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MODELING PRODUCTIVITY GROWTH IN U.S. AGRICULTURE

Jackie B. Langston and Fred C. White*

UNIVERSITY OF CALIFORNIA
DAVIS
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Agricultural Economics Library

*Graduate Research Assistant and Professor, respectively, Department of Agricultural Economics, University of Georgia, Athens, GA.

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Abstract

MODELING PRODUCTIVITY GROWTH IN U.S. AGRICULTURE

This paper analyzes the impact of public and private research on U.S. agricultural productivity. An econometric model explaining changes in agricultural productivity is developed and estimated. A feedback rule is derived to choose research funding levels using optimal control techniques.

MODELING PRODUCTIVITY GROWTH IN U.S. AGRICULTURE

The levels and sources of funding for agricultural research have changed markedly over the past half century. At times additional funds were provided for newly identified high-priority needs, often increasing the aggregate level of funding. In times of austerity the level of funding has been reduced. What impacts have these fluctuations had on the effectiveness of the agricultural research system? Understanding the answer to this question is important for the efficient management and control of the agricultural research system.

The overall objective of this paper is to analyze the impact of agricultural research funding on agricultural productivity. Specific objectives are (a) to distinguish between anticipated and unanticipated fluctuations in the level of research funding; (b) to econometrically measure the separate effects of anticipated and unanticipated fluctuations in research funding on agricultural productivity; and (c) to use these econometric results in an optimal control framework to achieve selected levels of growth in agricultural productivity.

Rational Expectations Model

Agricultural research is a process that requires time to develop the research objectives and procedures and implement the procedures before the final results are achieved. The academic community recognizes that it takes time to conduct research, as evidenced by the fact that new faculty members are generally evaluated for promotion and tenure after a period of five to seven years. In contrast, industrial workers are often hired on a probationary basis for a period of only a few months, because their productivity can be measured on a continuous basis unlike researchers. The period of time required for any researcher to conduct a research project can in general be only moderately impacted by adjusting research funding. Administrators have limited ability to speed up the research process, which raises questions about the effectiveness of incremental changes in research funding. A hypothesis to be tested in this study is that the effectiveness of anticipated levels of research funding is different from the effectiveness of unanticipated changes in research funding.

The first step to test this hypothesis would be to develop a model to explain the anticipated or expected level of public funding. A rational expectations formulation is assumed to apply in this case. Under this formulation subjective expectations are implied by the underlying economic model generating values of economic variables (Muth). Subjective expectations are based on available information at the time the expectation is made. The empirical model that is assumed to generate public research funding R_t at time t is given by:

$$(1)\ R_t = a_0 + \sum_{i=1}^{m} a_i R_{t-i} + a_2 O_{t-1} + U_t$$

where U_t is a normally distributed random error term with a zero mean and variance $_U$. Government outlays as a percentage of GNP are represented by the variable O_{t-1}. The anticipated or expected component of research funding ER_t assumes U_t is zero: $ER_t = a_0 + \sum_{i=1}^{m} a_i R_{t-i} + a_2 O_{t-1}$. The unanticipated change in research funding is given by $U_t = R_t - ER_t$.

The second step is to develop a model relating agricultural productivity, P_t, to public research funding, in particular both anticipated levels of funding and unanticipated changes in the level of public funding. Productivity in year t is also assumed to be related to private research and development (Q) and lagged productivity. The equation explaining productivity changes is complicated by the fact that both public and private research funding in any particular year will influence agricultural productivity for a number of years in the future. Hence, agricultural productivity in any particular year is a function of research funding in previous years. The equation explaining agricultural productivity P_t is given by

$$(2)\ P_t = b_0 + b_1 \sum_{j=0}^{n} c_j ER_{t-j} + b_2 \sum_{j=0}^{n} d_j (R_{t-j} - ER_{t-j})$$

$$+ b_3 \sum_{j=0}^{q} e_j Q_{t-j} + b_4 P_{t-1} + V_t$$

where b_j, c_j, d_j and e_j are parameters to be estimated or specified from prior information, and V_t is a normally distributed random error term with a zero mean and variance σ_V^2. The disturbance terms U_t and V_t are assumed to be uncorrelated.

Substituting equation (1) into equation (2) yields

$$(3)\ P_t = b_0 + b_1 \sum_{j=0}^{n} c_j [a_0 + \sum_{i=1}^{m} a_i R_{t-i} + a_2 O_{t-1}]$$

$$+ b_2 \sum_{j=0}^{n} d_j [R_{t-j} - (a_0 + \sum_{i=1}^{m} a_i R_{t-i} + a_2 O_{t-1})]$$

$$+ b_3 \sum_{j=0}^{q} e_j Q_{t-j} + b_4 P_{t-1} + V_t$$

Equations (1) and (3) constitute the basic model for this study. These equations can be jointly estimated with cross-equation restrictions so that the a_0 and a_i parameter estimates in both equations are equal.

Estimation Procedure and Data

The structural model, equations (1) and (3), is a simultaneous system of nonlinear equations. The parameters in this model were estimated using the nonlinear iterated seemingly unrelated regressions procedure in SAS. In this procedure the covariance of residuals across models is recalculated and reused in the seemingly unrelated regressions procedure until the estimates converge. This procedure has an invariance property yielding the same parameter estimates for equivalent formulations of the model, which is desirable in shared parameter systems such as the one estimated in this study.

The period of analysis for econometric estimation was 1949-1984. However, data on public research expenditures covered the 1930-1984 period to account for the lag structure on these expenditures. Public research expenditures included only production oriented expenditures, excluding such nonproduction-oriented activities as marketing research and human nutrition research. Data sources for these expenditures include Budget of the United States Government; Combined Statement of Receipts, Expenditures and Balances of the United States Government (U.S. Department of Treasury), and Funds for Research at State Agriculture Experiment Stations and Other State Institutions (U.S. Department of Agriculture, Cooperative State Research Service). A detailed description of these data sources is given in Cline. Data for production-oriented research expenditures since 1972 were obtained from the annual issues of Inventory of Agricultural Research (U.S. Department of Agriculture, Cooperative State Research Service) by summing the expenditures for production-oriented Research Program Areas (RPA's). Government outlays and GNP for the years 1929-1984 were taken from various issues of Statistical Abstract of the United States. Research expenditures and government outlays are deflated by the implicit deflator for government purchases of goods and services with 1977 as the base (U.S. Department of Commerce, Survey of Current Business).

Private research expenditures are not observed directly, so a proxy variable was used. The value of manufactured farm inputs and farm gross capital expenditures as obtained from Economic Indicators of the Farm Sector (U.S. Department of Agriculture, Economic Research Service, 1986), were summed and used as the private research proxy variable. This formulation assumes that a fraction, f, of sales by these farm input suppliers is spent on research. This type of behavior has been empirically observed by Mansfield (1986). Furthermore Seldon (1985, pp. 42-47) has indicated that such an approach would be optimal behavior for a competitive industry in a dynamic setting under conditions of steady growth.

The model to be estimated includes lag structures on private research expenditures, anticipated fluctuations in public research expenditures and unanticipated fluctuations in public research expenditures. Although these lag structures may be different, there is not adequate previous research or theory to show these differences. It also appears to be heroic on our part to attempt to identify these differences from this data base. Therefore, these lag structures are assumed to be similar. Following the work of Lu, Cline, and Quance; White and Havlicek; and others it was assumed that the agricultural research activities impact on agricultural technology according to an inverted U-shaped distributed lag for 14 years. Hence, the c_j, d_j and e_j parameters in equation (3) were assumed to follow a second degree polynomial with both end points restricted at zero. The c_j, d_j, and

e_j parameters were specified in the models using prior information and not estimated. It was further assumed $c_j = d_j = e_j \; \forall \; j = 1, \ldots, n$. The length of the lag research expenditures in calculating expected expenditures was assumed to be 5 years on a conceptual basis as discussed earlier. Multicollinearity problems were encountered in the five lags on research expenditures so a 5-year moving average was used to explain the anticipated level of research expenditures. These structural considerations leave only eight unknown parameters to be estimated: a_0, a_1, a_2, b_0, b_1, b_2, b_3, and b_4.

Econometric Results

The parameter estimates of the two-equation model explaining agricultural productivity, equations (1) and (3), are reported in Table 1. The overall fit of the model was good: the R^2 for the research equation was 0.97 and the R^2 for the productivity equation was 0.95. Seven out of eight variables were statistically significant at the 10 percent level or better.

The b_1, b_2, and b_3 coefficients in equation (3) could be interpreted as short-term impacts. To derive the long-term impacts, these coefficients have to be adjusted to take into account the effect of the lagged dependent variable: long-term impact equals $b_i/(1 - b_4)$. Considering that the coefficient on the lagged dependent variable is negative, the long-term impacts are smaller than the short-term impacts. The long-term impacts are approximately one-quarter lower than short-term impacts, indicating the importance of maintenance research in stabilizing agricultural productivity.

The short-term impact of anticipated public research funding is a 0.0634 percentage point increase in the productivity index for each $1

Table 1. Parameter Estimates for the Agricultural Productivity Model

Parameter	Estimate	T Statistic
a_0	28.192**	3.90
a_1	0.916**	32.04
a_2	-0.735**	-2.55
b_0	56.952**	6.50
b_1	0.634**	5.80
b_2	0.201	0.64
b_3	0.092**	2.97
b_4	-0.305*	-1.70

**Statistically significant at $\leq$ 5% level.

*Statistically significant at 10% level.

R^2 for equation (1) is 0.97.

R^2 for equation (3) is 0.95.

million expenditure. The long-term impact is a 0.049 percentage point increase in the productivity index. The impact of unanticipated research funds is much lower and in fact may not be significantly different from zero. Unanticipated research funds increased the productivity index by .020 and .015 percentage points for the short run and long run, respectively. This model suggests that a steady, known supply of research funds will be more than three times as effective in the short run in raising the productivity index. The cumulative effects of a research policy that is stable would be much larger.

Optimal Control

Using the econometric model as the equations of motion, research levels may now be chosen optimally. In Lucas' critique (1976) he said rational expectations must be considered in any evaluation of policy because the environment will change in response to the actions of the policy maker. Following the method suggested by Taylor (1979), this model takes into account the reaction to policy by substituting in the mathematical model for the expectations variables in equation 3.

Optimal Control Model

Specifically, the goal was to achieve a growth rate in the productivity index equal to the historical rate of 1.8% annually while minimizing public expenditures. A quadratic cost function that penalizes deviations from the productivity target and minimizes cost may be represented by

(6) $J = (y_t - a_t)' \, W \, (y_t - a_t)$

where y_t is the p x 1 vector of endogenous variables, a_t is the p x 1 vector of targets, and W is the p x p matrix of weights assigned by the policy maker. The first two elements of y (productivity and research) are the variables of interest in this study. The vector of targets has one non-zero element in the first position, all_t, which is the target for productivity. The weights assigned to W are 100 in position 1,1 and 1 in position 2,2. All other elements in W are zero. In a scalar format the cost function to be minimized is

$$(7)\ J = (P_t - P_t)'100(P_t - P_t) + R^2$$

The weights of 100 and 1 were chosen to give each variable the same magnitude of impact on the cost function. Other weights could be chosen to reflect the preferences of the policy maker.

The econometric model (eqn. 3) is the system to be controlled and may be compactly written in state space form as

$$(8)\ y_{t+1} = Ay_t + Cx_t + b$$

where y_t is the p x 1 vector of all the endogenous and exogenous state variables, x_t is the m x 1 vector of control variables, and b is the n x 1 vector of known constants. A and C are time invariant conformable matrices of reduced form coefficients.

In the optimal control problem equation (6) is minimized subject to the system equations (8). The solution is a closed loop feedback rule of the form

$$(9)\ X_t = Gy_{t-1} + g$$

Following the method proposed by Chow (1983) the steady state G and g were found by a dynamic programming method where

$$(10)\ G_t = -(C'H_tC)^{-1}C'H_tA$$

$$(11)\ H_t = W + (A + CG_{t+1})'H_{t+1}(A + CG_{t+1})$$

$$(12)\ g_t = -(C'H_tC)^{-1}C'(H_tb - h_t)$$

(13) $h_t = Wa_t + (A + CG_{t+1})'(h_{t+1} - H_{t+1}b)$

where H_N is W, h_N is a_N. G is calculated by evaluating equation 10 and 11 backward from the terminal time to the beginning time period t_0. Equations 12 and 13 are evaluated to find g. The iterations will converge after several of these matrix multiplications to give a steady state G and g to use in equation 9.

Results Using Optimal Control

The results of the optimal control method are given in Table 2. The negative coefficient on lagged research suggests that research funds in time t decrease when there has been high levels of funding in the past. Since there is a cumulative long term impact of research on productivity, high levels of past research will continue to increase the productivity index in future periods. The positive coefficient on productivity implies that research increases are needed to maintain high levels of productivity and so funding must increase. A variable that might give more intuitive information on research levels would have been $P_t - P_{t-1}$. An expected negative coefficient would imply a increase in research funds with negative deviations and a decrease in funds with a positive deviation. The coefficient on lagged outlays as a percent of GNP are all negative and imply that if the tax burden is already great, then research funding will decrease. The most interesting result is the negative coefficient on sales. This suggests that as sales increase, research funding will decrease. If private research is some percentage of sales, then these results at least hint at an inverse relationship between public and private research funds. This situation suggests a dynamic game of the

Table 2. Reaction Function for Optimal Feedback Rule, $R = G'Y_{t-1} + g$

G Vector	Y_{t-1}
0.456	P_t
-0.325	R_{t-1}
-0.361	R_{t-2}
-0.379	R_{t-3}
-0.378	R_{t-4}
-0.362	R_{t-5}
-0.329	R_{t-6}
-0.276	R_{t-7}
-0.219	R_{t-8}
-0.166	R_{t-9}
-0.125	R_{t-10}
-0.101	R_{t-11}
-0.092	R_{t-12}
-0.107	R_{t-13}
-0.136	R_{t-14}
-0.172	R_{t-15}
-0.211	R_{t-16}
-0.240	O_t
-0.281	O_{t-1}
-0.307	O_{t-2}
-0.306	O_{t-3}
-0.287	O_{t-4}
-0.255	O_{t-5}
-0.213	O_{t-6}
-0.169	O_{t-7}
-0.127	O_{t-8}
-0.091	O_{t-9}
-0.062	O_{t-10}
-0.038	O_{t-11}
-0.021	O_{t-12}
-0.0001	O_{t-13}
-0.675	$Sales_t$

g = 1123.43

Stackleberg type with the government as the dominant player. The government has the power to set the level of public research funds and the private sector must react to this announced policy. In a dynamic game situation, the reactions of the different players which are suggested implicitly in the rational expectations model would be made explicit.

Summary and Conclusions

This paper analyzes the impact of public and private research on U.S. productivity. Using an econometric model that assumes agents have rational expectations, an optimal policy reaction function was derived using a dynamic programming technique. The results of the econometric estimation suggest that unexpected research funds are much less effective than expected funds in increasing the level of productivity. This information is relevant to policy makers who sometimes allocate funds sporadically. Researchers operating on short term grants may find it difficult to plan effective research, may be unable to complete research, or may spend a large portion of their time searching for funds. The optimal control rule was derived and may be used to suggest levels of research funding for a given target of agricultural productivity.