percent causes the productivity index and supply to increase by 2.36 percent yearly. With the demand shift being less than the supply shift, prices fell by .25 percent per year. GFR rose by 2.02 percent and NFI rose by .25 percent compounded annually, because increased output compensated for falling prices.

Differences in time span covered notwithstanding, we compare our projections with some previous simulation studies. Projections for 1981-1990 (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 according to projections by Yao-Chi Lu, Leroy Quance, and Chun-lan 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 seem too low in the light of our results discussed. The disparity may be attributed to the size of parameters used. While we used our estimate of parameter on

POPR, White and Havlicek, and Yao-Chi Lu and Quance used parameter on POPR of .037.

Notice that larger rates of increase in POPR outlays increase productivity and aggregate supply growth rates. Assuming a constant rate of shift in demand, larger increases in productivity cause a larger decline or slower increase in prices and farm income. This raises the question as to who benefits from agricultural research and extension. Some contend that all farmers are beneficiaries while others maintain the benefits accrue to early adopters of new technology while the small farmer benefits little or none.

The validity of the assertions depends, at least in part, on the elasticity of demand and the annual rate of shift in demand. Farmers do not receive lower prices if the shift in demand is equal or larger than the shift in supply. As discussed earlier, an annual shift of 1.86 percent in supply when demand shifts at an annual rate of 1.5 percent depressed prices received by 0.30 percent and incomes by 0.90 percent yearly. The larger the investments on POPR, the larger the loss to the farm sector.

The rate of shift in demand is a major determinant of economically optimal funding of agricultural research and extension, ceteris paribus. Consumers benefit from increased supply and lower demand shifts while farmers lose from lower prices. The analysis of social costs and benefits comes into the picture. Although the net social benefit could be greater than the cost, there may be dislocation in the farming sector due to individual losers (Tweeten, 1979). We now move to estimate the marginal returns on POPR investments for the scenarios considered.

Estimating Marginal Returns

Decisions to invest in agriculture are made at the margin. Estimates of the contribution of POPR outlays to productivity is the ability to directly estimate the marginal benefits of POPR. It is apparent from (5.2.6) that:

$$\frac{\partial \ln Qs_t}{\partial \ln POPR_{i-j+1}} + \frac{\partial \ln Qs_t}{\partial \ln POPR_{t-j+1}} = \delta(r_j - r_{j-1}) + (r_j - r_{j-1})$$

$$j = 1, \ldots, n+1 \qquad [5.2.8]$$

By definition, the elasticity (E) of output (Qs_t) with respect to $POPR_{t-j+1}$. is:

$$\frac{\partial Qs_t}{\partial POPR_{t-j+1}} \quad \frac{POPR_{t-j+1}}{Qs_t} \qquad [5.2.9]$$

Substituting (5.2.9) into (5.2.8) and rearranging terms

$$MP_j = \left[\frac{\delta(r_j - r_{j-1})}{POPR_{i-j+1}} + \frac{(r_j - r_{j-1})}{POPR_{t-j+1}} \right] Qs_t \quad j = 1, 2, \ldots, n+1 \qquad [5.2.10]$$

Equation (5.2.10) approximates the marginal product (MP) of $POPR_{t-j+1}$ and indicates that the MP of POPR is distributed over time in much the same pattern as the parameters on POPR discussed in the previous section. The MP of an outlay in POPR accrues over a lag of j number of years--16 years in the context of this study. A sample of the pattern of flow of MP through j periods is shown in Table X. The inflow of these benefits, much like the parameters, starts low, rises,

TABLE IX

MARGINAL PRODUCT OF POPR OVER 16 LAGS FOR SELECTED YEARS

Lag	1982	1985	1988	2025
1.	0.11243	0.10195	0.09703	0.05842
2.	0.23090	0.19682	0.18731	0.11278
3.	0.35726	0.30867	0.27016	0.16267
4.	0.49502	0.41869	0.34447	0.20741
5.	0.61409	0.53378	0.40931	0.24648
6.	0.77485	0.65717	0.46379	0.27925
7.	0.88352	0.74995	0.55101	0.30512
8.	0.98108	0.88438	0.62100	0.32324
9.	1.07642	0.95063	0.68618	0.33294
10.	1.15201	0.99779	0.74671	0.33341
11.	1.17331	1.03203	0.75687	0.32373
12.	1.12511	1.03280	0.78932	0.30314
13.	1.06143	0.96713	0.7353	0.27062
14.	0.87909	0.82403	0.64131	0.22517
15.	0.69826	0.64053	0.50250	0.16563
16.	0.41134	0.35757	0.29512	0.09102

reaches a maximum and declines in an inverted U shape. Figure 7 shows the inflow of marginal benefits over time.

Table X shows that the marginal product of POPR outlays declines 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 $10.20 in 1982 to $3.60 in 2025. Allowing POPR to grow at a higher annual rate of 9.0 percent results in faster decline of MP from $10.20 in the base year to $0.48 in 2025. MP declines within the range of $10.20 in 1982 to $0.38 in 2025 for POPR growth rates of 5.0 percent and 7.0 percent, as can be gleaned from Table X.

TABLE X

ECONOMIC OUTCOMES FOR FARMING INDUSTRY UNDER DIFFERENT GROWTH RATES OF POPR AND ALTERNATIVE YEARLY DEMAND SHIFTS 1982-2025

Year		Scenario I			Scenario II			Scenario III			Scenario IV		
	1982	1995	2010	2025	1995	2010	2025	1995	2010	2025	1995	2010	2025
POPR Growth Rate			3%			5%			7%			9%	
	ANNUAL SHIFT IN DEMAND = 1.5 Percent												
P	620.00	593.97	568.73	543.74	589.98	558.33	526.31	586.10	548.30	509.75	582.31	538.64	494.01
PR	60.67	58.12	55.65	53.20	57.73	54.63	51.50	57.35	53.65	49.88	56.98	52.70	48.34
Qs[1]	142.40	186.95	245.09	320.86	187.83	249.05	330.51	188.69	252.99	340.25	189.54	256.93	350.09
GFR[1]	142.40	179.10	224.82	281.40	178.73	224.27	280.56	178.37	223.74	279.75	178.14	223.21	278.95
NFI[1]	24.60	25.01	22.62	16.50	23.91	18.80	7.68	22.84	14.50	1.20	21.78	11.22	- 10.13
POPR[1]	1.74	2.60	3.99	6.21	3.35	6.96	14.48	4.36	12.04	33.21	5.65	20.60	75.02
MP	10.23	5.55	4.35	3.60	4.88	2.88	1.80	4.33	1.93	0.93	3.88	1.32	0.49
VMP	10.23	5.31	3.99	3.15	4.64	2.59	1.52	4.09	1.71	0.75	3.64	1.14	0.38
IRR	42.20	25.51	19.83	15.66	21.73	12.02	4.88	18.66	6.10	- 2.88	16.12	- 1.40	- 8.93
	ANNUAL SHIFT IN DEMAND = 2.0 Percent												
P	620.00	618.39	615.28	610.76	614.23	604.02	591.19	610.19	593.18	572.79	606.24	582.72	554.91
PR	60.67	60.51	60.20	59.70	60.10	59.10	57.85	59.71	58.04	56.03	59.32	57.02	54.30
Qs[1]	142.40	190.40	258.67	351.53	191.28	262.85	362.09	193.03	267.01	372.76	193.03	271.16	383.55
GFR[1]	142.40	189.90	256.70	346.29	189.51	256.07	345.26	189.13	250.43	344.26	188.75	254.86	343.28
NFI[1]	24.60	32.96	43.26	56.02	31.83	39.18	46.25	30.22	35.12	36.43	29.62	31.08	26.51
POPR[1]	1.70	2.59	3.99	6.12	3.35	6.96	14.48	4.36	12.04	33.21	5.65	20.60	75.02
MP	10.23	6.29	5.22	4.48	5.52	3.43	2.22	4.88	2.29	1.13	4.36	1.56	0.59
VMP	10.23	6.27	5.18	4.41	5.47	3.34	2.11	4.80	2.19	1.04	4.26	1.46	0.52
IRR	42.16	29.22	24.98	21.73	24.91	15.98	9.16	21.43	9.31	0.44	18.58	4.13	- 6.18

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[1] All figures are in billions of 1982 dollars.

A similar pattern of diminishing returns (decline in MP) is shown in Table X when the 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. The projected decline in marginal product is less in magnitude in the case of 2.0 percent shift in demand. For example, a 3.0 percent growth rate in POPR yearly resulted in the decline of MP from \$10.20 in 1982 to \$4.48 in 2025, while a 9.0 percent increase in POPR yearly resulted in a MP decline from \$10.20 to \$0.58 during the same period.

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. Thus the IRR (R) on POPR_{t-j+1} is:

$$\text{IRR} = R: \left\{ \sum_{j=1}^{n+1} \left[Qs_t \left(\frac{\delta(r_j - r_{j-1})}{\text{POPR}_{i-j+1}} + \frac{(r_j - r_{j-1}}{\text{POPR}_{t-j+1}} \right) \frac{P_t}{P_{to}} \right] (1+R)^{-j} \right\} - 1 = 0 \quad [5.11]$$

where:

The expression inside the square brackets is the MP_j of POPR

P_t = Prices received by farmers at time t.

P_{to} = Prices received by farmers at time t = 0

$MP_j \frac{P_t}{P_{to}}$ = is the value marginal product (VMP_j) of POPR.

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

Based on the simulated scenarios, and the above equation, we computed the IRR summarized in Table X. Notice the IRRs for all the scenarios are the same for the base year and slowly diverge thereafter. For example, compare the IRR for scenario I and IV and demand shift of 1.5 percent annually. The IRR for scenario I starts at 42.20 percent in 1982 and falls to 25.52 percent in 1995, to 19.83 percent in 2010 and to 15.66 percent in 2025. The IRR for scenario IV declines from 42.2 percent in 1982 to 16.12 percent in 1995, to 1.4 percent in 2010, and to -8.93 in 2025. On the other hand, annual demand shift of 2.0 percent results in IRR decline from 42.20 in 1982 to 30.04 in 1995, 24.94 in 2010 and 21.73 in 2025 for Scenario I. The decline is to 18.58 in 1995, 4.11 in 2010 and -6.2 in 2025 from 42.20 in 1982 for Scenario IV. Clearly the decline in IRR is much faster and magnitude of decline is larger for scenario IV relative to scenario I. This is the law of diminishing returns. As more is invested, the marginal benefits and the IRR decline. The drop is greatest for a higher rate of growth in POPR.

The Table X shows that investing in POPR at the historical rate of 3 percent yearly results in an IRR that is high (about 42 percent) in the past but declines to about 22 percent in the future based on our simulation results. Economically efficient allocation of resources requires that investments continue until returns to resources committed on various undertakings of similar risk are equal. A case is made that there is more social benefit to be gained by increasing investment in POPR. The following section elaborates on this issue.

CHAPTER VI

OPTIMAL CONTROL MODEL

Econometric studies, including this one, have shown that the IRR on POPR investment are very high relative to that on alternative public undertakings. An economically efficient allocation of scarce public resources demands that the risk-adjusted IRR on various investments be equal (Arrow, 1969). This implies that more public outlays are needed to reduce the IRR on agricultural research and extension to that of IRR on comparable investments. Simulation, optimization and optimal control models can be used to make an ex-ante analysis of the adjustment path to equilibrium.

An optimal control model is suited to obtain, based on a designated target IRR, an optimal level and time path of future POPR investments. The model requires that benefits from future outlays be measured, a criteria function be determined, and target and instrument variables be specified. Given these variables, the pattern of future investments to achieve the desired goals can be sought. With the foregoing in mind, we briefly discuss the general formulation of an optimal control model.

Optimal control is a mathematical formulation of a system to determine the values of control (instruments) variables that cause a particular system to maximize (minimize) a given performance measure subject to a set of boundary constraints. The system to be controlled, input and output variables, performance measure and the control variables must be described by models composed of equations for an optimal control problem to be optimized (Kirk, 1970).

Mathematically, the general optimal control can be formulated as:

$$f\ (X_t, Y_t, Z_t, U_t) = 0 \qquad [7]$$

where:

X_t = $(X_{1t}, X_{2t}, \ldots, X_{nt}$ = A vector of endogenous (State) variables. Values of state variables over the period analyzed (t_o to t_f) make up the State trajectory.

Y_t = $(y_{1t}, y_{2t}, \ldots, y_{nt}$ = A vector of subset of endogenous variables used as performance measure

Z_t = $(z_{1t}, z_{2t}, \ldots, z_{nt}$ = A vector of uncontrollable variables.

U_t = $(U_{1t}, U_{2t}, \ldots, U_{nt}$ = A vector of exogenous controls that can be manipulated by decision makers. Values of the controls over the period analyzed (t_o to t_f) constitute the control path.

The essential feature of optimal control is that it specifies an objective function in terms of instruments and targets and derives solutions for the policy instruments and their corresponding targets utilizing an optimization technique. The difficulty with this approach in economics is the formulation of the objective function. The specification of the objective function presumes knowledge of the policy makers' desired values for both the target and instrument variables. Assume that policy makers state their preferences in the form of a desired path of target variables and that their objective is to achieve the time path of their targets by manipulating the control variables such that the path of the controls through time correspond to the time path of their targets as closely as possible. Then, the optimal path of the target variables can be compared against the path of the instruments. Following Turnavsky (1974) the performance measure can thus be formulated as a quadratic cost function.

$$J \quad = \quad \sum_{i=t}^{t} (Y_t - U_t)' \, K \, (Y_t - U_t) \qquad [7.1]$$

where Y_t and U_t are as defined in [7] and K represents a matrix of boundary constraints imposed on the controls and, if necessary, also on the state variables. The boundary constraints are based on political, social, economic and/or physical conditions affecting the system to be controlled. The constraints limit the number of alternative control paths that must be investigated. Equation (7.1) implies that the performance measure can be evaluated as a squared sum of the deviations of the desired targets from instruments for the period analyzed (t = 1, 2, . . ., T).

In formulating an optimal control model, the state variables X_t can be functions of the controls (U_t), other State variables X_t and noncontrollable variables (Z_t). As a minimum, at least one of the equations describing the state variables must contain the control variable for the system to be controlled (Richardson and Trapp). In a closed loop control problem, controls are expressed as a function of the state variables, otherwise, the system is an open-loop control problem.

Given the general optimal control framework, we can now discuss its application to our study. Assume that policy makers have through some process identified a long-run desired target rate of return (IRR_t) and wish to allocate public resources efficiently through control of POPR expenditures overtime. As mentioned in the introduction, POPR is a policy instrument that has been historically employed to create and disseminate productivity-increasing technology to the farm sector. We thus express POPR outlays -- the control variable -- as a function of time:

$$POPR_t = f(t); \quad t = 1, 2, . . ., T \qquad [7.2]$$

The objective is to control the economic system by adjusting investments in POPR through time to keep the target variable (IRR_t) as close to the desired level (IRR_d) as possible. Once the functional form of (7.2) is specified, the optimal expenditure and its time path can be sought. The performance of the system can, therefore, be measured by the deviations of the actual (IRR_a) from the target (IRR_t). The performance measure can be specified as a quadratic cost minimization function:

$$J = \sum_{t=1}^{T} (IRR_a - IRR_t)^2 \qquad [7.3]$$

The IRR_a is that which must be derived from the investment in POPR through time, t=1, 2, . . ., T as expressed by (7.2). The IRR_t is exogenously determined by policy makers. In this regard there are two questions that must be addressed. Equation (7.3) assumes that IRR is the sole criteria for efficient allocation of public funds.

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 can be included in (7.3). For purposes here, IRR is assumed to be the sole criterion in the investment decision.

The next question concerns the measurement of IRR_a. The essence of POPR investments is to create and disseminate productivity increasing technology. The effect of new technology induced by POPR outlays is to increase productivity and aggregate agricultural output, ceteris paribus. The relationship between output and POPR outlays is derived elsewhere and expressed by equation (7.4)

$$\begin{aligned} \ln Qs_t &= \ln A_t + \beta \ln PR_t + (1-\delta s) \ln Qs_{t-1} \\ &+ \delta s \sum_{i=to}^{t-1} \sum_{j=1}^{n+1} (r_j - r_{j-1}) \ln POPR_{i-j+1} \\ &+ \sum_{j=1}^{n+1} (r_j - r_{j-1}) \ln POPR_{t-j+1} \end{aligned} \qquad [7.4]$$

where:

PR_t = Parity ratio at time t

Q_{st} = Quantity demanded at time t

$POPR_{t-j+1}$ = Productivity oriented public expenditure in research and extension at time t-j+1

A_t = A conglomeration of shifters

δs = Rate of adjustment

βs = Price elasticity of supply

r_j = Parameters on POPR, j=1,2,. . ., n+1

ln = Natural logarithm

In order to compute the IRR on POPR expenditures, the marginal benefits through time (stream of inflows) are necessary. These marginal benefits can be derived from (7.4) as follows:

$$\sum_{j=1}^{n+1} \frac{\partial \ln Qs_t}{\partial \ln POPR_{i-j+1}} \quad \frac{\partial \ln Qs_t}{\partial \ln POPR_{t-j+1}} = \sum_{j=1}^{n+1} \delta(r_j - r_{j-1}) + (r_j - r_{j-1}) \qquad [7.5]$$

Where [7.5] is the elasticity (E) of output with respect to POPR expenditures. By definition, the elasticity with respect to an input is

$$E = \sum_{j=1}^{n+1} \frac{\partial Qs_t}{\partial POPR_{t-j+1}} \cdot \frac{POPR_{t-j+1}}{Qs_t} \qquad [7.6]$$

Equating (7.5) and (7.6) and rearranging we get

$$MP_j = \sum_{j=1}^{n+1} \frac{\delta(r_j - r_{j-1})}{POPR_{i-j+1}} + \frac{(r_j - r_{j-1})}{POPR_{t-j+1}} Qs_t; \; j=1,2,. . ., n+1 \qquad [7.7]$$

The marginal benefits from POPR in (7.7) are distributed over time. The lagged inflows of benefits impact on farm prices and incomes in a lagged manner. Since choice of expenditure in a time period restricts the possibilities in the future time periods, decisions to invest must be scrutinized carefully. Nevertheless, the rate of return on the stream of inflow of benefits can be computed as:

$$IRR = R: \quad \sum_{j=1}^{n+1} [VMP_j | (1+R)^j] - 1 = 0 \qquad [7.9]$$

where:

VMP_j is the value marginal product of POPR calculated as:

$VMP_j = MP_j \, (p_t / P_{to})$

where P_t is prices received by farmers at time t

P_{to} is prices received by farmers in base year, a constant

Equation [7.9] implies that the achieved IRR_a will change for changes in the values of the control variable POPR. Each time, the new IRR_a is compared against the target IRR_t until a value is found for IRR_a which minimizes (7.9). All the values for the control variable constitute the time path of the expenditures on POPR.

To limit the number of possible paths of the control variable, it is convenient to use growth in investment in POPR per year instead of POPR outlays directly. The annual rate of growth in POPR expenditure is constrained to within 3 percent and 10 percent which is deemed realistic based on historical, economic and political considerations.

The minimum growth rate of 3 percent is the historical yearly increase in POPR outlays for the last five decades. It is plausible to expect continuation to maintain agricultural productivity at about historical levels. The 10 percent maximum limit is imposed due to several reasons. The research and extension system may be unable to absorb 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 would unduly dislocate farmers through increased output and depressed prices and incomes. The social costs associated with such decision may be judged unacceptable. Too, in these times of budgetary crunch, investments beyond growth rates of 10 percent may not be politically feasible.

Given the boundary constraints of 3 percent minimum and a maximum of 10 percent, an infinite number of investments within the constraints can be made that would eventually stabilize the achieved rate of return (IRR_a) 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 (7.9).

There are numerous algorithms that can solve the model. In this study, we employ the sequential search algorithm of Box complex (Box 1965). The procedure minimizes the criteria function subject to constraints on the control variables. The algorithm also generates initial random numbers for the control variable to form the initial control path if the values are admissible i.e. are within the control boundary constraints. Inadmissible control values are moved into the bounds by increments of small amounts provided by the user.

The admissible controls are inputed to the system to be controlled. Values for the state variables trajectories are generated and used in the performance measure to obtain a unique real number that forms a member of the control path. The process is repeated by replacing the minimum valued performance measure with a higher valued performance measure until the performance measure is optimized. An optimum result is declared when the difference between the highest and lowest values of the criteria function is within a tolerance level provided by the user. A new control variable value is generated otherwise and tested for admissibility. The process is repeated until convergence is obtained.

Optimal Control Results

The optimal control model considered the period 1982-2025. For given functional forms of equation (7.2), i.e. POPR expenditures through time, equilibrium demand and supply conditions for aggregate agricultural products are simulated. As detailed in Chapter IV, productivity is determined endogenously as a function of the control variable POPR expenditures. Weather conditions and educational level of farmers are assumed to be average. Demand for aggregate agricultural products is assumed to shift at the rate of 1.5 percent and 2.0 percent compounded annually. The target variable, IRR is assumed to be ten percent throughout the simulation period. The functional forms of the control variable were varied as follows:

1. Exponential growth function
2. Step function - The growth rate in POPR expenditure is divided into segments. Initially, investment is allowed to grow relatively rapidly followed by a transition or deceleration period and a constant growth rate.

Exponential Growth Function

We can now analyse the equilibrium demand and supply conditions for the first functional form of the control variable - POPR expenditure. Given the parameters on the supply and demand equations (5.2 and 5.2.6), and an annual shift in demand at 1.5 percent, the yearly rate of growth in POPR outlays that minimizes the performance measure is found to be 4.00 percent per year. Table XI shows the impact of the optimum value of the control variable on the endogenous

TABLE XI

EQUILIBRIUM VALUES OF VARIABLES USING EXPONENTIAL GROWTH RATE OF THE CONTROL VARIABLE UNDER ALTERNATIVE YEARLY DEMAND SHIFTS; 1982-2025

YEAR	P	PR	Q_s	GFR	NFI	MP	VMP	IRR	POPR
ANNUAL DEMAND SHIFT = 1.5 PERCENT									
1982	620.00	60.67	142,400	142,400	24,570	10.19	10.19	42.01	1,766
1995	591.96	57.92	187,392	178,917	22,479	5.19	4.96	23.52	2,817
2010	563.48	55.14	247,070	224,547	20,708	3.53	3.29	16.60	5,277
2025	534.91	52.34	325,673	280,978	12,097	2.54	2.19	9.90	9,503
ANNUAL DEMAND SHIFT = 2.0 PERCENT									
1982	620.00	60.67	142,400	142,400	24,570	10.19	10.19	42.08	1,776
1995	614.52	60.13	191,278	189,537	31,904	5.57	5.52	25.18	3,388
2010	604.79	59.18	262,556	256,117	39,462	3.54	3.45	16.57	6,701
2025	592.52	57.98	361,350	345,334	45,933	2.33	2.23	9.88	13,655

TABLE XII

EQUILIBRIUM VALUES OF VARIABLES USING STEP FUNCTION GROWTH OF THE CONTROL VARIABLE UNDER ALTERNATIVE YEARLY DEMAND SHIFTS: 1982-2025

		Annual Demand Shift					
		1.5 Percent			2.0 Percent		
	1982	1995	2010	2025	1995	2010	2025
P	620.00	584.52	558.60	533.75	609.75	601.35	592.37
PR	60.67	57.19	54.66	52.23	59.66	58.84	57.96
Q_s	142.40	189.33	249.27	326.58	196.70	269.61	361.42
GFR	142.40	178.50	224.58	281.15	189.34	256.06	345.31
NFI	24.60	21.83	8.32	10.92	30.04	33.61	46.25
POPR	1.74	3.45	5.55	8.78	3.31	6.46	12.89
MP	10.20	3.98	2.91	2.60	4.48	3.14	2.46
VMP	10.20	3.75	2.62	2.23	4.59	3.05	2.34
IRR	41.93	17.58	12.59	10.24	21.36	14.64	10.10

demand of 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, declining at the rate of 1 percentage point each year for 1991-95, increasing by 5.1 percent in 1996-2005, falling by 1.8 percentage points each year during 2006-2010 followed by annual rate of growth of 3.0 percent for the remainder (2011-2025)-- results in a 10 percent IRR. Translated into actual expenditure, the pattern is variables i.e. Qs, GFR, NFI, PR, PD. The productivity index grew at a yearly rate of 2.05 percent, Q_s grew at the rate of 1.90 percent, P and PR declined at the rate of .34 percent. GFR grew modestly at the rate of 1.56 per annum. The equilibrium value of NFI also fell at the rate 1.60 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 outlays that minimizes the performance measure (7.3) averaged 4.86 percent per year throughout the period under study. Figure 8 depicts the optimal time path of POPR investments. Equilibrium values for the endogenous variables show marked difference as can be observed from Table XI. The equilibrium value of Q_s grew at the rate of 2.14 percent and GFR rose by 2.03 percent yearly while NFI increased at an annual rate of 1.50 percent. Productivity index rose at an annually compounded rate of 2.11 percent. Due to higher demand shift, the change in prices received showed only a modest decline of about .10 percent yearly. It is obvious that 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 under the previous scenario.

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. Assuming an annual shift in that spending starts at $1,740 million in 1982, grows to $3,750 million in 1995, $5,550 million in 2010 and $8,780 million in the year 2025. These results are given in the Table XII.

The optimal expenditures discussed would increase aggregate agricultural output. The productively index grew at the average rate of 2.07 percent yearly through 2025. The supply quantity increase was 1.90 per annum. Assuming that demand shift remains at 1.5 throughout the period under consideration, prices received declined at an annual rate of 0.34 percent. In addition, GFR grew by 1.56 percent while NFI declined by 1.83 percent annually.

The optimal results assuming 2.0 percent demand shift are given in Table XII. The criteria function is minimized for POPR outlays growing at 9 percent rate during 1982-1990, declining at the rate of .34 percentage points each year during 1991-1995 then rising at 7.4 percent yearly rate during 1996-2005, falling slightly by .38 percentage points each year for 2006-2010, followed by an annual growth rate of 4.7 percent during the 2011-2025 period.

The time path of optimal investment in POPR given a step function is depicted by figure (8).

A look at the above table shows that MP of POPR fell from $10.20 in 1982 to $2.24 in 2025 while IRR declined from 42 percent to 10.24 percent during the same period if the assumed rate of demand shift is 1.5 percent yearly. Under the assumption of 2.0 percent demand shift compounded annually, productivity index, prices received, supply, GFR and NFI increased at a yearly rate of 2.11, .10, 2.14, 2.03 and 1.45 percent respectively, while MP falls from $10.20 in 1982 to $2.34 in 2025 and IRR declines from 42 percent to 10.10 percent.

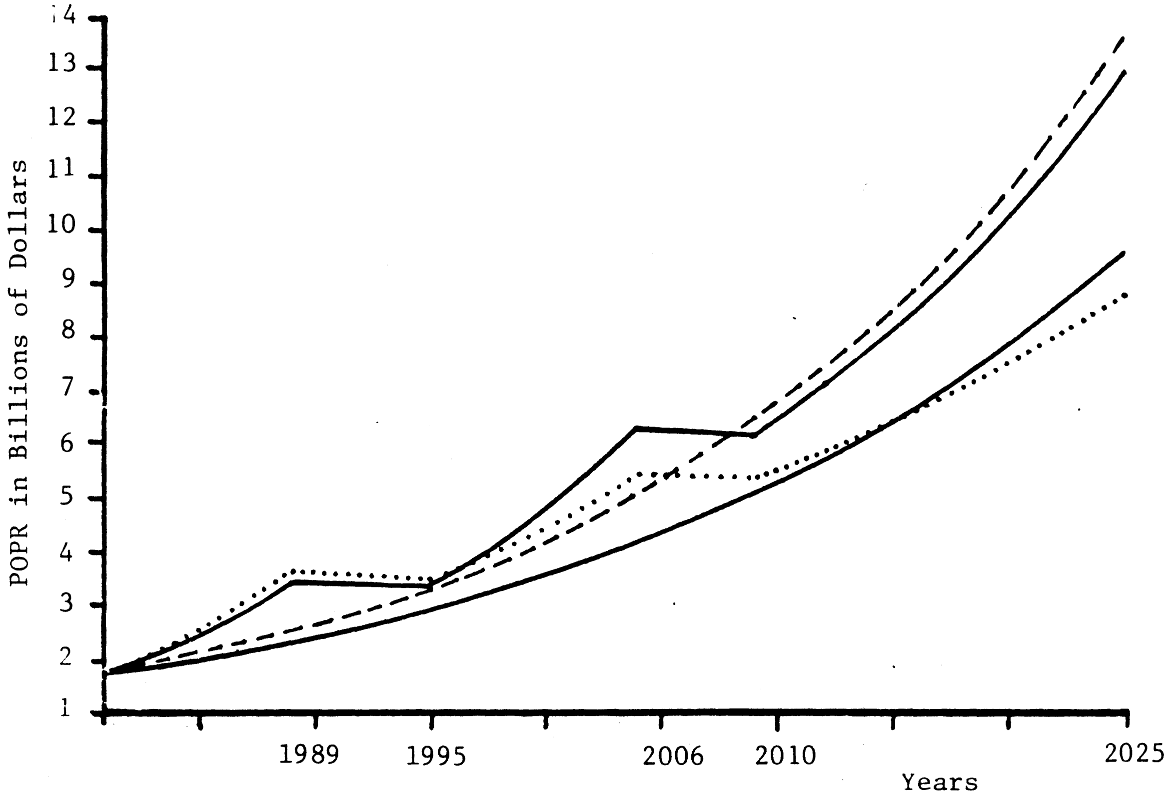

Figure 8. Time Path of Optimal POPR Investments Under Exponential and Step Functions And Altenatiue Demand Shifts.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The objectives of the study as specified in the introduction are restated briefly:

1. Reappraisal of the contribution of POPR to agricultural productivity using USDA, Divisia and Default indices.
2. Estimate the contribution of PVPR to agricultural productivity using USDA, Divisia and default indices.
3. Estimate the lag structure of POPR, PVPR.
4. Investigate the effect of an increase in supply of agricultural products due to POPR and PVPR on prices and incomes, using a simulation technique.
5. Determine optimal levels and the time path of POPR and PVPR over a planning horizon with prices and incomes endogenous, using an optimal control technique.

This study evaluated the ex post contribution of POPR to productivity in U. S. Agriculture and investigated its impact on farm prices and incomes using simulation and optimization techniques. USDA, Divisia and Default productivity indices were used as dependent variables. An autoregressive polynomial lag production function model was used to estimate the parameters on POPR using more recent data than used in previous studies. Unlike past studies, (Evenson, 1967; Cline, 1975; Havlicek, 1980), this study found, using the USDA Productivity index as the dependent variable, larger parameters and longer lags between research, extension input and crop-livestock output. A 1 percent investment increase in POPR in time t was estimated to increase productivity by a total of .064 percent distributed over 16 years in an inverted U shape by starting low, rising, reaching a maximum in eight years and then declining. The sum of the lag coefficients was .064 for the USDA index. The lag coefficients for each year are given in Table V, chapter V.

The Divisia Index of productivity as the dependent variable gave larger parameter estimates than did the USDA productivity index. The sum of the lag coefficients estimated using the Divisia index was .067 distributed over 15 years as shown in Table V. The inverted U shape that emerged from the distributed coefficients was similar to the USDA index.

The Table V also showed parameter estimates on POPR using the Default Index of productivity as the dependent variable. The sum of the lag coefficients was .087 distributed over 16 years. The advantage of the USDA index of total factor productivity is that fixed weight (base period weights) are used to aggregate outputs and inputs through time. Thus, the data requirements relative to the Divisia are less. But the USDA index fails to account for changes in factor ratios, especially if the underlying production function is not linear (Nadiri, 1972). The Divisia index requires more data since the weights to aggregate outputs and inputs are changed frequently to account for factor ratio changes (Jorgenson and Griliches, 1967). The advantage of the default index lies in its simplicity in constructing index numbers by working backwards as discussed in Appendix B.

The difference between the estimated parameters of the USDA and Divisia indices was not significant. A possible explanation is the approximation made on both indices. The otherwise fixed weight (Laspeyres) total factor productivity index of the USDA is corrected for its shortcomings in accounting for price changes over time by changing the price weights about every decade (USDA, 1977). Since the Divisia index cannot be applied to economic indices in its continuous form, it is approximated as shown by equation (A.11) in Appendix A. The approximations made on both formulae may have brought about the closeness of the sizes of the parameters.

Chapter IV, noted that the contribution of productivity oriented private sector expenditure on research and extension (PVPR) cannot be estimated due to inadequate number of observations. Consequently, we adjusted the estimated parameters, MPs and IRR on POPR by a factor of .196. The adjusted MPs and IRR were given in Table VI. The adjusted returns are larger for our study than for most previous results using the production function approach.

The estimated parameters were used in a simulation model to simulate equilibrium demand and supply conditions of the agriculture sector and to trace the effects of increases of POPR on productivity, supply, prices and incomes. The rational for using simulation was to allow feedback from POPR decisions to rates of return through farm price and output. A modified SIMPAS simulation model was used. Unlike the original model (Tweeten and Quance, 1971) which assumed an exogenously determined constant rate of productivity to shift supply, the modified SIMPAS computed endogenously the productivity rate and supply shift induced by exogenously determined POPR outlays. The model captured the lagged effect of POPR investments on productivity and supply shifts.

Growth rates in POPR of 3 percent, 5 percent, 7 percent and 9 percent were simulated. As discussed in the previous chapter, productivity and supply increased due to growth in POPR outlays. The annual 3 percent rate of growth in POPR, for example, resulted in a supply shift of 1.86 percent yearly. Prices received fell by .30 percent and income fell at the rate of .90 percent per annum, assuming an annual constant demand shift of 1.5 percent. If demand shift is assumed to be 2.0 percent yearly, the growth rate is 1.99 percent for productivity and for aggregate supply. Farm prices fell by .03 percent, while net farm income increased at a rate of 1.89 percent annually.

The marginal product and IRR on POPR were calculated over time. The results showed that marginal products and IRR continue to decline and display diminishing marginal returns over time. Higher growth rates in POPR bring a more rapid decline in marginal products and IRR from POPR. This can be illustrated by considering an annual growth rate in POPR of 3 percent. The marginal product declined from $10.23 in 1982 to $3.15 in 2025, and the IRR fell from 42.2 percent in 1982 to 15.66 percent in 2025, assuming demand shift of 1.5 percent per year throughout the simulation period. If the shift in demand is assumed to be 2.0 percent yearly, the marginal product fell from $10.23 to $4.41, while the IRR declined from 42.2 percent to 21.73 percent.

Higher rates of investment in POPR, say 9.0 percent compounded annually, pushed the marginal product from $10.23 in the base year to $0.38 in 2025, and IRR from 42.2 percent in 1982 to -8.93 percent by the end of the simulation period if demand shifts at the rate of 1.5 percent yearly. However, given a demand shift of 2.0 compounded annually, the decline was from $10.23 in the base year to $0.52 in 2025 for the marginal product and from 42.2 percent in the base year to -6.18 percent by the end of the simulation period for the IRR. The general pattern of decline in marginal product and IRR were the same for growth rates in POPR of 5.0 percent and 7.0 percent, as apparent from Table X.

Chapter VI showed the results of the optimal control model. Given that the IRR on POPR is high relative to alternative public outlays, efficient allocation of public resources demands that returns on public funds from alternative investments be equal. POPR outlays were increased to reduce the IRR on POPR. The criteria function was specified as a minimization of the sum of the squared differences of the IRR endogenously computed and IRR exogenously determined.

Two functional forms: (1) exponential growth in POPR and (2) a step function of POPR growth were assumed and solved using the Box complex algorithm for optimal control. The results of the exponential function indicate that an annually compounded growth rate of 4.0 in POPR is the optimal investment to minimize the objective function, assuming that demand shifts is 1.5 percent annually. Translated into actual expenditures, the time path of investment in POPR is shown by Table VIII. POPR starts at $1,766 million in 1982 and grows to $2,817 million 1995, $5,277 million in 2010 and $9,503 million in 2025.

The optimal investment growth rate of 4.0 percent in POPR brought about annually compounded growth rates of 2.05 percent, 1.91 percent, 1.56 percent and -1.60 percent in the productivity index, aggregate supply quantity, GFR and NFI respectively. Prices declined and the parity ratio fell by the same .34 percent annually, since the index of prices paid to farmers was assumed to remain constant. The optimal investment rate of 4.0 percent also reduced the marginal product of POPR from $10.20 in the base period to $2.19 in 2025, and the IRR to the target internal rate of return of 10 percent.

Assuming a 2.0 percent constant demand shift yearly and an exponential functional form for the control variable, the rate of growth of POPR that minimizes the objective function averaged 4.86 percent throughout the simulation period. In actual expenditures, the optimal investments range from $1,861 million in 1982 to $3,388 in 1992, to $6,701 million in 2010 and $13,655 million in 2025. These optimal investments increase the productivity index by 2.11 percent, output by 1.90 percent, GFR by 1.56 percent and NFI by 1.04 percent compounded yearly. Prices received and parity ratio declined at an annual rate of .10 percent. In addition, the marginal product of POPR declined from $10.20 in 1982 to $2.56 in 2025.

In the case of the step function, the period under study was divided into four segments such that outlays would be allowed to initially grow relatively faster and subsequently decline to lower growth rates. An annual compound growth rates of 10 percent for the first eight years, declining at 1 percent rate for 1992-1995, growing at rate of 5.1 percent for 1996-2005, slowing at 1.8 percent for 2006-2010 and finally a growth rate of 3.0 percent for the remaining period under consideration reached the target rate of return of 10 percent.

Given an annual shift in demand for agricultural products of 1.5 percent throughout the simulation period and rates of POPR growth aforementioned, productivity annually increased by 2.07 percent, supply quantity by 1.90, GFR by 1.56 and NFI rose by 1.83 percent. The index of prices received by farmers fell by .34 percent yearly. The index of price paid by farmers was assumed to remain constant, hence, the parity ratio fell by the same proportion as prices received by farmers. Furthermore, the marginal product of POPR fell from $10.20 to $2.23 during the period under study. The results are significantly different if the shift in demand is assumed to be 2 percent per year. Productivity annually increased by 2.11 percent, supply quantity increased 2.14 percent, GFR 2.03 percent and NFI by 1.45 percent. Prices received and the parity ratio declined by .10 percent annually. The marginal product of POPR also fell from $10.20 in 1982 to $2.35.

Some caveats with respect to the foregoing optimal results are in order. It is apparent that the results are based on the choice of exponential and step functional growth rates of the control variable. It is possible to obtain different sets of optimal results due to different functional forms of the control variable, set of constraints imposed on the control and other variables and different values of parameters on the system of equations in the control model. Furthermore, optimal results change with changes in projected future supply-demand balance as evident by outcomes from shifts in demand of 1.5 percent versus 2.0 percent shown in Tables VIII and IX.

The findings show, like many before, that investment in POPR increases productivity in agriculture. Aggregate supply increases due to productivity gains. Under the equilibrium conditions analyzed, we showed that prices and incomes decline or rise less due to the supply shift. The decline is greater for cases where the demand shifts forward most slowly. The study shows that a shift in demand of 2 percent concomitant with the growth rates in POPR outlays (optimal) the sector is relatively stable, ceteris paribus. That is, the farming economy does not need to make large adjustments in aggregate resources.

Policy Implications

Economic efficiency is achieved by investing to reach an equilibrium IRR. If the shift in demand is small and the increase in supply is large, then there is a cost in declining farm prices and incomes due to increased output induced by improved techniques. One policy option is to subsidize the producers to compensate for losses. The consumer is better off by virtue of the lower market price of agricultural products.

The simulation and control results show that if the demand shifts (due to growth in population, income per capita and exports) less than the supply shifts (due to technology), prices and incomes fall. Short-run dislocation occurs as early adopters gain and nonadopters lose. In the absence of public interference, resources adjust out of agriculture until earnings equal those for like resources elsewhere.

Subsidies to cushion impacts of productivity gains in the farming industry might retain some resources in farming that would have higher value in other uses. Concurrent public provision of productivity increasing technology and subsidy may appear to be inconsistent if resources do not adjust out of farming.

The lag between investment in POPR and its peak output contribution was 8 years and total obsolescence of POPR was 16 years. Current investment decisions impact productivity, supply, incomes and prices for the coming 16 years. Policy makers have only limited flexibility once a decision is made. Under- or over-funding POPR can have undesirable consequences in time. Short-term changes in research extension and prices can rectify mistakes, but at considerable cost to farmers, consumers or the public treasury. Social costs include higher consumer prices in the case of under-funding and low farm incomes in the case of over-funding. Optimal investment minimizes these costs.

The sum of the lag coefficients on POPR (.064, .067, .086 for the USDA, Divisia and Default indices, respectively) are small and may give the impression that productivity is unresponsive to POPR outlays. But the magnitude of benefits is large. Also, the estimated marginal products and IRR shown in Tables VI and VIII are high enough to justify increased investment in POPR. On the other hand, the parameter on NPOPR (nonproductivity oriented public expenditure on research and extension) was found to be insignificant. The true coefficient on nonproductivity oriented public expenditure on research and extension (NPOPR) may not be zero. Inability to find effect of NPOPR on productivity may be the result of statistical complications including multicollinearity.

Recommended Research

This and previous studies have failed to estimate the contribution of private sector expenditure on research and extension (PVPR) to productivity, primarily because of inadequate data. It is desirable that agricultural research and extension expenditures data by the private sector be gathered so that a more accurate estimate of the effect of research and extension on productivity can be made.

Demand parameters including the price elasticities and shift due to income and exports are crucial in studying the impact of POPR on farm incomes and prices. Recent indications are that the values of these parameters are higher than those used in earlier studies (cf. Tweeten, 1983, Schuh, 1984). In the light of this, fresh estimates of the parameters may be necessary.

This study has made the supply shift a function of POPR expenditures in the simulation model of agriculture. In contrast, many prior studies assumed a constant rate of growth in productivity. Endogenizing the shift in demand from the population, income and export shifters could improve the simulation model and results.

Since there are losers and gainers from publicly created technology, the question of the distributional effects of POPR outlays is a sticky one and needs to be addressed.

Commodity programs remove excess capacity while public research and extension create supply increasing technology. It would be desirable to determine the payoff from agricultural research and extension accounting for social costs of removing excess capacity by commodity programs.

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APPENDIXES

APPENDIX A

INDEX NUMBER PROBLEM

APPENDIX A

Index Number Problem

This section deals with the index number problems alluded to in the introduction. The arithmetic index of MFP used by the USDA is discussed first, followed a the discussion of the Divisia MFP index. The arithmetic and Divisia indices are both derived from production theory. For our purposes all indices are referred to as TFP or MFP interchangeably.

Arithmetic Index:

Assume that the United States Agriculture can be described by

$$Q = f(K,L) \tag{A.1}$$

where Q,K and L are quantities of output, capital and labor respectively. By Euler's theorem:

$$Q = f_k K + f_l L \tag{A.2}$$

where $f_k K$ and $f_l L$ are marginal products of capital and labor respectively. Capital and labor are heterogenous even within their respective group. They are aggregated using prices. Multiplying (A.2) by output prices, we obtain:

$$V = VMP_k K + VMP_l L \tag{A.3}$$

where $V = PQ$ (value of Output)

$VMP_k K = Pf_k K$ (value marginal product of capital)

$VMP_l L = Pf_l L$ (value marginal product of labor) under conditions of competitive equilibrium;

$$VMP_1K = r \text{ (r is price of capital)} \qquad (A.4)$$

$$VMP_1L = w \text{ (w is wage rate)} \qquad (A.5)$$

Substituting (A.4) and (A.5) into (A.3)

$$V = rK + wL \qquad (A.6)$$

Equation (A.6) is the formula used by the USDA to construct the TFP index. This formula implicitly assumes that the underlying production function is linear (Christensen, 1975), in which case it is exact. Problems arise if the function is not linear, because comparison of indices through time as relative prices of inputs change becomes a problem. The use of base period prices to aggregate inputs results in the Laspeyres index. The comparison period price aggregators result in the Paasche index. Both formulae for computing TFP indices are biased (Gardner, 1975) as elaborated below:

TFP is measured as the ratio of output index to the input index. If the Laspeyres index formula is used, TFP is computed as:

$$TFP = \frac{\sum_{i=o}^{n} P_{io}Q_{it}}{\sum_{i=o}^{n} P_{io}Q_{io}} \bigg/ \frac{\sum_{j=1}^{m} W_{jo}I_{jt}}{\sum_{j=1}^{m} W_{jo}I_{jo}} \qquad (A.7)$$

where

Pio,Wjo = Prices in the base period of the ith output and jth input respectively,

Qio,Ijo = Quantities in the base period of the ith output and jth input respectively, Qit,Ijt = Quantities in time t of the ith output and jth input respectively.

The Laspeyres formula in (7) uses the base period price weights to aggregate the outputs, as well as the inputs. The assumption is that the base period price weights will remain constant over time. But output mix may change. Some outputs may be replaced by new, more profitable outputs. Changes in factor ratios may occur, producers substitute cheaper more productive inputs. The Laspeyres formula fails to account for these changes over time. The Paasche index has similar shortcomings.

Ritcher (1966) and Hulten (1972) showed that the Divisia Index is a superior measure of TFP. The advantage of the Divisia Index is that the output share and input share weights change continuously so that changes in the output mix, input mix and changes in factor ratios are accounted for. The Divisia index can be derived from production function.

Derivation of the Divisia Index

To derive the Divisia TFP index from a production theory, assume a production function of the type:

$$Q = A(t)f(X_1, X_2, . . ., X_n) \qquad (A.8)$$

where Q is output and Xi, i = 0, 1, 2, . . ., n are inputs. A(t) is Hicks-Neutral technical change. Differentiating with respect to time:

$$\dot{Q} = \dot{A}(t) + \sum_{i=0}^{n} \frac{\partial f}{\partial X_i} \dot{X}_i \qquad (A.9)$$

Rearranging with some manipulation, (A.9) can be written as:

$$\frac{\dot{A}(t)}{A(t)} = \frac{\dot{Q}}{Q} - \sum_{i=0}^{n} \frac{\partial f}{\partial X_i} \cdot \frac{\dot{X}_i}{Q} \cdot \frac{X_i}{X_i} \qquad (A.10)$$

Assuming profit maximization behavior

$$\frac{\partial f}{\partial X_i} = \frac{W_i}{P} \text{ for all i:}$$

$$\frac{\dot{A}(t)}{A(t)} = \frac{\dot{Q}}{Q} - \sum_{i=1}^{n} \frac{W_i X_i}{PQ} \cdot \frac{\dot{X}_i}{X_i} = \frac{\dot{Q}}{Q} - \sum_{i=1}^{n} \alpha i \frac{\dot{X}_i}{X_i} \qquad \text{(A.11)}$$

Equation (A.11) is the continuous Divisia expression for productivity change. Since the sum of cost shares ($\Sigma\alpha_i = 1$), the underlying production function is assumed to be linearly homogenous (constant returns to scale).

The continuous Divisia index can also be derived from an accounting identity by assuming competitive markets for all output and all factors of production (Jorgenson and Griliches, 1967). Thus:

$$\sum_{i=1}^{n} P_i Q_i = \sum_{j=1}^{m} W_j X_j; \quad \begin{array}{l} i=1,2,\ldots, n \\ j=1,2,\ldots, m \end{array} \qquad \text{(A.12)}$$

where P_i and W_j are prices of the ith output and jth input respectively. Differentiating (A.12) with respect to time, we obtain

$$\sum_{i=0}^{n} P_i \dot{Q}_i + \sum_{i=0}^{n} \dot{P}_i Q_i = \sum_{j=1}^{m} W_j \dot{X}_j + \sum_{j=1}^{m} \dot{W}_j X_j \qquad \text{(A.13)}$$

Divide (A13) by (A.12)

$$\frac{\Sigma P_i \dot{Q}_i}{\Sigma P_i Q_i} + \frac{\Sigma \dot{P}_i Q_i}{\Sigma P_i Q_i} = \frac{\Sigma W_j \dot{X}_j}{\Sigma W_j X_j} + \frac{\Sigma \dot{W}_j X_j}{\Sigma W_j X_j} \qquad \text{(A.14)}$$

Equation (14) can be written as

$$\Sigma\beta_i \frac{\dot{Q}_i}{Q_i} - \Sigma\alpha_j \frac{\dot{X}_j}{X_j} = \Sigma\alpha_j \frac{\dot{W}_j}{W_j} - \Sigma\beta_i \frac{\dot{P}_i}{P_i} \qquad \text{(A.15)}$$

Where β_i = the value share of the ith output in the total output and α_j = is the cost share of the jth input in the total input. The right hand size of the equation

$$\Sigma\beta_i \frac{\dot{Q}_i}{Q} - \alpha\frac{\dot{X}_j}{X_j} \tag{A.16}$$

is the continuous expression for the percentage change in MFP index (Griliches, Jorgenson).

The problem with the Divisia Index in its continuous form is that it requires continuous price and quantity data. However a discrete approximation can be made following Hulten (1972), as follows:

$$\frac{MFP_{t+1}}{MFP_t} = \frac{\sum_{i=1}^{n} \frac{1}{2}(\beta_{it}+\beta_{i(t+1)}\log \left(\frac{Q_{1(t+1)}}{Q_{it}}\right)}{\sum_{j=1}^{n} \frac{1}{2}(\alpha_{jt}+\alpha_{j(t+1)})\log \left(\frac{X_{j(t+1)}}{X_{it}}\right)} \tag{A.17}$$

Expression (7) is used in this study to compute the Divisia MFP index of the U.S. agriculture.

In computing the Divisia productivity index, twelve output and nine input categories are used. The output categories are: Meat products, Diary 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, Fertilizers, Feed, Livestock, Miscellaneous Inputs.

The data on output categories are taken from Economic Indicators of the Farm Sector, Income and Balance Sheet Statistics. 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 fruit and nuts which is deflated by the index "all crops". All price deflators are taken from *Agricultural Statistics*.

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 supplies is used to deflate expenditures on repair and operation of machinery. Depreciation is deflated by the average of motor vehicles index and machinery index; and miscellaneous inputs expense is deflated by index of all commodities bought for production.

Real estate and labor input categories are adjusted for quality and family labor respectively, as discussed below:

Land

In principle, the land input should be the rental value of land which is not available and must be computed. Land qualities vary due to improvements. The land input is corrected using Hooker's (1962) conversion factor:

$L = H + EI*I \ EP * P.$

L = Corrected land acreage

H = Harvested acreage

I = Irrigated acreage

P = Pasture acreage

EI is the correction factor for irrigated land to an equivalent dry cropland

EP is the correction factor for pasture land to an equivalent dry crop land.

To find the service flow from land, L is multiplied by the average price per acre of harvested land. The result is the constant dollar value of land, which multiplied by the interest rate in a given year approximates the yearly service flow from land.

CR = Ratio of cash rent/land value on farms rented for cash P and CR are taken from <u>Farm Real Estate Market Developments</u>. V is calculated using the acreage of land adjusted above and value of land taken from <u>Farm Real Estate Market Developments</u>.

<u>Labor Input</u>

The USDA data on hired labor expenses are corrected for family labor and composition of operator and other family labor. Adjustment is made following Evenson and Landau (1973):

FL = Family labor

THLR = Total hours required annually estimated by the USDA

EHL = Expenditure on hired labor

CWR = Composite wage rate

IHHL = Implicit hours of hired labor

$$= EHL/CWR \tag{A.18}$$

$$FL = (THLR - IHHL) \tag{A.19}$$

Family labor (FL) is composed of owner operator and other family labor. FL is adjusted for the composition by multiplying family labor hours by 1.15 (Evenson and Landau, 1973). Thus adjusted family labor hours (AFLH) is:

$$FL*1.15 \tag{A.20}$$

The expenditure on adjusted family labor (EAFL) is

$$EAFLH = AFLH*CWR \tag{A.21}$$

The sum of expenditures on hired labor as reported by the USDA and the adjusted expenditures on family labor deflated by the composite wage rate is the labor input used in this study.

APPENDIX B

DEFAULT INDEX

APPENDIX B

DEFAULT INDEX

The Default index was one of the TFP indices mentioned in the introduction to be used as dependent variable to estimate the contribution of POPR to productivity. The rational behind the Default index and method of construction are discussed below:

The Rational for Default Index

Instability in the farm economy is nothing new. Causes of instability have long been detailed (Tweeten, 1979). Following good years of the early 1970's, prices and incomes continued to fall during the late 1970's and 1980's causing crisis in agriculture. The roots of the problem seem to elude conventional explanation.

Demand for farm output for 1979/80 shifted by 3.4 per year, double the average of the growth rate of the previous five decades (Tweeten, 1982). Supply shifted by yearly average of 1.6. In 1980 real demand increased 4.4% and supply rose by 3.4 to create excess demand of 7.8%. Excess demand should cause higher prices and incomes. Instead prices and incomes fell. This raises the question, among others, that productivity may be much higher than is reported by the USDA index of TFP. The default index is an attempt to construct TFP index by working backwards.

Method of Construction

The default index is constructed by assuming a base year and that demand and supply for farm output can be described by the following:

$$Qd_t = AdP_t^n Y_t^v N_t + E_t \qquad [\ 1\ ]$$

$$Qs_t = [AsPR^m \; X_{t-1}^w\ ]\ T \qquad [\ 2\ ]$$

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 (percent of output exported in real quantity).

N = Short-run price elasticity of demand.

V = Income elasticity of demand.

M = Price elasticity of Supply.

W = Rate of adjustment of input demand.

On the demand side, we choose Ad so that demand quantity in the base year, say 1972 = 100 and on the supply side, we choose As so that input demand in the base year is equal to 100. Once, we solve for Ad and As, we use equation (1) and (2) and solve for T under equilibrium conditions:

$$AdP_t^n Y_t^v N_t + E_t = [AsPR^m X_{t-1}^w]\ T \qquad [3]$$

$$T = \frac{AdP_t^n Y_t^v N + E}{AsPR_{t-1}^m\ X_{t-1}^{1-W}} \qquad [4]$$

The TFP indices constructed using equation (4) are used as dependent variables to explain the change in productivity due to technology induced by investments in POPR.

APPENDIX C

DATA AND SOURCES

APPENDIX C

DATA AND SOURCES

The definition and sources of data used to estimate the econometric model in chapter IV are detailed in Cline, P. L. Sources of Productivity Change in U.S. Agriculture. Ph.D. Dissertation, Oklahoma State University, Stillwater, 1975. For the most part we followed the same definition and sources. Research and Extension expenditures are composed of Agricultural Research Service (ARS), Economic Research Service (ERS), Cooperative Research Service (CES), State Agricultural Experiment Stations (SAES) and Soil Conservation Service (SCS).

Data on ARS expenditures for the period 1939-1972 is taken from Cline (1975). Data for 1973-1984 is obtained from U.S. Department of Treasury. Bureau of Accounts. Combined Statement of Receipts, Expenditures, and Balances of the United States Government. Washington, D.C.: Annual issues 1973-1974 and U. S. Department of Treasury. The Budget of the United States Government. Annual issues 1973-1984.

SAES are funded by the Hatch Act of 1887, State Appropriations and private grants. Data for 1939-1984 is taken from Cline, P. L. Sources of Productivity Change in U.S. Agriculture, Ph.D. Dissertation, Oklahoma State University, Stillwater, 1975. The

1973-1984 data is compiled from U.S. Department of Agriculture. Inventory of Agricultural Research. Cooperative State Research Service, Washington, D.C.: Annual issues 1973-1984.

Data on CES expenditures for the 1973-1984 is unpublished obtained by telephone from Mr. Dan Domingo of the USDA Cooperative Extension Service. The data for 1939-1972 is taken from Cline, P. L. Sources of Productivity Change in U.S. Agriculture, Ph.D. Dissertation, Oklahoma State University, Stillwater, 1975.

Productivity index has been subjected to numerous revisions through the years. Observations on productivity index for the period 1939-1984 are taken from the Council of Economic Advisors. Economic Report of the President, Government Printing Office, Washington, D.C.:1984.

Education and weather indices for 1939-1972 period are form Cline, P. L. Sources of Productivity Change in U.S. Agriculture. Ph.D. Dissertation, Oklahoma State University, Stillwater, 1975. These indices are updated for the 1973-1984 period using the same methodology. Weather index is found by regressing crop yield index on time. The residual is attributed to weather. Data on crop yield index is from: U.S. Department of Agriculture. Changes in Farm Production and Efficiency, ERS, EClFS 2-6, 1983.

Educational attainment index of farmers (EDI) is the level of education of farmers adjusted for age, sex and income. Observations on EDI for the 1939-1972 period are from Cline, P. L. Sources of Productivity Change in U.S. Agriculture. Ph.D. Dissertation, Oklahoma State University, Stillwater, 1975. Observations for 1973-1984 are constructed following the methodology used by Cline.

The observations are based on the 1980 census of population. Subject Reports PC(2) - 5B and PC (2) - 7A, educational attainment and occupational characteristics, respectively. Years of schooling completed estimates for farmers and farm managers, farm laborers and foremen are also reported for 1974, 1975 and 1979 in current population reports, Educational attainment. Observations in which data were not available were obtained by linear extrapolation. The detailed sources are:

U.S. Department of Commerce. *Bureau of the Census. Population Characteristics*, Educational Attainment: Series P-20 No. Washington, D.C.: Government Printing Office.

U.S. Department of Commerce. Bureau of the Census. *Population Characteristics, Educational Attainment*: Series P-20 No. Washington, D.C.: Government Printing Office.

U.S. Department of Commerce. Bureau of the Census. *Population Characteristics, Educational Attainment*: Series P-20 No. Washington, D.C.: Government Printing Office.

U.S. Department of Commerce. Bureau of the Census. *United States Census of Population, 1980 Educational Attainment*. Subject Report PC(2)-58 Washington, D.C.: Government Printing Office.

U.S. Department of Commerce. Bureau of the Census. *United States Census of Population, 1980, Occupational characteristics*. Subject Report PC(2)-7A. Washington, D.C.: Government Printing Office.

APPENDIX D

PRICE DEFLATORS

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PRICE DEFLATORS

The major portion of POPR expenditure is for scientific personnel salaries. This expenditure is deflated by the index of average salaries of college and university teachers. The residual of POPR expenditure is deflated by the implicit deflator of government purchases of goods and services obtained from: U.S. Department of Commerce. Office of Business Economics. The National Income and Product Accounts of the United States. Government Printing Office, Washington, D.C.: Various issues.

Deflator indices for expenditures on scientific personnel salaries for 1939-1972 are from Cline, P. L. Sources of Productivity change in U.S. Agriculture, Ph.D. Dissertation, Oklahoma State University, Stillwater, 1975. These indices are updated for 1973-1984. College and University teachers average salaries are obtained from: American Association of University professors. ACADEME Bulletine AAUP. Washington, D.C.: Annual issues, 1973-1984.

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