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A test of the underinvestment, myopia and commodity bias hypotheses for U.S. agricultural research

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ABSTRACT

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Analysts of agricultural research policy in the United States of America have claimed that the overall level of public investment in agricultural research is less than what would be socially optimal, that the present composition of public research investment is excessively myopic in that too little basic research is performed relative to the level of applied research, and that the allocation of research resources among commodities is inconsistent with economic efficiency.

A non-linear optimal growth model of the U.S. economy was developed to analyse these propositions. Strong support was found for the claim that the overall level of investment has been inadequate. No support was found for the contention that basic research has been relatively underfunded compared to applied research. Weak support was found for the view that crop research has suffered from more acute underfunding than has livestock research.

INTRODUCTION

A broad consensus has emerged that public expenditures on agricultural research have generated social benefits in excess of social costs (Ruttan, 1982). High rates of return to these investments have been interpreted as indicative of underinvestment. Little effort, however, has been devoted to the determination of the extent to which underfunding has occurred. Griliches (1964, p. 969) estimated that a fourfold increase in research expenditure would yield positive net social benefits for the U.S. economy. Knutson and Tweeten (1979) estimate that annual research investment should double by the year 2000. Johnson and Wittwer (1984) suggest that research funding should be

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increased in real terms by 10% annually until total expenditure is tripled. These estimates, while useful as preliminary indications of the magnitude of under-investment, suffer from some important limitations. None of these studies incorporate the full opportunity cost of public funds. Fox (1985) has demonstrated that the marginal excess burden reduces the net social benefits arising from agricultural research. Also, the static partial equilibrium structure of these models fails to capture important inter-temporal and inter-sectoral linkages that transmit the impact of changing technology through the economy.

Furthermore, Ruttan (1983) and Judd, Boyce and Evenson (1983) have suggested that the allocation of research effort may have been subject to a commodity bias. If this hypothesis is true, then reallocation of research funds among commodities would increase the net social benefits of the total research program even if the overall level of research funding were unchanged. True (1937), Knoblach et al. (1962) and more recently Bonnen (1983) have also argued that political expediency has prompted research administrators to emphasize applied research with prospects of more immediate payoffs at the expense of more basic scientific research with longer term payoffs. Economic analysis of both of these claims has been limited (see Fox, Evenson and Ruttan, 1987).

In order to test this last proposition it is necessary to define categories of research. The terms 'basic' and 'applied' are used quite loosely in the agricultural research policy literature.[1] In the present context 'basic' research will be used as shorthand for general biological research that is not specifically associated with any particular commodity, and which would be expected to have a long payoff horizon. 'Applied' research will refer to commodity specific research expenditures with more rapid payoffs. Similar definitions of applied and basic agricultural research have been used by Evenson (1978, p. 72).

[1]The National Science Foundation uses the following definitions of basic research, applied research and development for research activities of corporations:
Basic research. Basic research has as its objective "a fuller knowledge or understanding of the subject under study, rather than a practical application thereof." To take into account industrial goals, NSF modifies this definition for the industrial sector to indicate that basic research advances scientific knowledge "not having specific commercial objectives, although such investigation may be in fields of present or potential interest to the reporting company."
Applied research. Applied research is directed toward gaining "knowledge or understanding necessary for determining the means by which a recognized and specific need may be met." In industry, applied research includes investigations directed "to the discovery of new scientific knowledge having specific commercial objectives with respect to products of processes."
Development. Development is the "systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes."

These definitions afford little assistance in efforts to identify categories of publicly funded agricultural research in the United States. In one sense, nearly all public research could be seen as basic because of the limited commercial objectives. On the other hand, most of the work done by USDA and SAES scientists are concerned with projects designed to meet specific needs.

This paper examines the extent to which agricultural research has been underfunded in the United States and investigates the hypotheses of commodity bias and the neglect of basic research. A general equilibrium optimal growth model is used as the framework for analysis. Research costs include the marginal excess burden of tax-financed public expenditures. The scope of the analysis is limited to expenditure on farm production-oriented research on field crops and livestock for the United States.[2] This excludes research on problems of processing, product utilization and other categories of post-harvest research. It is hoped that the present investigation, while limited in commodity coverage, can provide preliminary insights into the problem of agricultural research resource allocation at a broader level. It should be noted, however, that the covered commodities generated over 80% of the gross sales of U.S. agriculture in 1982.

DESCRIPTION AND ESTIMATION OF MODEL

Output of the two agricultural sectors is expressed as the farm value of final consumption. The third sector is the rest of the economy. This composite sector includes the non-farm sectors of manufacturing and services, encompasses the activities which account for the marketing margin between farm value and retail value of food commodities from the crop and livestock sector and includes the farm value of output of commodities such as fruits, vegetables, tobacco and cotton which are excluded from the two farm sectors identified above. A summary of the model is presented in Table 1.

Criterion function

Public and private resources are allocated among alternative employment opportunities to maximize a benefit function defined over the infinite streams of consumption of the products of the three sectors (Table 1, equation 1). Future consumption benefits are discounted at the social rate of time preference.[3] In any particular period, the benefit function is assumed to be linear in the logarithms of the sectoral consumption levels. Weights, denoted by γ_i, attached to the logarithms of consumption, reflect the share of disposable income devoted to the consumption of the output of the respective sector. Subscripts 0, 1 and 2 denote the non-agricultural sector, the livestock sector and

[2]Field crops are defined to include wheat, rice, grain corn, grain sorghum and soybeans. These crops generated 63% of all crop revenues in the U.S.A. in 1982. Livestock is defined to include beef, hogs, sheep and lambs, milk, poultry meat and eggs, as well as the production of forage crops for ruminants.

[3]Kula (1984) has estimated the social rate of time preference for the U.S. economy to be 0.053. This gives a value of 0.9497 for β (see Table 1).

TABLE 1

Summary of the growth model

Maximize

$$\sum_{t=0}^{\infty} \beta^{t} \left[\sum_{i=0}^{2} \gamma_i \ln C_{it} \right] \quad (1)$$

subject to

$$F_{0t}(\cdot) - C_{0t} - \sum_{i=0}^{2} I_{it} - \tau \sum_{i=1}^{2} (\mathrm{EA}_{it} + \mathrm{EB}_{it}) - R_{2t} + M(X_{2t}) \geqslant 0 \quad (2)$$

$$F_{1t}(\cdot) - C_{1t} \geqslant 0 \quad (3)$$

$$F_{2t}(\cdot) - C_{2t} - X_{2t} - F_{1t} \geqslant 0 \quad (4)$$

$$K_{it} = \delta K_{it} + I_{it} \qquad i = 0, 1, 2 \quad (5)$$

$$\mathrm{AR}_{it} = \epsilon_{\mathrm{A}i} \mathrm{AR}_{it-1} + \mathrm{EA}_{it} \qquad i = 1, 2 \quad (6)$$

$$\mathrm{BR}_{it} = \epsilon_{\mathrm{B}i} \mathrm{BR}_{it-1} + \mathrm{EB}_{it} \qquad i = 1, 2 \quad (7)$$

$$L_{0t} + L_{1t} + L_{2t} \leqslant \bar{L}_t \quad (8)$$

$$N_{1t} + N_{2t} \leqslant \bar{N}_t \quad (9)$$

for

$t = 0, 1, 2, \ldots \rightarrow \infty$

$i = 0$, non-farm sector
$i = 1$, livestock sector
$i = 2$, crop sector

C_{it}	Consumption of output of sector i in period t
β	1.0 plus the social discount rate
γ_i	Share of consumption expenditures for sector i
$F_{it}(\cdot)$	Production function of sector i in period t
I_{it}	Gross investment in capital stock of sector i in period t
τ	Social opportunity cost of public spending inclusive of the marginal excess burden of taxes
EA_{it}, EB_{it}	Current expenditures on applied and basic research respectively for sector i in period t
R_{2t}	Level of current input use in the crop sector in period t
$M(X_{2t})$	Imports purchased with crop exports in period t
K_{it}	Stock of conventional capital in sector i in period t
δ	Depreciation rate for conventional capital
AR_{it}, BR_{it}	Stock of applied and basic research, respectively, for sector i in period t
$\epsilon_{\mathrm{A}i}$, $\epsilon_{\mathrm{B}i}$	Rates of depreciation of applied and basic research stocks for sector i
L_{it}	Employment in sector i in period t
N_{it}	Land used by sector i in period t
F_{1t}	Livestock feed in period t

the crop sector, respectively. Estimation of the parameters γ_0, γ_1 and γ_2 is based on consumption expenditure shares data.[4].

Constraints

Consumption of each sectoral output in each time period is constrained by the production technology of the sector, by investment decisions, by current input demands from other sectors and opportunities for foreign trade. Production functions are assumed to be of the Cobb–Douglas form. Constant returns to scale are imposed in all sectors by computing the output elasticity of labor as a residual.[5].

The production function for the non-farm sector (F_{0t}) uses capital and labour. An exogenous rate of technological change of 2% per year is assumed to generate a neutral shift in this production function over time. This shift parameter is intended to capture the effects of investments in human capital as well as private investments in research and development. The impact of these investments is transmitted indirectly to the agricultural sectors of the model. The shift parameter increases the productivity of capital and labour employed in non-farm economy. This reduces the real resource cost, in terms of foregone consumption, of purchased inputs used in the crop sector (see Table 1, equation 2). This in turn reduces the real resource cost of feed used in the livestock sector (equation 3).[6].

Output of the non-farm sector can be consumed directly as C_{0t}, it can be invested in new capital in any or all of the three sectors. I_{0t}, I_{1t}, I_{2t}, it can be used as a current input in crop production. R_{2t}, or it can be invested in agricultural research. EA_{1t} denotes investment in commodity specific (applied) research in the livestock sector in period t. EB_{1t} represents investment in more general biological (basic) research pertaining to livestock in that period. EA_{2t} and EB_{2t} are the corresponding variables for the crop sector. The coefficient τ indicates that the marginal social opportunity cost of public funds exceeds one, since public expenditure is financed through taxation, which creates deadweight losses in factor and product markets. Ballard et al. (1985) have produced estimates of τ in the range of 1.2–1.5 for the United States. The model incorporates an opportunity to export some of the output of the crop sector, X_{2t}, to purchase goods which are perfect substitutes for Y_{0t} according to the relationship $M(X_{2t})$, an implicit export demand function (equation 2).

[4]The share of net national income devoted to the farm value of livestock and grain products fell systematically from 1963 to 1982. This pattern of declining expenditure is retained in the model solutions. Details of these calculations are reported in Fox and Haque (1987).

[5]Discussion of the empirical validity of this assumption is deferred until later in the paper.

[6]A less aggregative approach to modeling the multiple sources of technological change that effect the crop and livestock sectors would clearly be desirable, but the present state of empirical documentation of the transition mechanisms is inadequate to justify detailed modelling.

The production function for the livestock sector uses stocks of research, capital, as well as labor, feed-grain, and land in forage production, to produce output. The major purchased input in livestock production is feed. Intermediate products purchased from the manufacturing sector enter the livestock production functions indirectly through feed purchases. Output of the sector is measured in million metric tons of beef equivalent. Aggregation to beef equivalent is based on relative prices for 1982.[7]. It is assumed that the output of the livestock sector can only be consumed (equation 3) since livestock product exports from the United States are small relative to crop exports.[8]

Output of the crop sector is measured as million metric tons of wheat equivalent determined in a manner similar to the aggregation procedures in the livestock sector. The production function for the crop sector uses the accumulated stocks of applied and basic research, as well as capital, current purchased inputs such as pesticides, fuel and fertilizer, and land, and labor. Output for this sector can either be consumed, exported or fed to livestock (equation 4).

It is assumed that durable inputs wear out at a constant geometric rate. Capital wears out at rate δ and research investments wear out at rate ϵ. Capital depreciation is assumed to be 10% per annum in each sector. Each of the four research categories has a separate rate of depreciation (equations 6 and 7). Several authors (see Cline, 1975, for example) have chosen to represent the effect of research investment on output as a finite polynomial lag. A quadratic lag with zero end points has been the most popular version. This study treats research investments in a manner analogous to the usual treatment of capital. This implies that research influences output according to a geometric pattern. Both representations have limitations. The initial shakedown period of the quadratic model captures delays in implementation of new technology which is an attractive feature. The geometric model has no shakedown period. After K years, however, the quadratic model shows no effect of research on production, and yet the knowledge gained K years earlier has not disappeared. For later years, the geometric lag seems more plausible. Early empirical work by Evenson (1968, pp. 42–43) is consistent with this lag structure, and more recently Norton and Swallow (1985) and Swallow et al. (1985) have challenged the conventional quadratic lag structure. Another advantage of the geometric lag structure which is important in the present context is the ease with which it can be incorporated in a dynamic non-linear programming model.

Finally, in each time period, it is assumed that the total employment of the

[7]For example, a metric ton of dressed pork was worth about US$2.109 in 1982. A metric ton of dressed beef was worth US$2.935. A ton of pork, therefore, contributes 0.72 t of 'beef equivalent' to the output of the livestock sector.

[8]The largest category of livestock products exported in 1980–1984 was hides and skins, ranging from US$1.0 to 1.4 billion annually (USDA *Agricultural Statistics*). billion (US) = 10^9.

three sectors cannot exceed some upper limit, $\overline{L_t}$, and that total land in crops and forages cannot exceed $\overline{N_t}$ (equations 8 and 9).

Estimation of output elasticities

Estimates of a total of ten output elasticities for conventional, that is, nonresearch factors of production are required to implement the model. However, the convention of deriving the output elasticity of labor as a residual means that only seven of the estimates are independent.[9]

Inadequate time series data on input use by sector prompted the use of a factor shares approach to the estimation of output elasticities (see Tyner and Tweeten, 1965, 1966). Griliches (1964, p. 970) found that observed factor shares in U.S. agriculture between 1949 and 1959 were statistically indistinguishable from those deduced from his estimated production function. More recently, Shumway et al. (1979) have provided additional support for the factor shares approach.

Efforts to estimate aggregate production functions for U.S. agriculture are long on history but short on consensus – see Griliches (1964), Peterson (1967), Bredahl and Peterson (1976), Lyu et al. (1984) and Chambers and Lee (1986). Some generalizations relevant to the present study can be drawn from this literature. First, although early estimation efforts found evidence of substantial increasing returns to scale (for example, see Griliches, 1964, p. 966), more recent work has modified this finding. Lyu et al. (1984) and Chambers and Lee have concluded that slight decreasing returns to scale may in fact be the case. Also, Kislev and Peterson (1982) have suggested that the adjustments of farm firms to changing relative factor prices may have been mistakenly interpreted as evidence of increasing returns to scale in early studies. These results are taken as the empirical rationale for the maintained hypothesis of constant returns to scale in the production functions for the crop and livestock sectors. Second, econometric work has explored alternative functional forms without conclusively rejecting the Cobb–Douglas production function. Griliches (1964, pp. 962–964) was unable to reject the hypothesis of an elasticity of substitution of 1.0. Peterson (1967), Bredahl and Peterson (1976) and Shumway et al. (1979) have employed the Cobb–Douglas functional form with success. Third, while there seems to be some agreement on the economies of scale question, and on the matter of the choice of functional form, very little consensus has been achieved on the value of particular output elasticities. Variations in the definitions of categories of inputs make it difficult to compare elasticities across studies.

[9]Documentation of data sources and procedures used to estimate model parameters is summarized in Fox and Haque (1987).

Estimation of output elasticities and obsolesence rates for agricultural research

Output elasticities for the research inputs were estimated using the approach introduced by Cline (1975). Arguments in the production function are separated into conventional inputs such as land, labor and fertilizer and non-conventional inputs such as research, extension, weather and farmer's education level. For present purposes, let the conventional inputs be denoted by a vector, X, and the non-conventional inputs be denoted by a vector Z. The production function can be thought of as:

$$Y_t = g(Z_t)\ h(X_t)$$

In the absence of time series data on sectoral inputs, Cline used the USDA index of multi-factor productivity as a proxy for $Y_t/h(X_t)$. Time series data on Z_t and productivity index were used to estimate $g(Z_t)$.

In the present study, $g(\cdot)$ includes extension expenditures, the level of farmer's education, an index of weather conditions, and the undepreciated stocks of past investments in applied and basic research as arguments. Since all of the right-hand side variables can be viewed as predetermined to entrepreneurs in the farm sector, ordinary least squares is an appropriate estimation procedure.

The present study is less aggregated than Cline's model, and a measure of multifactor productivity for the livestock and crop sectors is needed. The USDA does not publish such an index, but several disaggregated measures of labor productivity are published. Also, a sectoral index of labor productivity for agriculture is available. The sectoral index of multi-factor productivity is quite closely correlated with the sectoral index of labor productivity.[10] A least squares regression of multi-factor productivity on labor productivity from 1944 to 1982 was used to predict multi-factor productivity indexes for crops and livestock using the appropriate series of labor productivities published by the USDA.

Four time series of research stocks were constructed, two for the crop sector and two for the livestock sector. Each sector has a stock of undepreciated applied and basic research investment. Expenditure data were obtained from two sources. For the period 1968–1983, the Current Research Information System (CRIS) maintained by the National Agricultural Library was used. This system classifies all publicly supported agricultural research expendi-

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[10] It should be acknowledged that these series can trend upward for different reasons. Multifactor productivity measures increase in response to changes in unmeasured inputs and in response to changes in the quality of measured inputs. Single-factor productivity measures can increase in response to these variables or they can increase in response to factor substitution in the face of changes in relative prices. The assumption maintained in this study is that the correlation between labor productivity and multifactor productivity observed in aggregate is not coincidental and that most of the historical change in labor productivity in U.S. agriculture has been the result of changes in the levels of non-conventional factors and of changes in input quality.

tures in the United States by commodity or resource, by research problem area, and by scientific discipline. Research expenditures prior to 1968 were calculated from data reported in the annual House appropriations hearings for the Department of Agriculture. Estimates of the expenditure categories were computed for 1944–1969, the two final years of the series being used to match the appropriations totals with the CRIS data. The data series of nominal and real expenditures for the four research categories are reported in Fox and Haque (1987). The total expenditure on the four research categories was US$704 million in 1983, out of a total public budget for agricultural research of US$1.7 billion for that year.

In order to implement the Cline model, time series data on other non-conventional inputs are needed. Nominal extension expenditures were taken from Peterson and Fitzharris (1977) for 1944–1973. Observations from 1974 to 1983 were extrapolated from the trend in the earlier period. Cline's education index was employed for the period 1944–1972. This series was updated with census data. The weather index was constructed by measuring the deviation from trend yields for the crops in the model. Nominal expenditure data for research and extension were converted to real 1982 dollars using the price deflator for state and local government purchases of goods and services (U.S. Gov. Printing Office, 1984).

AR_{it} and BR_{it} are stocks of undepreciated research expenditure. It follows that the output elasticity of each type of research for each sector must be estimated simultaneously with ϵ_{ji}, the rate at which research obsolesces. Evidence on the rate of research obsolescence relevant to this context is limited. A grid search procedure was used to identify appropriate values (see Fox and Haque, 1987). The search for values for the ϵ's was guided by the goodness of fit of the equations, as well as the sign and significance of the coefficients. Final results for the livestock and crop equations are reported in Table 2. Weather and extension expenditures did not contribute significantly to the explanation of variation of productivity in the livestock equation and these variable were deleted. Both equations were plagued by autocorrelation in the residuals when fitted with OLS. The final equations were estimated with the maximum likelihood procedure of Beach and MacKinnnon (1978) to correct for first-order serial correlation. Problems of intercorrelation between the research variables in each equation contributed to their low levels of significance.

Estimates of the output elasticities of the research variables are individually of the same order of magnitude as those reported by Cline (1975) and Davis (1979). In the present model, however, two research variables appear in each estimating equation, and both Cline and Davis have a single research variable. Separation of basic and applied research has led to significantly higher combined elasticity estimates than have been found when research ex-

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billion (US) = 10^9.

TABLE 2

Coefficients in the livestock and crop sector productivity equations

Variable	Coefficient	Standard error	't' statistic
Livestock			
Constant	3.21	0.368	8.73
Logarithm of applied research	0.0870	0.0730	1.19
Logarithm of basic research	0.0600	0.0910	0.660
Education index	0.00241	0.000764	3.16
$\epsilon_A = 0.620$			
$\epsilon_B = 0.925$			
$\bar{R}_2 = 0.970$			
Crops			
Constant	2.36	0.253	9.32
Logarithm of applied research	0.0560	0.0453	1.23
Logarithm of basic research	0.0750	0.0623	1.20
Weather index	0.284	0.0258	11.0
Logarithm of real extension	0.113	0.0715	1.58
Education index	0.00225	0.000417	5.39
$\epsilon_A = 0.68$			
$\epsilon_B = 0.91$			
$\bar{R}^2 = 0.998$			

penditures have been aggregated into a single variable or when research and extension expenditures have been combined. Basic and applied research were found to depreciate at quite different rates in both farm sectors. In contrast to Cline's 13-year quadratic lag, basic research in livestock has more than 28% of its effect left after 13 years. Applied research in the livestock sector had less than 1% of its effect left after 13 years, so that different research categories translate into distinctly different effects on productivity.[11]

Trade function

The trade function reflects a decline in the purchasing power of exports at the margin as exports increase. The U.S.A. is modeled as having the effect of a 'large country' in the market for crop exports, but it is not allowed to exploit its resulting monopoly power. Tweeten (1967, 1977) and Johnson (1977)

[11]Evenson (1978) obtained a similar result.

have estimated the elasticity of this excess demand schedule to be about -6.0. Bredahl et al. (1979) have recently challenged this view arguing that many potential buyers of U.S. crop exports insulate their domestic markets from the effects of changes in world grain prices. As a result, a less elastic excess demand would be more plausible. The reference solution in this study assumed an elasticity of -1.5, and the effect of lower elasticity values was explored in sensitivity analysis.

COMPUTING THE OPTIMAL RESEARCH BUDGET

The first step in solving the model outlined above is to convert it from an infinite horizon non-linear programming problem to a finite dimensions to facilitate solution. The planning horizon is divided into two sub-horizons, the first running from year 0 to T and the second from $T+1$ to ∞. In year T, the economy is forced to invest in its depreciable assets at a level which just maintains the stock accumulated to that point. This investment plan is repeated throughout the second sub-horizon.

Also, it is assumed that $\overline{N_T}$ and $\overline{L_T}$ are constant through the second subperiod, and that inter-sectoral allocations of land and labor do not change. The steady state allows consumption of the vector (C_{0T}, C_{1T}, C_{2T}) forever. This is reflected in the finite horizon non-linear programming model by giving consumption in year T the weight $\beta^T/(1-\beta)$ in the criterion function.

The Modular In-Core Non-Linear Optimization System (MINOS) was used to compute the optimal solution. The structure of the growth model guarantees that satisfaction of the first-order conditions for positive values of the choice variables identifies a global constrained optimum of the criterion function.

Values for reference solution

Variables in the growth model were initialized with 1982 as the base year. The total civilian labor force was assumed to remain at 100 million man-years throughout the 25 year horizon of the model. Total crop and forage acreage harvested in 1982 was 309.5 million acres (125 million ha), which was assumed constant over the planning horizon. Stocks of research investment were computed from historical expenditure data using the estimated rates of obsolescence. Capital stock variables for the crop and livestock sectors were derived from USDA estimates of the capital stock of the total farm sector (USDA *Agricultural Statistics*, various years), and allocated on the basis of the share of total farm revenue generated in each sub-sector. See Table 3.

TABLE 3

Production function variables and parameters – 1982

Variable	Value	Elasticity (dimension 1)
Non-farm sector		
Output (billion US$)	2940	
Capital stock (billion US$)	3231	0.18
Labor (million man-years)	99.3	0.82
Intercept	15.82	
Livestock sector		
Output (million t)	19.35	
Value (billion US$)	56.7	
Capital stock (billion US$)	44.5	0.14
Applied research (billion US$)	0.77	0.087
Basic research (billion US$)	1.41	0.06
Feed (million t)	127	0.28
Land		
(million acres)	69.2	0.04
(million ha)	28.0	
Labor (million man-years)	0.452	0.393
Intercept	3.39	
Crop sector		
Output (million t)	293.3	
Value (billion US$)	36.66	
Capital stock (billion US$)	28.7	0.130
Applied research (billion US$)	0.346	0.056
Basic research (billion US$)	0.743	0.075
Purchased inputs (billion US$)	10.3	0.28
Land		
(million acres)	240.3	0.300
(million ha)	97.2	
Labor	0.256	0.159
Intercept	25.67	

t, metric ton = 1000 kg; billion (US) = 10G.

Farm price supports

A complex set of instruments are employed in the United States to support prices for agricultural commodities above what would be market clearing levels in the absence of public intervention. It is not the intent of this study to model these instruments in detail. Nevertheless, the problem of establishing an optimal research budget depends on the level of output of the farm sector, and output depends on prices. Prices are not explicitly represented in the model. They can be computed, however, from the ratios of marginal utilities in the criterion function. By placing upper bounds on consumption levels of the products of the farm sectors, the effects of price supports are obtained indirectly. The assumption used in this study is that public policy will maintain constant real prices for livestock and crop products over the 25-year planning horizon.

Summary of the reference solution

A comparison of the actual values of selected variables in 1982 and their corresponding values in the reference solution is presented in Table 4. While output levels and exports in the reference solution were relatively close to 1982 values, the level of some inputs in the farm sector varied considerably from the base year. When the model was allowed to select an optimal level of research investment, the farm sector stocks of capital, the level of employment, the amount of purchased current inputs, and the level of feed purchased for livestock fell from 1982 levels.

Since the model assumes constant real prices for the products of the crop and livestock sectors, research investments are prevented from generating social benefits through reducing food costs. However, resources are released to

TABLE 4

Comparison of selected variables in reference solution with 1982 actual values

Variable	1982 actual value	Reference Solution (t=0)	Percent deviation
Livestock output (million t)	19.50	19.50	–
Crop output (million t)	293.3	252.8	–13.8%
Non-farm capital (billion US$)	3529.0	3523	–0.1%
Livestock capital (billion US$)	44.5	44.5	–
Crop capital (billion US$)	29.7	29.7	–
Non-farm labor (million man-years)	99.30	99.58	+0.3%
Livestock labor (million man-years)	0.45	0.33	–26.7%
Crop labor (million man-years)	0.28	0.09	–65.4%
Crop exports (million t)	127	114.1	–10.2%
Livestock feed (million t)	127	99.9	–21.3%
Land in forages			
(million acres)	69.2	48.8	–29.5%
(million ha)	28.0	19.75	
Land in crops			
(million acres)	240.3	260.7	+8.5
(million ha^{-1})	97.2	105.5	
Crop sector			
Current input purchases (billion US$)	$10.3	$4.1	–60.2

t, metric ton = 1000 kg; billion (US)–10^9.

the rest of the economy as farming becomes more research intensive and less capital and labor intensive. There is an apparent shift of land from forage to crop production, but this is most likely an artifact of the assumption that land in the farm sector is of homogeneous quality.

Optimal levels of livestock and crop research from 1982 to 2006 are reported in Figs. 1 and 2. Historical expenditure levels from 1976 to 1981 are included as a basis for comparison. Chronic underinvestment in all farm types of research is reflected in the model's dramatic jump in optimal expenditure in 1982, the first year in the optimization. Clearly, such a radical influx of resources in a single year would be an inefficient way to increase the capacity of public efforts in agricultural research. Construction of facilities and training of personnel could not be accomplished in such a short period of time. These adjustment costs are not included in the model, but would dictate that the expansion of public research efforts be implemented gradually. It should be noted, however, that the true opportunity costs of this increase in research investment are accounted for the model, even though adjustment costs are ignored. The marginal excess burden of tax collection is charged against research investments, and these funds are obtained in competition with investment demand and consumption. After 1982, annual optimal research expenditures are approximately four times the actual level in 1981.

Research investments from 1983 to 1989 are characterized by moderately increasing funding levels followed by a slight decline. This is the period of time for which gross capital investment in the farm sector is zero. Excess cap-

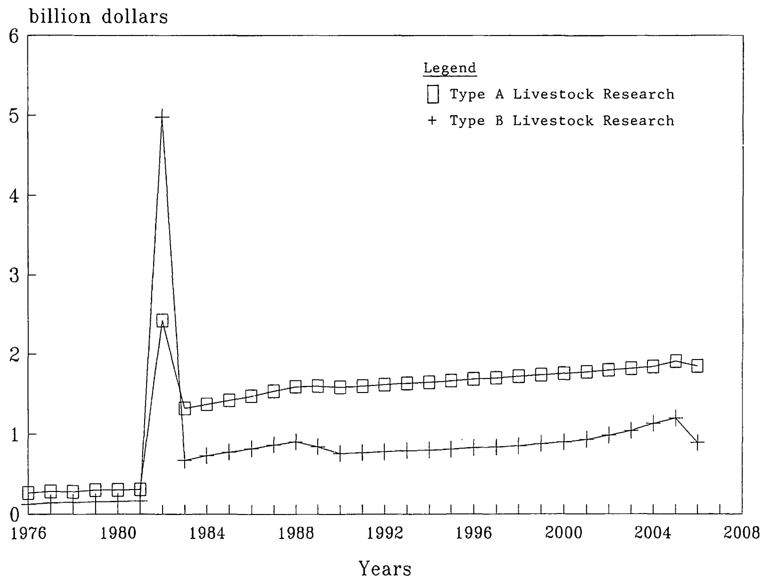

Fig. 1. Optimal annual expenditures for basic and applied livestock research – reference solution.

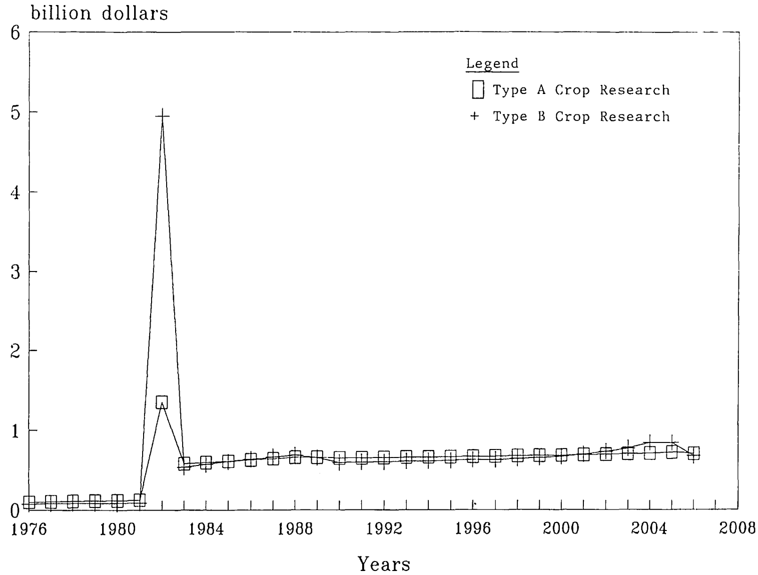

Fig. 2. Optimal annual expenditures for basic and applied crop research – reference solution.

ital can only leave the sector through depreciation, and until the desired capital stock is achieved the productivity of public research is artificially high. In 1990, gross capital formation becomes positive. The years between 1989 and 2003 can be thought of as a long-run growth path. After 2003, a rise and fall of research investment is driven by the proximity of the steady state, which begins in 2006. This final phase arises from the compromise required to finesse the infinite horizon problem into finite dimensions.

In the final period or steady state, crop research of applied research and basic research amounted to 1.0% and 1.8% of the value of the crops produced in the sector. For livestock, the corresponding figures were 3.0% and 2.2%, respectively. These rates of investment can be thought of as long-run equilibrium values.[12]

Sensitivity analysis

The response of the optimal pattern of research expenditures to variations in selected parameters of the growth model was examined using sensitivity analysis. Changes in the rate of technical change in the non-farm sector, in the elasticity of the demand for crop exports and in the size of the marginal excess burden were considered. These particular parameters were selected based on their anticipated potentially large effects and because of the lack of professional consensus on particular values.[13]

Values for the excess demand elasticity of 1.0 and 2.0 were examined. Both basic and applied crop research change in the direction of the change in the export demand elasticity. Improvement in the terms of trade for higher levels of crop exports increases the value of the marginal product of crop research. The effect is less pronounced for later years in the simulations. Also, the effect of changes in the export demand elasticity is reduced in 1989, the year in which the excess capacity problem in agricultural capital is resolved. Overall, increasing the export demand elasticity from 1.5 to 2.0% increases optimal crop research by 5 – 7%.

[12]The model and its optimal solution can be used to compute estimates of the marginal internal rates of return for each of the four research categories. The production technology employed in this study makes it possible to calculate the rates of return analytically. The internal rate of return for a particular research category, ρ, is determined by:

$$\rho = \frac{\tau R(\epsilon - 1) + \epsilon\delta\,\mathrm{PY}}{\tau R}$$

Values for the research stock of a particular type of research (R), the rate of obsolescence (ϵ), the output elasticity (δ) and gross revenues of commodity production (PY) are substituted into this expression to obtain estimates for ρ. The marginal excess burden τ, is assumed to be 1.35.

For actual values of the research stocks and total revenues for 1982, ρ was found to be about 150% for applied livestock research and about 116% for basic livestock research. Both types of crop research had marginal internal rates of return of 180% per annum.

Rates of return to all research categories fall to about 40% in the optimal solution for 1982, after the initial top-loading stage. By 2000, the rates fall to 18% and in the steady state, ρ is 15% for each of the research stocks. This final figure is consistent with the social rate of return of conventional capital in the U.S. (Fox, 1985).

The rate of return estimates for the actual 1982 situation are higher than those reported elsewhere in the literature. However, Evenson (1978) found that separation of research expenditures into applied and basic categories produced rate of return estimates closer to 100% per annum. Furthermore, many authors have treated the research variable as the sum of private and public expenditures. In the absence of data on private spending on agricultural research, many studies have simply doubled the public research stock. This confounding of public and private research has been unfortunate. It has failed to recognize the contrasting motives of public and private research and more critically, it does not acknowledge the different ways in which research results find their way into the economy. To a private firm, research is similar to other forms of investment in that it is expected to generate profit. The results of research are sold to the firms customers as new products, as variations on old products, or the firm's costs are reduced through process innovation. In this way, part of the selling price of the firm's output represents a return to that firm's research efforts. Therefore, if input use is correctly measured in the construction of a multi-factor productivity index, the effects of private research are already accounted for.

Public research results, in contrast, are intended to be given away. There is no market. Nevertheless, farmers and farm input suppliers incorporate their results in their production practices, and an index of multi-factor productivity will rise from the effect of an unmeasured input. By arbitrarily doubling the size of public research expenditure, the rate of return to that expenditure falls. Observe that the expression derived above for ρ is declining in R. Doubling R goes a long way toward reconciling the rate of return estimates of this study with those obtained elsewhere.

[13]Detailed summary of the results of this sensitivity analysis is reported in Fox and Haque (1987).

Variations in the export demand elasticity leave annual levels of applied livestock research expenditure largely unchanged. However, both increases and decreases in the size of this parameter reduce optimal expenditures on basic livestock research. Annual expenditure on this category of research are 5–7% lower when the export demand elasticity is changed from -1.5 to either -1.0 or -2.0%.

Increasing the value of the marginal excess burden from 35 cents per dollar of public expenditure to 50 cents reduces optimal research expenditures in all categories. basic and applied crop research and applied livestock research are reduced by about 10% in each year. Basic livestock research is more seriously effected, being reduced by about 13% per year on average.

Reductions in the rate of technical change in the non-farm sector tend to reduce the optimal rate of investment in agricultural research. Inputs purchased from the non-farm sector become relatively more expensive over time under this regime, reducing the marginal product of agricultural research. At the same time, crop exports become increasingly valuable as a means of obtaining goods to substitute for the output of the non-farm sector. As a result, reductions in optimal crop research are smaller than those in livestock research. The indirect effect of using crop exports to obtain imports puts upward pressure on the opportunity cost of feed. By the end of the planning horizon, annual livestock research expenditures fall by 15% for applied research and 25% for basic research. The corresponding values for crop research are 9% and 18%.

Overall, the results of the sensitivity analysis indicate that the optimal expenditure paths are relatively robust to major perturbations in the underlying parameters of the model. The largest impact observed was for the cumulative effect of reduced technological change in the non-farm sector. This result was anticipated by Ruttan and Fox (1983) in an informal way and illustrates the potential importance of general equilibrium effects on the farm sector that are often neglected.

EVALUATING THE HYPOTHESES

1. Underinvestment hypothesis

The optimization results reported in Figs. 1 and 2 indicate a path of gross research investment substantially above the historical record. This is true for all four research categories. The optimal gross investment for the second year, after the initial top loading of the research stocks in the first year, is about four times the level of 1982 actual expenditures.

2. Myopia hypothesis

If chronic underinvestment is confirmed in the evaluation of the first hypothesis, then this second hypothesis claims that the underinvestment problem is more severe for basic research. This was not found to be the case. In fact, the optimal investment level for applied livestock research was larger relative to 1982 actual expenditure than was the case for basic livestock research. The opposite was true for the case of crop research. For neither crop nor livestock research, however, did applied or basic research appear to be severly relatively underfunded.

3. Commodity bias hypothesis

Again treating this hypothesis as something independent of hypothesis 1, the claim is that even if overall funding is inadequate, crop research has suffered more. Weak support was found for this hypothesis. Optimal funding for the sum of both types of crop research in the second year of the model was 4.45 times actual 1982 levels. The corresponding multiple for livestock research was 4.06. The extent of this differential is not large, however, and is reversed for some combinations of values for the marginal excess burden and the rate of technical change in the non-farm sector. Support for the commodity bias hypothesis has traditionally been drawn from measures of congruence. In the present more general model, it can be seen that differences in consumer preferences, output elasticities of research in sectoral production functions and research obsolescence rates can contribute to optimal expenditure patterns which depart from congruence guidelines.

CONCLUSIONS

The results of this paper indicate that the underinvestment problem in public agricultural research in the United States may be more serious than earlier literature indicated, even when the cost of the excess burden is taken into account. Claims that basic research has been neglected and that crop research has been more severely underfunded were not supported. The underinvestment argument has not had an appreciable impact on research appropriations decisions in the past, and fiscal priorities at the state and federal level are unlikely to change soon. At the same time, private sector interest in agricultural research is growing. From a research policy perspective, the challenge is to create an incentive structure which encourages private investment in new biological intellectual property while continuing to serve the broad constituency of public research programs.

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REFERENCES

Ballard, C.L., Shoven, J.B. and Whalley, J., 1985. General equilibrium calculations or the marginal welfare costs of taxes in the United States. Am. Econ. Rev., 75: 128–138.

Beach, C.M. and MacKinnon, J.G., 1978. A maximum likelihood procedure for regression with autocorrelated errors. Econometrica, 46: 51–88.

Bonnen, J.T., 1983. Historical sources of U.S. agricultural productivity: Implications for R&D policy and social science research. Am. J. Agric. Econ., 65: 958–966.

Boyce, J.K. and Evenson, R.E., 1975. National and international agricultural research and extension programs. Agricultural Development Council, New York, 229 pp.

Bredahl, M. and Peterson, W., 1976. The productivity and allocation of research: U.S. Agricultural Experiment Stations. Am. J. Agric. Econ., 58: 684–690.

Bredahl, M.E., Meyers, W.H. and Collins, K.J., 1979. The elasticity of foreign demand for U.S. agricultural products: the importance of the price transmission elasticity. Am. J. Agric. Econ., 61: 58–69.

Chambers, R.G. and Lee, H., 1986. Constrained output maximization and U.S. agriculture. Appl. Econ., 18: 347–358.

Cline, P.L., 1975. Sources of productivity change in the United States agriculture. Ph.D. dissertation, Oklahoma State University, OK.

Davis, J.S., 1979. Stability of the research production coefficient for U.S. agriculture. Ph.D. dissertation, University of Minnesota, Stillwater, MN, 173 pp.

Evenson, R.E., 1968. The contribution of agricultural research and extension to agricultural production. Ph.D. thesis, Univ. Chicago, St. Paul, IL, 168 pp.

Evenson, R.E., 1978. A century of productivity change in U.S. agriculture: an analysis of the role of invention, research and extension. Disc. Pap. 296, Economic Growth Center, Yale University, New Haven, CT, 77 pp.

Fox, G.C., 1985. Is the United States really underinvesting in agricultural research? Am. J. Agric. Econ., 67: 806–812.

Fox, G.C. and Haque, A.K.E., 1987. A model of optimal public investment in U.S. agricultural research: Further results. Work. Pap. 87/12. Department of Agricultural Economics and Business, Univ. Guelph. Ont, 38 pp.

Fox, G.C., Evenson, R.E. and Ruttan, V.W., 1987. Balancing basic and applied science: the case of agricultural research. BioScience, 37: 507–509.

Griliches, Z., 1964. Research expenditures, education, and the aggregate agricultural production function. Am. Econ. Rev., 54: 961–974.

Johnson, G.L. and Wittwer, S.H., 1984. Agricultural technology until 2030: Prospects. priorities and policies. Spec. Rep. 12, Agricultural Experiment Station, Michigan State University, East Lansing, MI, 61 pp.

Johnson, P.R., 1977. The elasticity of foreign demand for U.S. agricultural products. Am. J. Agric. Econ., 59: 735–736.

Judd, M.A., Boyce, J.K. and Evenson, R.E., 1983. Investing in agricultural supply. Disc. Pap. 442, Economic Growth Center, Yale University, New Haven, CT, 54 pp.

Kislev, Y. and Peterson, W., 1982. Prices, technology, and farm size. J. Polit. Econ., 90: 578–595.

Knoblach, M.C., Law, E.M. and Meyer, W.P., 1962. State Agricultural Experiment Stations: a history of research policy and procedure. Misc. Publ. 904, U.S. Department of Agriculture, Washington, DC, 304 pp.

Knutson, M. and Tweeten, L.G., 1979. Toward an optimal rate of growth in agricultural production research and extension. Am. J. Agric. Econ., 61: 70–76.

Kula, E., 1984. Derivation of social time preference rates for the United States and Canada, Q. J. Econ., 99: 873–882.

Lyu, S.L., White, F.C. and Lu, Y., 1984. Estimating effects of agricultural research and extension expenditures on productivity: a translog production function approach. South. J. Agric. Econ., 16: 1–8.

Norton, G. and Swallow, B., 1985. Evaluating depreciation and maintenance of agricultural research. Paper presented at the Annual Meetings of the American Agricultural Economics Association, Ames, IA, August 1985.

Peterson, W., 1967. The returns to poultry research in the United States. Ph.D. dissertation, Univ. Chicago, IL, 88 pp.

Peterson, W.L. and Fitzharris, J.C., 1977. Organization and productivity of the federal–state research system in the United States. In: T.M. Arndt, D.G. Dalrymple and V.W. Ruttan (Editors), Resource Allocation and Productivity in National and International Agricultural Research. University of Minnesota, Minneapolis, MN, pp 60–85.

Ruttan, V.W., 1982. Agricultural Research Policy. University of Minnesota Press, Minneapolis, MN, 370 pp.

Ruttan, V.W., 1983. Agricultural research policy issues. HortScience, 108: 809–818.

Ruttan, V.W. and Fox, C., 1983. The decline in industrial productivity and its implications for agriculture. Hearings before the Subcommittee on Economic Stabilization of the Committee on Banking, Finance and Urban Affairs, House of Representatives, Washington, DC, 4 August 1983.

Shumway, C.R., Tolpaz, H. and Beattie, B.R., 1979. The factor share approach to production function 'Estimation': Actual or estimated equilibrium shares. Am. J. Agric. Econ., 61: 561–564.

Swallow, B., Norton, G.W., Brumback, T.B. and Buss, G.R., 1985. Agricultural research depreciation and the importance of maintenance research. Pap. AE 56, Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA, 20 pp.

True, A.C., 1937. A history of agricultural experimentation and research in the United States, 1607–1925. Misc. Publ. 251, U.S. Department of Agriculture, Washington, DC, 178 pp.

Tweeten, L., 1967. The demand for United States farm output. Food Res. Inst. Stud., 7: 343–369.

Tweeten, L., 1977. The elasticity of foreign demand for U.S. agricultural products: Comment. Am. J. Agric. Econ., 59: 737–738.

Tyner, F.H. and Tweeten, L., 1965. A methodology for estimating production parameters. J. Farm Econ., 47: 1462–1467.

Tyner, F.H. and Tweeten, L., 1966. Optimum resource allocation in agriculture. J. Farm Econ., 48: 613–631.

U.S. Gov. Printing Office, 1984. Economic Report of the President. U.S. Government Printing Office, Washington, DC, February 1984.