PROJECTING AGRICULTURAL PRODUCTIVITY AND ITS ECONOMIC IMPACT

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INTRODUCTION

Public investment in U. S. agricultural research and extension (R&E) programs, mostly by the USDA and State Agricultural Experiment Stations, increased rapidly in recent decades. Such expenditures oriented to increasing agricultural production increased from $149 million in 1939 to $377 million in 1972 (1958 dollars). But with such visible signs as Proposition 13 in California to zero based budgeting at the national level, both public and private decision makers are demanding greater accountability for, and productivity from, burdensome tax dollars.

Many studies indicate that the rate of return to agricultural R&E in the U. S. has been high, in the range of 24 to 31 percent according to our previous estimates (Lu and Cline). However, very little research has gone beyond *ex post* evaluation of past R&E. Since higher returns to R&E are realized through increased productivity, it is also important to establish the quantitative relationship between R&E and productivity growth. From this relationship we can project the *ex ante* rate of return to R&E and also determine how much R&E needed to sustain agricultural productivity growth to meet future demands for food and fiber at home and abroad.

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We first examine the relationship between R&E and agricultural productivity growth and formulate a productivity simulation model including R&E as a principal decision variable. Under alternative R&E growth rate scenarios, we use the simulation model to project agricultural productivity growth. We then evaluate the impacts of R&E derived productivity growth on social benefits and estimate benefit/cost ratios and the ex ante rate of return to R&E investments.

AGRICULTURAL PRODUCTIVITY SIMULATION MODEL

Many factors contribute to productivity growth, but because it is impossible and impractical to include all factors influencing productivity growth, we include in the model only the most important, observable, and measurable variables. We hypothesize that productivity change depends on technological change, the rate of diffusion of new technology, weather, relative factor and product prices, and farm programs. The rate of technological change in turn depends on public and private research expenditures while the rate of diffusion depends on extension expenditures and the educational attainment of farmers.

Although important, farm programs and relative prices are excluded in this study. So far we have not been able to separate the price effect from the effect of technological change. Past attempts to measure the effect of farm programs on agricultural productivity have not been successful primarily because of measurement and data problems. Due to data limitations, private research expenditures were also excluded in this study. Thus, our study attributes changes in agricultural productivity to lagged values of production oriented R&E, changes in farmers' education, and weather.

Based on the above observation, the productivity change model is specified as:

$$(1)\ P_t = \prod_{i=0}^{n} R_{t-i}^{a_i}\, E_t^{b}\, e^{cw_t}$$

where P = aggregate productivity index for U. S. agriculture in year t,

R = lagged production-oriented R&E expenditures directed at increasing agricultural production,

E = index of educational attainment of farmers in the current period,

W = U. S. weather index in the current period,

i = lagged year for R&E expenditures,

n = number of years for which R&E expenditures are lagged,

and a_i, b and c are coefficients.

To estimate equation (1), time series data from 1939 to 1972 were assembled. Production indexes are obtained from the 1964 and 1973 issues of Changes in Farm Production and Efficiency. Production-oriented R&E expenditures are from Cline (1975). Education indexes are constructed from a series reported by Evenson and weather indexes are constructed from Stallings and Kost. A detailed explanation of all data series can be found in Cline (1975).

The Almon distributed lag method and Durbin's two-stage procedure were used to estimate the parameters of equation (1). The results are as follows:

$$\hat{P}_t = R_t^{.0009}\, R_{t-1}^{.0017}\, R_{t-2}^{.0024}\, R_{t-3}^{.0029}\, R_{t-4}^{.0033}\, R_{t-5}^{.0036}\, R_{t-6}^{.0037}\, R_{t-7}^{.0037}$$

$$R_{t-8}^{.0036}\, R_{t-9}^{.0033}\, R_{t-10}^{.0029}\, R_{t-11}^{.0024}\, R_{t-12}^{.0017}\, R_{t-13}^{.0009}\, E_t^{.7851}\, e^{.0020\, W}$$

According to these estimates, a 1-percent increase in R&E will increase productivity gradually, reach its peak impact 6 to 7 years later by increasing agricultural productivity in each of those years by .0037 percent, and continue impacting productivity for the following six years when the annual impacts become negligible. We also estimate that a 1-percent change in the weather index will change agricultural productivity 0.2 percent in the same direction and a 1-percent increase in the education index will increase productivity 0.78 percent (Lu and Cline).

ALTERNATIVE FUTURES FOR AGRICULTURAL PRODUCTIVITY GROWTH

Public decisions made now and in the near future about research and extension programs will affect productivity growth for many years. Thus, we need to make assumptions concerning possible scenarios for such decisions so that we can simulate productivity growth and analyze results in terms of benefits, costs, and rates of return.

To project alternative paths for agriculture productivity growth under different sets of assumptions about the R&E rate, the educational level attained by farmers, and weather conditions, we consider three scenarios. Under the first scenario, R&E is maintained at a zero growth rate. Since this scenario assumes a low level of R&E to create new technology, it is called the low technology scenario.

Under the second scenario, we assume that real R&E growth during the 1939 to 1972 period continues into the future; i.e., real R&E grows 3 percent per year. Since this scenario uses the average historical R&E growth rate, we call it the baseline scenario.

The third scenario assumes a 7-percent R&E growth rate to accelerate research and development of new technologies and to increase extension activities for disseminating new technologies. With increased emphasis on R&E, it is likely that more new technologies will become available for adoption under this scenario. Thus, we call this the high technology scenario and assume that unprecedented technologies, if any, will be produced and adopted, and their potential impacts on productivity are evaluated and incorporated into the productivity projections under this scenario.

For all scenarios, farmers' educational attainment is assumed to increase along an S-shaped growth curve fitted to the education index data from 1939 to 1972 with the equivalent of four years college training being an upper limit.

Decision makers cannot exercise control over weather, thus it is included in the model as a stochastic variable. Based on the frequency distribution of the weather index from 1900 to 1972, a normal distribution was selected to approximate the probability distribution of weather. The parameters of the normal distribution were obtained from the estimated weather index as follows: mean = 100.7 and the standard deviation = 11.4. These parameters are in the simulation model and future weather indexes are generated for all scenarios.

The projected education index and the three alternative R&E growth rates were used to prime the simulation model to project future agricultural productivity. However, to keep random weather from masking the impact of R&E induced technological change on productivity growth, 200 weather indexes were generated from the normal distribution for each year to simulate normalized weather conditions. The mean, standard deviation, and range of the productivity index were computed but only the mean values of the productivity indexes are reported in this paper.

Columns 1 and 2 of table 1 show the mean values of the projected productivity indexes under the low technology and baseline scenarios, respectively. For comparison, actual average productivity index in the base years (1974-1976) is presented in row 1. The agricultural productivity index increases from 112 in the base period to 144 in 2000 under the low technology scenario where nominal R&E growth is just offset by inflation. Here the annual productivity growth rate is 1-percent. Under the baseline scenario, where real R&E grows 3 percent per year, productivity increases from 112 in the base period to 146 in 2000 at an annual growth rate of about 1.1 percent.

FUTURE TECHNOLOGIES

Since we assume that any new technologies will be produced under the high technology scenario, we had to assertain what new technologies are being studied by agricultural scientists and whether there will likely be technological breakthroughs by 2000. Then we evaluated the potential impacts of new technologies on productivity and incorporated the impacts into the simulation of productivity growth under the high technology scenario.

Several studies have been conducted to identify future agricultural technologies. Wittwer's study on maximum production capacity of food crops identifies ten technologies on the scientific frontier. Photosynthesis and nitrogen fixation are listed as on the leading edge of the frontier.

In a recent study by the Office of Technology Assessment, a panel of scientists representing agricultural and non-agricultural interests, private research organizations, and industries identified three areas of basic research possessing great opportunity for fundamental scientific discoveries. These three areas are photosynthesis, nitrogen fixation, and genetic engineering for plants.

Table 1.--Projections of U. S. Agricultural Productivity, 1985-2000 (1967=100)

Year	Projected Productivity Indexes			Expected Increases in Productivity Due to Impacts of			Maximum Productivity Projections
	Low Technology	Baseline	High Technology	Photosynthesis	Bioregulators	Twinning	
Base Years (1974-76)	112.0	112.0	112.0	0.0	0.0	0.0	112.0
1985	125.0	125.3	126.4	0.0	0.1	0.0	129.2
1990	131.0	132.1	134.8	0.0	0.6	0.0	139.6
1995	137.0	139.4	144.4	0.1	1.8	0.1	152.9
2000	143.6	145.9	156.0	0.4	3.7	1.4	167.3

The Economic Research Service also conducted a study in cooperation with Resources for the Future and the Ford Foundation in 1974 (Cline 1974). Researchers in the Agricultural Research Service, the Cooperative State Research Service, and the Cooperative Extension Service were interviewed using modified Delphi and relevance tree methods. Initially, 12 emerging technologies were identified as having significant potential for impacting agricultural productivity. However, most researchers felt that many of these emerging technologies would merely maintain the present productivity trend in the face of new environmental constraints. As a result, the impacts of these technologies are already captured in the base projections. Only four technologies were considered to have the potential for unprecedented impact on agricultural productivity: Photosynthesis, nitrogen fixation, bioregulators, and twinning of beef cattle. Since photosynthesis and nitrogen fixation are closely related, we combined them into a single technology--photosynthesis. These three technologies are included in our impact analysis.

To estimate and incroporate impacts of the emerging technologies in the productivity projections, we estimated the probability of each new technology coming on stream in each future year, the expected adoption profile, specific crops or livestock impacted by the technology, increase in productivity of the affected commodities, and the output of affected commodities as a percentage of total output. From this information we derived the potential impact of each emerging technology on productivity growth as well as the total expected increase in productivity due to the adoption of all three technologies in a specific year.

The expected increases in productivity due to photosynthesis, bioregulators and twinning, respectively, are presented in columns 4 to 6 of table 1.

Column 3 shows the projected productivity index under the high technology scenario where the impacts of the three technologies are incorporated into the productivity projection. Column 7 shows the productivity projections if all three technologies become available for adoption with certainty in the earliest year mentioned either in the literature or by the agricultural researchers interviewed. Thus column 7 provides the most optimistic productivity projections from our study.

For year 2000, the expected increases in productivity due to the impacts of photosynthesis, bioregulators, and twinning are 0.4, 3.6, and 1.4 index points, respectively. If the three emerging technologies become commercially available for adoption as anticipated, their impacts would cause the productivity growth curve to shift to a new S-shaped curve. But since most of these technologies would not be ready for commercial adoption until the 1990's and since it takes decades to complete the adoption processes, their impacts on agricultural productivity would be small by the year 2000. As shown in column 3, productivity would grow from 112 in the base years to 156 in 2000 at an average rate of 1.3 percent per year. This growth rate is less than the historical rate of 1.5 percent for the past 50 years. However, if we project this growth pattern to the year 2025 to allow more time for widespread adoption of the new technologies, productivity would be expected to grow an average of 1.5 percent per year. About the same growth rate can also be achieved before year 2000 under the most optimistic projection shown in column 7.

ECONOMIC BENEFITS OF R&E INVESTMENTS

Historically, we have had a feast-or-famine attitude about the world food situation and thus about our need or opportunities for increasing productivity in U. S. agriculture. With amazing regularity, some analysts have swung between the extreme views that agriculture has a chronic, built-in capacity for overproduction or that it has an equally durable characteristic for underproduction leading to food scarcity. Accepting the chronic overproduction view would lead one to conclude that R&E has a very low return in food and agriculture and that surely better uses could be found for limited public funds. Conversely, the scarcity position would indicate extremely high returns and call for massive doses of R&E because what more pressing need could there be for public funds than to insure the basic means of human survival. It is only in accepting the scenario of a food supply-demand manageable future that equating the rate of return on R&E with its opportunity costs takes on meaning. Thus, we applaud this current effort to measure the value of public research and extension programs in U. S. food and agriculture because it fits our conclusion that we have a very manageable food future in which the extremes of chronic overcapacity and scarcity can be avoided.

We caution our audience however, that the ex ante measurement of rates of return on R&E is the weakest part of our analysis. This is true partly because it is the most preliminary part of our work and partly because of the professional disagreement as to the appropriateness of consumer and producer surpluses as measures of social benefits. But nevertheless, we do think these preliminary results are worth reporting.

Based on agricultural productivity growth projected under alternative scenarios, the ESCS National-Interregional Agricultural Projections (NIRAP) system is used to project the resulting supply-demand interaction and resulting farm output and prices. These economic projections are then used to estimate social benefits, benefit/cost ratios and the rate of return on R&E where social benefits are defined as the sum of consumers' and producers' surplus.

Higher productivity resulting from greater R&E enables farmers to produce more food and fiber with the same quantity of resources or to supply more food and fiber at each price level. Thus, productivity growth shifts the supply function to the right. Comparing the baseline and the high technology scenarios, we estimate that in the one year 2000, farm output would increase 3.0 index points from 165 (1967=100) under the baseline to 168 under the high technology scenario.

With higher output and an inelastic demand for food and fiber, prices received by farmers decline, consumer's surplus increases and producer's surplus declines. In year 2000 for example, moving from the baseline to the high technology scenario causes consumer's surplus to increase $27.9 billion in 1974 constant dollars, but producer's surplus decreases $11.1 billion. Thus, social benefits, measured as the sum of consumer and producer surpluses, increase $16.8 billion.

However, to achieve higher productivity growth under the high technology scenario, the public increases R&E 7 percent per year compared to 3 percent under the baseline and this results in $3.1 billion greater program costs than under the baseline in year 2000. Thus, for the one year 2000, the total social direct economic benefits, net of program costs, of today selecting the high technology option over the baseline would be $13.7 billion ($16.8B-$3.1B).

To compute benefit/cost ratios, the stream of future annual social benefits and program costs from 1978 to 2000 are discounted at 6 percent per year. The discounted present value of the social benefits is estimated as

$41.4 billion and the discounted present value of the program cost is $12.4 billion. Dividing the discounted present value of the social benefits by the present value of program costs yields the benefit/cost ratio of 3.3.

We also estimated the internal rate of return to increased R&E. The internal rate of return as we move from no growth in R&E to the baseline real growth of 3% is estimated at 10 percent and in moving from the baseline to the high technology scenario and accompanying 7 percent per year increase in R&E is estimated at 15 percent. The internal rate of return for the high technology scenario of increasing R&E 7 percent per year compared to maintaining zero real growth in R&E is 25 percent. This suggests that if demand grows in the neighborhood of the baseline level of 2.7 percent per year, then increases in real public R&E expenditures could increase to 7 percent per year and still earn a very favorable return on investment. This is fairly consistent with a much more detailed recent analysis by Knutson and Tweeten.

SUMMARY AND CONCLUSIONS

This paper evaluates the impacts of public research and extension (R&E) expenditures on productivity growth in U. S. agriculture and provides ex ante estimates of the rate of return to R&E investment and benefit/cost ratios.

Our baseline projections indicate that productivity will continue to grow 1.1-percent per year over the next 22 years, which is considerably less than the 1.5 percent growth rate over the last half century. But with a higher 7 percent per year increase in real public R&E expenditures, and assuming that three unprecedented technologies--photosynthesis, bioregulators, and twinning of beef cattle--come on stream as predicted, the annual growth rate over the next 22 years would be 1.3 percent, which is still less than the historical growth rate.

But if we project our alternative futures beyond the year 2000 to allow more time for adoption, productivity could be expected to grow 1.5 percent per year for the next 50 years, which is the same rate we have experienced during the past 50 years. Or, alternatively, if we assume that the three unprecedented technologies become available for commercial adoption in the earliest dates indicated by scientists, productivity could grow more than 1.5 percent a year through the year 2000.

The internal rate of return to public agricultural R&E investments under the high technology scenario compared to no R&E growth is 25 percent and the and the internal rate of return of moving from the baseline to the high technology scenario is estimated at 15 percent. Benefit/cost ratio estimates for the above two examples are 3.4 and 3.3, respectively.

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