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ABSTRACT

This paper examines three claims of inefficient allocation of public expenditure in publicly funded agricultural research in the United States. It has been argued by analysts of research policy that:

1. The overall level of public investment in agricultural research is less than what would be socially optimal.
2. 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.
3. The allocation of research resources among commodities is inconsistent with economic efficiency.

A non-linear optimal growth model of the U.S. economy was employed to test 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.

I. Introduction

The creation of a national system devoted to agricultural research can be interpreted as an institutional innovation in response to the incentive problems involved in the provision of a public good. The knowledge produced from agricultural research is non-rival in consumption. If one farmer learns about a new production technique, this does not diminish the stock of knowledge available about that technique.[1] Put another way, the marginal cost of learning how to produce the <u>second</u> bushel of hybrid corn seed is zero, once someone has learned how to produce the first bushel. At the same time, the atomistic structure of the production sector of agriculture tends to exacerbate the problem of exclusion of non-contributors to the provision of a public good, and to diminish the degree of appropriability of private investment in that good.[2] In addition to the public good rationale for public support of agricultural research, evidence has acummulated which indicates that this has been a relatively productive area of public expenditure.[3] The agricultural research system in the United States received over $1.7 billion of state and federal funding in Fiscal Year (FY) 1983.

This is not to say that the system has been without detractors. Rachel Carson (<u>Silent Spring</u>, 1972) argued that the path to technical change in U.S. agriculture has been chosen with scant regard for environmental spillovers. Jim Hightower (<u>Hard Tomatoes, Hard Times</u>, 1973) claimed that the goal of productivity enhancement had been pursued at the expense of the welfare of those who no longer work on farms.

These authors are the most visible of a host of technological pessimists whose ranks continue to grow.[4]

In academic circles, political scientists and economists have leveled more formal criticisms of the level and composition of expenditures. Hadwiger (1982) cites incidents of porkbarrel bargains among legislators that have distorted both regional and commodity research funding divisions. Garren and White (1980), Garren (1981), Ziemer, White and Cline (1982), White and Havlicek (1981) and Havlicek and White (1983) have claimed that federal grants to the SAES's fail to reflect the pattern of spillover effects of research discoveries among states and regions.

Elsewhere (Fox, 1985b) I have outlined the criticism of U.S. public agricultural research system most strongly voiced by economists. It is widely believed that the overall level of expenditure is too low. This conclusion is based on estimates of social rates of return to public investment in agricultural research that have been interpreted as high. As I argued in an earlier paper, the conventional wisdom on the topic may be seriously flawed, but the question of determining an optimal or even a more appropriate level of funding remains unresolved.

It has frequently been suggested that political pressure brought to bear on research administrators has contributed to a neglect of more basic research agendas with longer term payoffs in favor of more applied work with immediate benefits. This theme is evident in the historical surveys of True (1937) and Knoblach *et al* (1962) and has recently been renewed by Bonnen (1983). The evidence in support of this view has tended to be of an anecdotal nature, however.

The appropriations process for funding research and the formula determining federal grants to state stations contain no formal provisions to allocate research funds by commodity. Historical funding patterns have evolved in which certain groups of commodities have been more successful than others in attracting research funding, in terms of research expenditure relative to gross revenue or value added. Ruttan (1983) has documented the level of research intensity for horticultural crops, field crops and livestock, and has suggested that inefficiency may have arisen in the apparent neglect of field crops. Judd, Boyce and Evenson (1983) report substantially more generous levels of research funding for livestock commodities than for field and staple crops in many LDC's.

The purpose of this paper is to formally investigate the last three criticisms of the U.S. public agricultural research system. Specifically, the propositions to be examined are that

(i) The overall level of public investment in agricultural research is less than what would be socially optimal.

(ii) 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.

(iii) The allocation of research resources among commodities is inconsistent with economic efficiency.

While each of these views has attracted substantial support in the literature, there has been little in the way of integrated analytical and empirical work done to directly test these hypotheses. In order to limit the scope of the present study, analysis of these propositions will be limited to expenditure on farm production oriented research on field crops and livestock for the United States. This excludes research on problems of processing, product utilization and other categories of post-harvest research. 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. in 1982. Livestock is defined to include Beef, Hogs, Sheep and Lambs, Milk, Poultry Meat and Eggs, as well as the production of forage feed crops for ruminants. 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 gross sales in U.S. agriculture in 1982.

In order to test proposition (ii) it is necessary to define categories of research. The terms "basic" and "applied" are used quite loosely in the agricultural research policy literature. 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 industry 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.

In this 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. Similarly, "applied" research will refer to commodity specific research expenditures with more rapid payoffs.

II. Description and Estimation of Model

The three hypotheses will be examined in the context of a three-sector non-linear optimal growth model. The demarcation of sector boundaries is as follows. The livestock sector consists of the red meats, poultry meats, eggs, milk, wool and sheep meat production and forage production. The crops sector includes wheat, rice, grain corn, grain sorghum and soybeans. Both of these agricultural sectors are defined for activities up to the farm gate but not beyond. Consumption of the output of these sectors is expressed as the farm value of final consumption. The third sector is simply the rest of the economy. This heterogenous composite sector includes the clearly non-farm sectors of manufacturing and services, but also encompasses the activities which account for the marketing margin between farm value and retail value of food commodities from the crop and livestock sector. Also, the rest of the economy 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.

The 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. Future consumption benefits are discounted at the social rate of time preference. 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. Algebraicly, the criterion function is represented as

$$\varphi(\{C_{ot}, C_{1t}, C_{2t}\}_{t=0}^{\infty}) = \sum_{t=0}^{\infty} \beta^t \{\sum_{i=0}^{2} \gamma_i \ln C_{it}\}$$

where β is the social rate of time preference. Subscripts 0, 1 and 2 denote the non agricultural sector, the livestock sector and the crop sector.

Estimation of the parameters γ_0, γ_1 and γ_2 is based on consumption expenditure shares data. (See Fox, 1985a, pp. 64-65 for details). Net National product was chosen as the measure of $C_{0t} + C_{1t} + C_{2t}$. γ_1 is computed by dividing the farm value of expenditures on the named livestock products by net national income. γ_2 is computed in a similar fashion, using the farm value of consumption of grain and bakery products. The values of γ_1, are on the order of 10 times the value for γ_2, but a large part of the farm value livestock products consumption reflects feed grain costs. For 1982, $\gamma_1 = 0.0209$, and $\gamma_2 = 0.001769$. γ_0 is computed as a residual and is 0.977331.

The share of net national income devoted to the farm value of livestock and grain products fell systematically from 1963-1982. On average, the value of γ_1, in any one year was 0.981 times the value for

for the previous year. The corresponding value for γ_2 was 0.972. This pattern of declining expenditure is retained in the model solutions.

Kula (1984) has estimated the social rate of time preference for the U.S. economy to be 0.053. This translates into a value of 0.9497 for β.

The Constraints

The criterion function is maximized subject to a system of 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 technologies 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.

The output of the non-agricultural sector composite product measured in dollars, is produced according to

$$Y_{ot} = \alpha_o(1+\theta)^t L_{ot}^{1-\beta_o} K_{ot}^{\beta_o}$$

An exogenous costless rate of technical change is represented as θ. Labor employed in the non-agricultural sector in period t is L_{ot}, and K_{ot} represents the capital stock. β_o is the output elasticity of capital.

Y_{ot} can be utilized in various ways. It can be consumed directly as C_{ot}, it can be invested in new capital formation 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. There are four categories of research investment. EA_{1t} denotes investment in commodity specific research in the livestock sector in period t. EB_{1t} represents investment in more general biological research pertaining to livestock in that period. EA_{2t} and EB_{2t} are the corresponding variables for the crop sector.

To reflect the fact that grain exports are an important component of the U.S. economy, 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 $M(X_{2t})$.

Using the notation $F_{0t}(\cdot)$ to represent the production function, the period by period constraints on C_{ot} can be written as

$$F_{ot}(\cdot) - C_{ot} - \sum_{i=0}^{2} I_{it} - \tau\sum_{i=1}^{2} (EA_{it} + EB_{it}) - R_{2t} + M(X_{2t}) \geq 0$$

The coefficient τ indicates that the marginal social opportunity cost of public funds exceeds unity. Traditionally it has been assumed that \$1 of public expenditure on agricultural research had a social opportunity cost of \$1. This assumption fails to recognize that public expenditure is financed through taxation, which given available tax instruments introduces distortions and deadweight losses in factor and product markets. Browning (1975) and Stuart (1984) have estimated that τ can exceed one by a considerable amount, due to the cost of these distortions. More recently, Ballard <u>et al</u> (1985) have produced estimated of τ in the range of 1.2 to 1.5 for the United States.

The livestock sector uses stocks of research, AR, BR, capital, K, as well as labor, L, feed-grain, F, and land in forage production, N, to produce output. The production function is written as

$$Y_{1t} = \alpha_1 AR_{1t}^{\delta_{A1}} BR_{1t}^{\delta_{B1}} K_{1t}^{\beta_1} F_{1t}^{\phi_1} N_{1t}^{\lambda_1} L_{1t}^{1-\delta_{A1}-\delta_{B1}-\beta_1-\phi_1-\lambda_1}$$

Output of the sector is measured in million metric tons of beef equivalent. Output of livestock products is aggregated to beef equivalent on the basis of relative prices for 1982. For example, a metric ton of dressed pork was worth about $2109 in 1982. A metric ton of dressed beef was worth $2935. A ton of pork, therefore, contributes 0.72 tons of "beef equivalent" to the output of the livestock sector.

It is assumed that the output of the livestock sector can only be consumed. Non-tariff barriers to trade in livestock products have been relatively effective in preserving autarky in the United States. As a result, the constraint on C_{1t} is

$$F_{1t}(\cdot) - C_{1t} \geq 0$$

Output of the crop sector, Y_{ot}, is measured as million metric tons of wheat equivalent determined in a manner similar to the aggregation procedures in the livestock sector. The crop sector uses the accumulated stocks of commodity specific research, AR, general research, BR, as well as capital, K, current purchased inputs such as feed, pesticides and fertilizers, R, land, N, and labor, L. The production function is

$$Y_{2t} = \alpha_2 \, AR_{2t}^{\delta_{A2}} \, BR_{2t}^{\delta_{B2}} \, K_{2t}^{\beta_2} \, N_{2t}^{\lambda_2} \, R_{2t}^{\mu_2} \, L_{2t}^{1-\delta_{A2}-\delta_{B2}-\beta_2-\lambda_2-\mu_2}$$

Output for this sector can either be consumed or exported, so the constraint on C_{2t} is

$$F_{2t}(\cdot) - C_{2t} - X_{2t} \geq 0$$

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. It follows then that

$$K_{it} = \delta K_{it-1} + I_{it} \qquad , i = 0, 1, 2$$

and

$$AR_{it} = \varepsilon_{Ai} AR_{it-1} + EA_{it} \qquad , i = 1, 2$$

$$BR_{it} = \varepsilon_{Bi} \, BR_{it-1} + EB_{it} \qquad , i = 1, 2$$

This representation of the rate of obsolescence of research investments is at variance with the usual practice in the literature on this subject. More typically, research investments have been represented as influencing output through either an inverted "V" or a quadratic polynomial distributed lag. Both of these formulations portray an initial shakedown period in which the marginal product of research expenditure rises year by year in the early years after the expenditure was made. Eventually a peak is reached, however, and after a finite number of years, usually between 10 and 16, no further influence is present. This formulation has important limitations, however. It certainly seems reasonable to assume that knowledge wears out, however, not all knowledge wears out in a finite number of years. Furthermore, the polynomial lag pattern tends to view the contribution of each year's research expenditure in isolation from expenditures in other years. While this may be a reasonable way to think about investment in machines, it is unlikely to adequately capture the effect of new knowledge on the rate of technical change. There is a synergism among individual components in the stock of knowledge which is unlike relationships among assets in the stock of capital. New knowledge is often the product of synthesis of previous discoveries which were intially thought to be unrelated.

Finally, in each time period, it is assumed that the total employment of the three sectors cannot exceed some upper limit, $\overline{L}_t$, and that total land in crops and forages cannot exceed $\overline{N}_t$. That is

$$L_{ot} + L_{1t} + L_{2t} \leq \overline{L}_t$$

$$N_{1t} + N_{2t} \leq \overline{N}_t$$

Estimation of Output Elasticities

Estimates of a total of ten output elasticities for conventional, that is non-research, 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.

The availability of time series of input use by sector or industry is incomplete, precluding a direct estimation of the production function parameters. Data on factor shares are more widely reported, however, and the information can be exploited to estimated output elasticities under the assumptions that technology is Cobb-Douglas and firms choose inputs and governments select research investment levels in a manner which maximizes sectoral profits.

Data sources for estimation were the national income accounts reported in the Survey of Current Business and the Economic Report of the President, as well as USDA annual publications Agricultural Statistics and Economic Indicators of the Farm Sector. Where possible, sector level time series of factors payments and output values are used to compute output elasticities. In some cases factor payments for the two farm sectors are not reported in a way that allows allocation between crops on livestock. In these instances, use is made of commodity level data in the input of Economic Indicators of the Farm Sector: Costs of Production. Table 1 summarizes the estimates of the output elasticities.

Table 1

Summary of Output Elasticity Estimates

	Non-Agricultural Sector	Livestock Sector	Crop Sector
Capital	.18	.14	.13
Labor	.82	0.393	0.159
Land		.04	.30
Feed Grain		.28	
Chemicals, Pesticides and Fuel			.28

The value for β_o was established using the national income accounts by type of income. Compensation of employees plus proprietor's incomes in the unincorporated non-farm sector were expressed as a percentage of national income of the non-farm sector. National income is reported for the farm and the non-farm sectors combined, so this total was adjusted downward by the percentages of GDP generated in agriculture, which is about 3%. In recent years, employee compensation plus non-farm proprietor's income represented about 82% of this estimated non-farm national income.

Factor share estimates for the crop sector are based on budget data on crop input costs reported in various issues of Economic Indicators of the Farm Sector: Costs of Production. The national average input costs on a per acre basis were computed for the categories of fertilizer, chemicals and fuel, capital consumption and land. These calculations were performed for the years 1980-83 inclusive for each commodity included in the crop sector. For each year, individual commodity factor shares were weighted by the acreage devoted to production of that commodity as a share of the total acres harvested for the five crops in the sector. The average of the four year's factor share estimates is reported in Table 1.

This leaves the problem of estimating output elasticities of the livestock sector. Economic Indicators of the Farm Sector: Income and Balance Sheet Statistics from various years were used to compile a time series of feed grain costs for the period 1970-82. In addition, the farm value of livestock production was calculated. The average share of feed grain costs over this 13 year period was about .28.

The share of costs going to land in forage production is more problematic. We do have records of total acreage devoted to hay and forage production, which has been about 70 million acres on average in recent years. It is difficult to determine an input value for this land, however, as we do not have budget estimates in the Costs of Production annuals nor are land rental statistics available. An average value of \$40 per acre per year was chosen to cost this input. This results in a value of λ_1 of 0.04. This is an arbritary figure, however this cost per acre per year is within the range of land costs per acre in the Costs of Production estimate for commodities in the crops section. In a certain sense, though, the particular values used for λ_1 and λ_2 are not critical for this study. Errors in estimates of the output elasticity for that sector which potentially could lead to a bias in the inter-sectoral allocations of labor and land. The focus of this study, however, is on the inter-sectoral allocations of investment. A value of which is too low would tend to depress $\{N_{1t}\}_{t=1}^{\infty}$ below its true optimum at the same time, the value of $1 - \delta_{A1} - \delta_{B1} - \beta_1 - \phi_1 - \lambda_1$ would be too high, tending to raise $\{L_{1t}\}_{t=0}^{\infty}$ above its true optimum. These factors would tend to be offsetting, although not necessarily exactly offsetting in their impact on $\{AR_{1t}\}_{t=0}^{\infty}$, $\{RB_{1t}\}_{t=0}^{\infty}$ and $\{K_{1t}\}_{t=0}^{\infty}$.

Finally, an estimate of β_1 of 0.14 was derived from cost of production data for livestock products. A much less complete information base is available to estimate livestock capital consumption than is the case for crops. First, only Swine, Dairy cattle and Beef Production cost of production estimates are reported in the Economic Indicators of the Farm Sector series. Second, only four years observations are available for swine and beef and three for dairy. Since commodity gross revenue estimates are not yet available for 1983, and since these revenues were used to compute a weighted average of capital output elasticities for the livestock sector as a whole, we are left with only two years observations.

Output elasticities for the research inputs were estimated with an adaptation of a technique introduced by Cline (1975). Conceptually, the Cline approach separates arguments in the production function into conventional inputs such as land, labor, fertilizer, feed and capital 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

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

If time series data on sectoral inputs were available the estimation of parameters of this function would be quite conventional. In the absence of these series, 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 was used to estimate $g(Z_t)$. The functional form employed by Cline for $g(\cdot)$ was

$$g(\cdot) = \alpha + \sum_{i=0}^{n} \beta_i \ln R_{t-i} + \beta_{n+1} \ln E_t + \beta_{n+2} W_t + U_t .$$

where R_{t-i} is a lagged expenditure on research and extension, E_t is an index of educational achievement of farmers, W_t is an index of weather and U_t is the error term. Weather entered the equation linearly and not in logarithmic form based on the results of agronomic studies cited by Cline (1975, p. 63 -55).

In the present study, $g(\cdot)$ is written as

$$g_i(\cdot) = \alpha_i + \delta_{Ai} \ln AR_{it} + \delta_{Bi} \ln BR_{it} + \beta_1 \ln X_t + \beta_2 \ln E_t + \beta_3 W_{it} + U_{it}$$

X_t is a measure of extension expenditure, since in the present context this is treated separately from research.

Cline's work dealt with the total agricultural sector, and so he could employ the sector multi-factor productivity index published by the USDA. The present study is less aggregated, and a measure of multi-factor productivity for the livestock and crop sectors was needed. While the USDA does not publish such an index, several disaggregated measures of labor productivity are produced. Also, an index of labor productivity for agricultural as a sector is published. It turns out that the sectoral index of multi-factor productivity is quite closely correlated with the sectoral index of labor productivity. A least squares regression of multi-factor productivity (MFP) on labor productivity (LP) from 1944-1982 produced the equation

$$MFP_t = 56.19 + 0.446\ LP_t$$

The coefficients of this equation were used to predict series of multi-factor productivity indexes for crops on livestock using the appropriate series on labor productivities published by the USDA. See Table A-1 for these series.

The Research Variables

Four time series of research stocks were computed, two for the crop sector and two for the livestock sector. Each sector has a stock of undepreciated research investment of "type A" research, that is commodity specific farm production oriented research, and of "type B" research, that is general biological research not necessarily related to a particular commodity. Expenditure data was 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 expenditures in the United States by commodity or resource, by research problem area, and by scientific discipline. By identifying expenditures by commodity, investments pertaining to the crop or livestock sectors can be totaled. By choosing only selected research problem areas, research not directly related to problems of farm production can be eliminated. Table 2 reports the commodities and research problem areas from the CRIS data set that were included in each of the four research variables.

Prior to 1968, research expenditures were calculated from data reported in the annual House appropriations hearings. Estimates of the expenditures categories were computed for 1955-1969, 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 Table A-2. It should be noted that the House appropriations hearings do not follow a standardized procedure for data reporting. For certain years it was necessary to linearly interpolate between observations. Given the high degree of inertia present in the budget process, it is likely that this interpolation reasonably approximates the actual expenditure series. The total expenditure on the four research categories was $704 million in 1983, out of a total public budget for agricultural research of $1.7 billion for that year.

In order to implement the Cline model, time series data on other non-conventional inputs is needed. Nominal extension expenditures were taken from Peterson and Fitzharris (1977) for 1944-1973. Observations from 1974-1983 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 using the procedure outlined in

Table 2

Identification of Research Expenditure Categories from CRIS Dataset

Research Type	Commodity or Resource Categories	Research Problem Areas
Livestock Type A	2900 Poultry	210 Control of Pests in Animals
	3000 Beef Cattle	211 Control of Disease in Animals
	3100 Dairy Cattle	212 Control of Parasites
	3200 Swine	213 Protection of Animals from Toxins
	3300 Sheep and Wool	214 Protection of Animals from Pollution
		310 Animal Reproduction
		311 Imp. Biological Eff. of An. Prod.
		312 Env. Stress in An. Prod.
		313 Prod. Mgmt. Sys. in An. Prod.
		317 Mech/Struct. in An. Prod.
		409 Improve An. Prod. Acceptance
		901 Alleviate Pollution
Livestock Type B	100 Soil and Land	101 Appraisal of Soil Resources
	200 Water	102 Soil Plnt. Wtr. Nutr.
	700 Range	103 Mgmt. of Saline Soils
	1900 Pasture	104 Alt. Use of Land
	2000 Forage Crops	105 Cons. Use of Water
	6500 Invertebrates	106 Drainage and Irrigation
	6800 Animals	107 Watershed Prot. & Mgmt.
	9800 Unclassified An. Sci.	110 Appraisal of Forest and Range
		112 Improve Range Resources

(continued)

Table 2

Identification of Research Expenditure Categories from CRIS Dataset
(continued)

Research Type	Commodity or Resource Categories	Research Problem Areas
Crops Type A	1400 Corn	102 Soil Plnt. Wtr. Nutr.
	1500 Grain Sorghum	105 Cons. Use Wtr.
	1600 Rice	107 Watershed Prot. & Mgmt.
	1700 Wheat	207 Cntr. Pest Fld. Crps
	2300 Soybeans	208 Cntr. Dis. Fld. Crps
		209 Contr. Weeds Fld. Crps
		214 Protect from Pollution
		307 Imp. Bio. Eff. Fld. Crps.
		308 Mech. Prod. Fld. Crps
		309 Prod. Mgmt. Sys. Fld. Crps
		405 Prod. Fld. Crps. Imp. Accpt.
		901 Alleviate Pollution
Crops Type B	100 Soil and Land	101 Apprais. of Soil Resources
	200 Water	102 Soil Plnt. Wtr. Nutr.
	6100 Weeds	103 Mgmt. Saline Soils
	6200 Seed Research	104 Alt. Use of Land
	6300 Bio. Cell Systems	105 Cons. Use Wtr.
	6600 Micro-Org. Viruses	106 Drainage and Irrigation
	6700 Plants	107 Watershed Prot. & Mgmt.
	9700 Unclassified Crp. Sci.	110 Appraisal of Forest & Range Resources

(continued)

Table 2

Identification of Research Expenditure Categories from CRIS Dataset
(continued)

Research Type	Commodity or Resource Categories	Research Problem Areas
		203 Forest Fire Protection
		207 Cntr. Pests. Fld. Crps.
		208 Cntr. Dis. Fld. Crps.
		209 Cntr. Weeds Fld. Crops
		210 Cntr. Pests Animals
		211 Cntr. Dis. Animals
		212 Cntr. Inter. Parasites
		213 Protect. An. from Toxins
		214 Protect from Pollution
		307 Imp. Bio. Eff. Fld. Crps.
		308 Mech. Prod. Fld. Crps.
		309 Prod. Mgmt. Sys. Fld. Crps.
		310 Animal Reproduction
		311 Imp. Bio. Eff. An. Prod.
		312 Env. Stress. An. Prod.
		313 Prod. Mgmt. Sys. An. Prod.
		315 Imp. Struct. Frm. Supp.
		317 Mech./Struct. An. Prod.
		405 Prod. Fld. Crp. Imp. Accpt.
		409 Prod. An. Pr. Imp. Accpt.
		901 Alleviate Pollution

(continued)

Table 2

Identification of Research Expenditure Categories from CRIS Dataset

(concluded)

Research Type	Commodity or Resource Categories	Research Problem Areas
		207 Cntr. Pest. Fld. Crps.
		208 Cntr. Dis. Fld. Crps
		209 Cntr. Weeds, Fld. Crps.
		307 Imp. Bio. Eff. Fld. Crps.
		308 Mech. Prod. Fld. Crps.
		309 Prod. Mgmt. Sys. Fld. Crps.
		318 Non-Com. Bio. Tech.
		405 Prod. Fld. Crps. Imp. Accept.
		408 Mkt. Qual. Fld. Crps.
		901 Alleviate Pollution

Cline (1975, pp. 153-158). The weather index was computed by measuring the deviation from trend yields for the crops in the model. Yields were normalized with their 1964 values. Deviations from a linear trend were then weighted by shares of harvested acreage for that year. This weighted average deviation was then added to 100 to produce the weather index.

Nominal expenditure data for research and extension was converted to real 1982 dollars using the price deflator for State and Local government purchases of goods and services (Economic Report of the President, 1984, Table B-3, p. 225). Data for nominal extension expenditures, the education and weather indexes and the price deflator series is reported in Tables A-3.

Recall that AR_{it} and BR_{it}, given the structure of the model outlined above, are stocks of undepreciated research expenditure. It follows, therefore, that δ_{ji}, the output elasticity of type j research for sector i, must be estimated simultaneously with ε_{ji}, the rate at which research obsolesces. Note that ε_{ji} is allowed to vary with the sector and with the type of research. Evidence on the rate of research obsolescence relevant to this context is limited. 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 equation are reported in Table 3 and the crop equation is reported in Table 4. Weather and real extension expenditures did not contribute significantly to the explanation of variation of productivity in the

Table 3

Coefficients in the Livestock Equation

Variable	Coefficient	Standard Error	"t" Statistic
Constant	3.21	0.368	8.73
Logarithm of Type A Research	0.0870	0.0730	1.19
Logarithm of Type B Research	0.0600	0.0910	0.660
Education Index	0.00241	0.000764	3.16

$\varepsilon_A = 0.620$

$\varepsilon_B = 0.925$

$\bar{R}^2 = 0.970$

d.w. = 0.444

Table 4

Coefficients in the Crop Equation

Variable	Coefficient	Standard Error	"t" Statistic
Constant	2.36	0.253	9.32
Logarithm of Type A Research	0.0560	0.0453	1.23
Logarithm of Type B 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

$\varepsilon_A = 0.68$

$\varepsilon_B = 0.91$

$\bar{R}^2 = 0.998$

d.w. = 1.40

livestock equation and these variables 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 MacKinnon (1978) to correct for first order serial correlation. As is indicated by the Durbin-Watson statistics reported in tables, neither procedure was particularly effective.

Problems of intercorrelation between the research variables in each equation contributed to their low levels of significance. As the value for ε for one type of research was decreased, the coefficient for that variable became smaller and less significant, and the other research coefficient became larger and more significant. Other coefficients in the equation were largely unaffected.

The Trade Function

Crop exports have become an increasingly important but volatile fact of life for U.S. agriculture. Export quantitites have ranged from 42.8 million metric tons of exports in wheat equivalent in 1968 to 135.5 million metric tons in 1981. The value of these exports in real terms ranged from less than $5 billion to over $18 billion.

In this study, the focus is on the effect of research investment on technical change. It is desirable for trade to play a role, but trade should not be the driving force in the model. Therefore, the model incorporates a limited opportunity to export the output of the sector in exchange for imports of goods which substitute for Y_o. The representation of the exchange opportunities reflects a decline in the purchasing power of exports at the margin as exports increase. The U.S. is modelled has having the effect of a "large Country" in the market for crop exports, but it is not allowed to exploit its resulting monopoly power.

Let $P(X_2)$ represent the number of units of Y_o that can be purchased with a marginal unit of exports when X_2 is the total level of exports. This means that the total amount of imports that can be purchased for exports X is

$$M(X_{2t}) = X_{2t} \cdot P(X_{2t})$$

It is assumed that $P(0) > 0$, $P'(X) < 0$. $P(X_{2t})$ is in fact the excess demand of the rest of the world for U.S. crop exports, expressed in price dependent form. Tweeten (1967, 1977) and Johnson (1977) 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 countries which purchase U.S. crop exports do not allow full transmission of world price changes to their domestic markets. As a result, a less elastic excess demand would seem more plausible. In this study, however, the estimates of Tweeten and Johnson are employed. A linear excess demand function is assumed. In 1982, crop exports of commodities covered in the model amounted to 127 m.m.t. and earned $15.96 billion. The parameters of the excess demand function,

$$P(X_{2t}) = a - bX_{2t},$$

were chosen so that

$$P(127) = \$0.125 \text{ billion/m.m.t.}$$

and the excess demand elasticity was -6.0 when $X_{2t} = 127$. The trade function, therefore, is

$$M(X_{2t}) = 0.090X_{2t} - 0.00016X_{2t}^{2}$$

III. 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 horizon non-linear programming problem which can subsequently be solved by available software. Actually, the version of the model that is solved retains certain features of the original infinite horizon problem. 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, economy is forced to invest in its depreciable assets at a level which just maintains the stock acummulated to that point. This investment plan is repeated throughout the second sub-horizon. In the notation introduced above, this means that

$$I_{iT} = \delta K_{it} \quad , \quad i = 0, 1, 2$$

$$EA_{iT} = \varepsilon_{Ai} AR_{iT}, \quad i = 1, 2$$

and

$$EB_{iT} = \varepsilon_{Bi} BR_{iT}, \quad i = 1, 2$$

and that this plan continues into the infinite future. Also, it is assumed that N_T and L_T likewise persist at constant levels through the second sub period, and that inter-sectoral allocations of land and labor do not change.

The steady state allows consumption of the vector (C_{oT}, C_{IT}, 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) developed at the Systems Optimization Laboratory of Stanford University was used to identify an optimal solution to the model. Documentation of the way in which the system identifies an optimum can be found in Murtagh and Saunders (1983) and Gill, Murray and Wright (1981).

MINOS can be used to solve mathematical programming problems with the following structure.

$$\underset{x,\ y}{\text{Maximize}} \quad F(x) + c'x + d'y$$

subject t

$$f(x) + A_1 y \gtrless b_1 \qquad \text{(nonlinear constraints)}$$

$$A_2 x + A_3 y \gtrless b_2 \qquad \text{(linear constraints)}$$

$$l \leq \begin{bmatrix} x \\ y \end{bmatrix} \leq U$$

where c, d, b_1, b_2, l , u are vectors of constants, A_1, A_2, A_3 are matrices of constants, F(x) is a smooth scalar non-linear function and f(x) is a vector of smooth non-linear functions. The vectors l and u denote lower and upper bounds respectively which may be imposed on the vectors of choice variables x and y.

The system uses a projected augmented Lagrangian alogrithm (Murtagh and Saunders, 1982). The algorithm solves a sequence of optimization sub-problems each of which is constrained by a linear approximation of the set of non-linear constraints. This linear approximation around the current vector of values of x, denoted x_K, is written as

$$\tilde{f}(x, x_k) = F(x_k) + J(x_k)\ (x - x_k)$$

$J(x_k)$ is the matrix of first partials of the non-linear constraints evaluated at x_k. That is

$$J(x_k) = \left[\left. \frac{\partial f^i(x)}{\partial x_j} \right| x = x_k \right]$$

Each of the sub problems or major interations seeks to maximize a merit function which reflects a tradeoff between improvements in the original objective function and feasibility of the non-linear constraints. This merit function or augmented Lagrangian is written as

$$F(x) + c^T x + d^T y - \lambda_k^T (f - \tilde{f}) - {}^1/2\rho\ (f - \tilde{f})^T (f - \tilde{f})$$

λ_k is vector of current estimates of the shadow values of the non-linear constants. The last component of the augmented Lagrangian is a penalty function which measures departure from feasibility quadratically. ρ is called the penalty parameter.

This augmented Lagrangian is maximized subject to

$$\tilde{f} + A_1 y = b_1$$

$$A_2 x + A_3 y = b_2$$

$$l \leq \begin{bmatrix} x \\ y \end{bmatrix} \leq u$$

The structure of the model has been rigged to guarantee that satisfaction of the first order conditions for positive values of the choice variables identifies a global constrained optimum of the criterion function. The Hessian matrix of the criterion function is negative definite for all positive values of the vector of consumption variables. The production functions exhibit constant returns to scale and the quadratic trade function is concave. It can be shown from the optimization results that Slater's constraint condition holds (see Takayama, 1974, pp. 68-70).

The Reference Solution

Using the elasticity estimates reported earlier the model was initialized for the year 1982, which is identified as $t = 0$. Values of accumulated durable inputs on hand in 1982 and current input levels for that year were substituted into the production functions. Using the output measures for 1982, the intercepts of the production functions were derived. Tables 5 to 7 report the values of input and output variables of each sector at t=0 as well as coefficients of the production functions and rates of depreciation of durable inputs.

The total civilian labor force has been about 100 million man-years in recent years (Economic Report of the President, February 1984, p. 256, Table B-30). Converting the USDA estimates of employment in agriculture to man-years at the rate of 2130 man-hours per man-year gives the labor figures of Tables 6 and 7. Employment in the rest of the economy is computed as a residual. The total labor force is assumed to remain at 100 million man-years throughout the 25-year horizon.

Values of acreage devoted to the two sectors are totals of USDA estimates of harvested acres in 1982. Total crop and forage acreage harvested in that year was 309.5 million acres. This land endowment, in total, is assumed constant over the planning horizon.

Stocks of research investment are computed from Table A-2, using the estimated rates of obsolescence. Capital stock variables for the crop and livestock sectors were derived from USDA estimates of the the capital stock of the total farm sector (USDA, Agricultural Statistics, 1983). Values for each of the two sub-sectors were determined on the basis of the share of total farm revenue generated in each sub-sector. As in the case of the capital stock variable in the non-farm sector, the values reported in Tables 6 and 7 reflect an adjustment for intra-year depreciation.

Table 5

The Production Function of the Non-Farm Sector at t = 0

Variable	Value	Elasticity	
Output	$2940 b		
Capital Stock*	$3231 b	0.18	$\delta_K = 0.90$
Labor	993 x 100,000 man-years	0.82	
Intercept	2.39		

*Capital stock was calculated as ten times the level of capital consumption allowances for 1982 (Economic Report of the President, February 1984, p. 242, table B-19). The stock figure above is 90% of the result of this calculation, which reflects intra-year depreciation.

Table 6

The Production Function of the Livestock Sector at t = 0

Variable	Value	Elasticity	
Output	64.5 x 300,000 m.t.		
Value	\$56.7 b		
Capital Stock	\$44.5 b	0.14	$\delta_K = 0.90$
Type A Research	\$0.77 b	0.087	$\varepsilon_A = 0.62$
Type B Research	\$1.41 b	0.60	$\varepsilon_B = 0.91$
Feed	127 m.m.t.	0.28	
Land	69.2 m. acres	0.04	
Labor	45.2 x 10,000 m. years	0.393	
Intercept	1.84		

Table 7

The Production Function of the
Crop Sector at t = 0

Variable	Value	Elasticity	
Output	293.3 m.m.t		
Value	\$36.66 b		
Capital Stock	\$28.7 b	0.130	$\delta_K = 0.90$
Type A Research	\$0.346 b	0.056	$\varepsilon_A = 0.68$
Type B Research	\$0.743 b	0.075	$\varepsilon_B = 0.91$
Purchased Inputs	\$103 x 100 m.	0.28	
Land	240.3 m. acres	0.300	
Labor	25.6 x 10,000 m. yrs.	0.159	
Intercept	6.48		

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 price of a metric ton of beef equivalent in 1982 was about $3000. The corresponding price for wheat was about $125. As the consumption expenditure share devoted to meat and grain output falls, consumption falls if prices remain constant. The assumption used in this study is that public policy will maintain approximately constant real prices for livestock and crop products over the planning horizon. These prices are sustained through imposing bounds on beef consumption of 19.3 m.m.t. for t = 0, falling steadily to 18.9 m.m.t. at t = 25 and on crop consumption of 39.3 m.m.t. and 31.3 m.m.t. respectively.

Summary of the Reference Solution

In a model the size of the one employed in this study, it would be difficult to discuss the optimal solution in its entirety. Almost 700 choice variables enter the optimal solution at non-zero values. Detailed discussion will be limited to a comparison of the actual 1982 values of variables included in the model and their values in the optimal

Table 8

Comparison of Selected Variables in Reference Solution with 1982 Values

Variable	1982 Value	Reference Solution (t = 0)	% Deviation
Non-Farm Output	$2940 b	$2981 b	+ 1.4
Livestock Output	19.35 m.m.t.	19.35 m.m.t	--
Crop Output	293.3 m.m.t.	277 m.m.t.	- 5.6
Non-Farm Capital	$3592 b	$3523 b	- 1.9
Livestock Capital	$49.4 b	$44.5 b	-10.0
Crop Capital	$31.9 b	$28.7 b	-10.0
Non-Farm Labor	99.3 m.m. yrs.	99.6 m.m. yrs.	+ 0.3
Livestock Labor	0.45 m.m. yrs.	0.31 m.m. yrs.	-31.1
Crop Labor	0.26 m.m. yrs.	0.09 m.m.yrs.	-65.4
Crop Exports	127 m.m.t.	127.4 m.m.t.	+ 0.3
Livestock Feed	127 m.m.t.	110.3 m.m.t.	-13.1
Land in Forage	69.2 m. acres	49.3 m. acres	-28.8
Land in Crops	240.3 m. acres	260.2 m. acres	+ 8.3
Crop Sector Current Inputs	$10.3 b	$3.8 b	-63.1

solution, contained in Table 8 and the time paths of gross investment in agricultural research, presented in Figures 1 and 2.

The first column of Table 8 reports values of outputs and conventional inputs actually observed in 1982 for the two farm sectors. The second column reports the values for these variables at t = 0 in the optimal solution. The final column is the percentage increase or decrease of the optimal solution over the actual value. 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 pruchased 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 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 homogenous quality. Recall that land was assumed to have a rental value of $40 per acre in the livestock production function. The implicit rental value of an acre of land at t = 0 in the optimal solution is about $60. The assumption of homogenous land causes a shift away from forage production at the higher rental rate. In a world with variations in land quality, this adjustment would be less pronounced.

Conceptually, the time series depicted in Figures 1 and 2 can be broken into 5 phases. The first five observations (1977-1981) are actual real expenditures taken from Table A-2. The peak in year 1982 is the first period of the optimization model's solution. Chronic underfunding has led to a stock of research which is too small and the model corrects this imbalance immediately. This instant correction arises from the treatment of output from the non-farm sector as a homogenous completely mallable resource. There is no acknowledgement that certain specialized forms of human and physical capital can be accumulated only gradually. In practice, this initial "topping up" would need to be spread out over several years. It should be recognized, however, that this burst of investment occurs as research competes with other investment and consumption opportunities in the economy.

The third phase of the time series covers 1983-1990, and is 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. It would seem that while public funding of farm research has erred on the side of miserliness, farmers have accumulated capital assets in excess of an efficient level in this model. These assets can only leave the sector through depreciation, and while they are present the productivity of public research is artificially high. After 1990, gross capital formation becomes positive and the fourth phase of the time series is entered. This period extends to about 2003 and 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

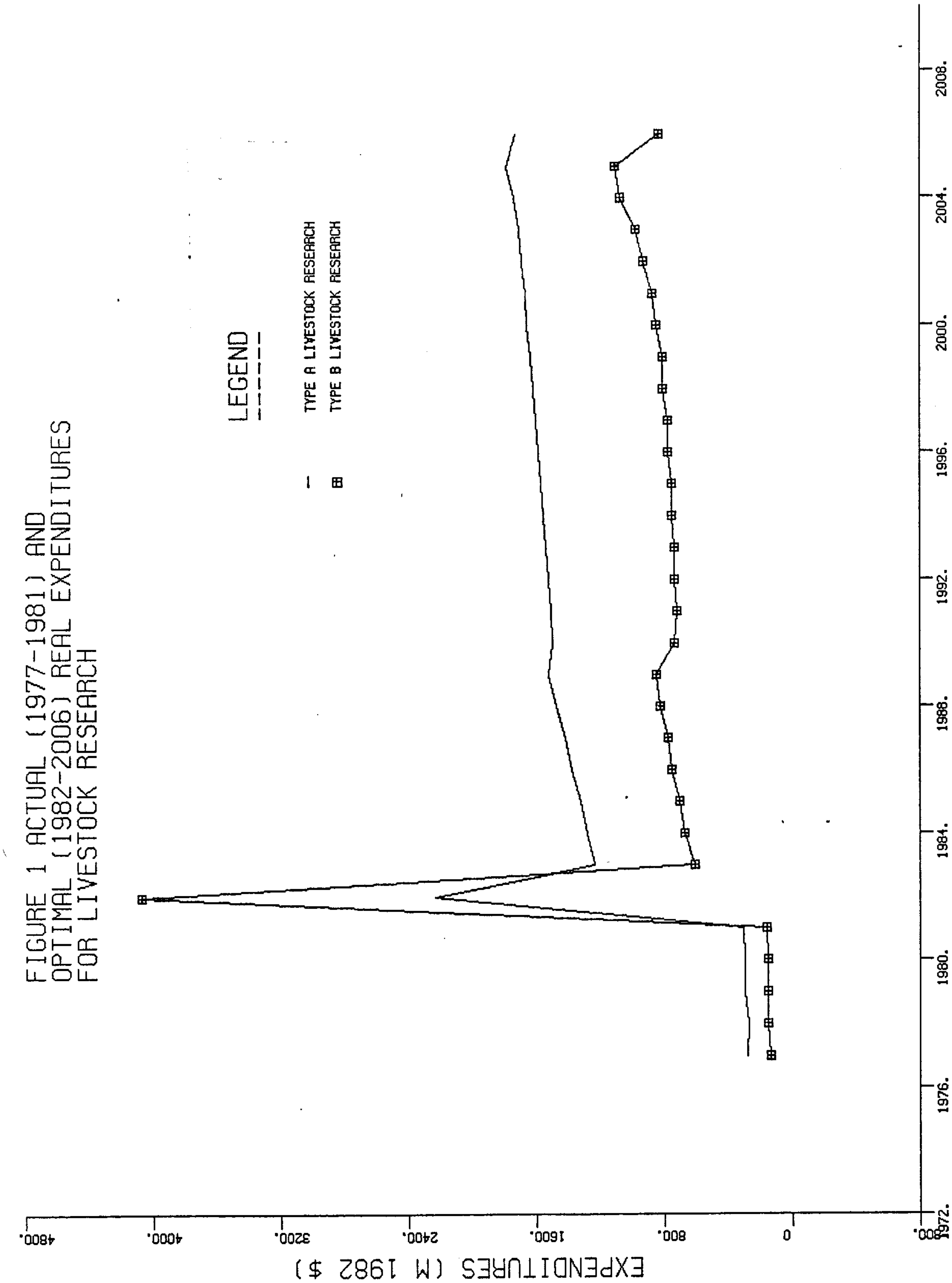

FIGURE 1 ACTUAL (1977-1981) AND OPTIMAL (1982-2006) REAL EXPENDITURES FOR LIVESTOCK RESEARCH

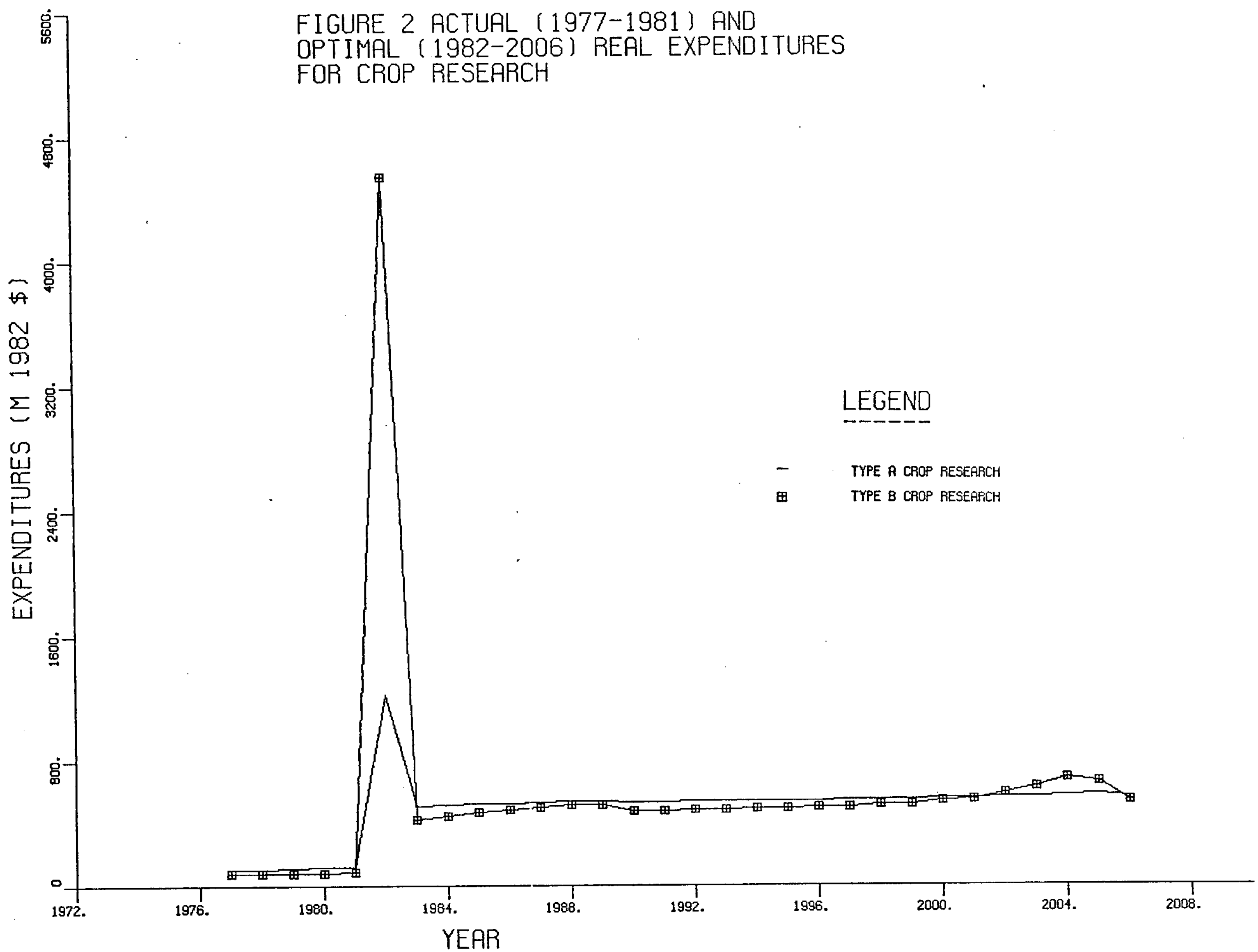

FIGURE 2 ACTUAL (1977-1981) AND OPTIMAL (1982-2006) REAL EXPENDITURES FOR CROP RESEARCH

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 Type A and Type B amounted to 1.9% 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.

Sensitivity Analysis

Because output elasticities and rates of obsolescence were found to vary across the four research categories, one could expect different degrees of responsiveness of optimal research investments to variations in parameters of the growth model. Two of the more important parameters are the size of the excess burden of the tax collection system and the rate of technical change in the rest of the economy.

The magnitude of the excess burden of collecting an incremental dollar of tax remains controversial. In the reference solution, the midpoint of the range of values reported by Ballard, et al. (1985), was used. The model was re-run with higher and lower values of the marginal excess burden, and an elasticity of research investment with respect to τ was computed.

This parameter, η^{τ}, is defined as

$$\eta^{\tau} \equiv \frac{\%\,\Delta \text{ Research Investment}}{\%\,\Delta\ \tau}$$

The percentage change in the research investment is an average over the 25-year horizon. A 1% change in τ resulted in an average and opposite change of 0.81% in both types of livestock research investment and 0.95% in crop research investments. Clearly, more precise knowledge of the extent of the deadweight loss imposed by the present tax system is required to establish an optimal research budget. However, even if the value of τ is in the upper range of the estimates of Ballard, <u>et al.</u>, this would reduce the optimal level of research expenditure by less than 10%.

In the reference solution, the rate of technial change in the non-farm sector (θ) was assumed to be 2% per year. The effect of this parameter on investment in farm-sector research is ambiguous. On the one hand, a higher rate of technical change increases the rate at which output of the non-farm sector grows. This reduces the opportunity cost of investment in research. At the same time, increasing θ raises the marginal utility product of capital investment in the non-farm sector, which would tend to inhibit research investments in the farm sector.

The effects of variations in θ are expressed in elasticity form. η_t^θ is the percentage change in agricultural research expenditure in time t for a 1% change in θ (that is, to increase θ from 1.02 to 1.0202). Because the effect of θ acts exponentially, changes in the parameter have almost no effect on research investment for $t = 0$, and a maximum effect for $t = 25$. The net effect of changing θ results in negative values of η_{25}^θ for both the livestock and crop research. Livestock research categories were more sensitive to variations in θ, with $\eta_{25}^\theta = -0.25$

for basic and applied research variables. Crop research was less sensitive, with $\eta_{25}^{\theta} = -0.074$ for both categories of research.

Evaluating the Hypotheses

1. The Hypothesis of Underinvestment

There is a long history of claims that public investment in agricultural research in the United States is too meager. Elsewhere (Fox, 1985b), I have argued that the analytical reasoning underlying these claims is weak. The findings of the study indicate, however, that the claims of underinvestment appear to be correct in diagnosis, if for the wrong reasons. Figures 1 and 2 clearly 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. The Hypothesis of Neglect of Basic Research

The view that basic research has been neglected in past budget allocations is treated in this context as something separate from across the board underinvestment. If chronic underinvestment is confirmed in the evaluation of the first hypothesis, then the second hypothesis claims that the underinvestment problem is more severe for type B research. This was not found to be the case. In fact the optimal investment level for Type A livestock research was larger relative to 1982 actual expenditure than was the case for Type B livestock research. The opposite was true for the case of crop research. Neither for crop nor for livestock research, however, did type A or type B appear to be severely <u>relatively</u> underfunded.

3. The Hypothesis of Neglect of Crop Research

Again treating this hypothesis as something independent of hypothesis 1, the claim is that even if overall funding is inadequate, crop research should suffer 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. Furthermore, the difference in the value of η^{τ} between crops and livestock is important here. If τ is less than 1.35, the effect of η^{τ} would be to increase optimal crop research levels relative to livestock. Obviously if $\tau > 1.35$, the evidence supporting this hypothesis is weakened.

IV. Conclusions

This paper has examined three claims of inefficiency of the U.S. public agricultural research system that have been frequently expressed in the agricultural research policy literature. These claims are that

1. The overall level of public investment in agricultural research is less than what would be socially optimal.
2. 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.
3. The allocation of research resources among commodities is inconsistent with economic efficiency.

The results of this study indicate a substantial degree of underinvestment in each of the four categories of agricultural research included in the model. In the first year of the optimal solution, research expenditure increased dramatically relative to recent funding patterns. This jump in spending reflected an attempt to compensate for an extended period of inadequate levels of investment. Subsequent to this year, optimal expenditure levels for each of the four research categories were on the order of four times recent actual expenditure.

The claim that basic research has suffered more acutely from underinvestment was not supported by the results of the model. In the case of livestock research, funding for the applied research categories increased proportionally more than funding for basic research. Rates of obsolescence for applied research were found to be considerably higher than those for basic research. Therefore, higher expenditure levels are required to maintain a given research stock.

Weak support was found for the claim that research on crops has been more seriously underfunded than has research on livestock. The extent of this differential is not large, however, and could even be reversed for some combination of values for the marginal excess burden of the tax system and the rate of technical change in the non-farm sector. Support for the third hypothesis listed above 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.

A major factor motivating this paper was the discovery that earlier claims of inadequate levels of public funding of the U.S. agricultural research system were based on incorrect reasoning. Previous analyses have failed to account for the deadweight loss imposed by tax instruments or to represent adequately the social opportunity cost of investment funds. The present analysis incorporates both of these features in a dynamic general equilibrium framework. Somewhat unexpectedly, the results of this more comprehensive modeling effort have confirmed the conclusion of underinvestment overall. Charging a public project with not only the cash costs of the project but also with the implied excess burden of the tax system would make a project less appealing than when this adjustment is not made. Similarly, if public projects are made to compete with the social rates of return to private investments, those projects will in general look less appealing than when the standard of comparison is the private rate of return to private investments. It would seem to be a paradox, then, that the underinvestment hypothesis has been confirmed in this study when these factors have been taken into account. The apparent paradox can be resolved by appealing to two artifacts of the analysis. First, the estimation of the research output elasticities in the farm-sector production functions departed from standard practice in two ways. Rather than adopt the conventional finite polynomial lag structure of output response to research investments, a geometrically decaying stock variable was used. Also, this study separated research investments into "applied" and basic components.

The combined effects of these procedures produced somewhat larger values for the research elasticities than those that have appeared earlier.[6] If the present structure more adequately represents the true effect of research on output, the older studies could be charged with specification bias, but of course, that charge cuts both ways. Ceteris paribus, larger output elasticities result in larger research investments.

A second factor that is important in resolving the paradox attached to the above is that in this model, private agents in the farm sector were implicity able to adjust other inputs in response to changes in public research. These adjustments were not permitted in earlier work, but they act to enhance the attractiveness of research investments.

Table A-1

Estimated Multi-factor Productivity Indexes for Crops and Livestock, 1944-1983

	Crop Sector	Livestock Sector
1944	62.1530	63.3260
1945	62.5990	63.3260
1946	63.3305	63.7720
1947	63.6739	63.7720
1948	64.9673	64.2180
1949	65.4044	64.2180
1950	66.4837	64.6640
1951	66.5595	65.1100
1952	68.2855	65.5560
1953	68.1205	66.0020
1954	68.7092	66.4480
1955	69.4407	66.8940
1956	70.7787	67.3400
1957	72.2415	67.7860
1958	76.3269	68.6780
1959	76.0771	70.0160
1960	78.9048	70.4620
1961	78.8379	71.8000
1962	79.9127	72.6920
1963	81.2329	74.0300
1964	81.7057	75.3680
1965	84.0784	76.2600
1966	84.5467	78.0440
1967	84.4887	79.8280
1968	86.3708	80.7200
1969	87.9363	82.5040
1970	89.4705	84.7340
1971	94.0197	86.5180
1972	95.6744	88.7480
1973	96.6690	90.0860
1974	91.7375	92.7620

(continued)

Table A-1

Estimated Multi-factor Productivity Indexes for Crops and Livestock, 1944-1983 (continued)

	Crop Sector	Livestock Sector
1975	97.6591	94.1000
1976	97.6635	97.6680
1977	100.790	100.790
1978	103.132	104.804
1979	108.707	108.372
1980	103.029	113.724
1981	111.699	116.846
1982	113.461	119.968
1983	103.881	124.874

Source: See Fox (1985a, Chapter 3)

Table A-2

Nominal and Real Expenditures on Research Categories (1949-1983)*
(million $)

	Livestock Research				Crop Research			
Year	Type A Nominal	Type A Real	Type B Nominal	Type B Real	Type A Nominal	Type A Real	Type B Nominal	Type B Real
1944	5.00000	44.9395	3.30000	29.6601	1.50000	13.4819	1.30000	11.6843
1945	6.40000	55.2930	5.00000	43.1977	2.30000	19.8709	2.00000	17.2791
1946	7.80000	61.0042	6.70000	52.4011	3.00000	23.4632	2.80000	21.8989
1947	9.30000	63.9806	8.40000	57.7889	3.80000	26.1426	3.50000	24.0787
1948	10.7000	65.5228	10.1000	61.8486	4.60000	28.1687	4.20000	25.7192
1949	12.1000	71.3516	11.8000	69.5825	5.30000	31.2532	5.00000	29.4841
1950	13.5000	77.3560	13.5000	77.3560	6.10000	34.9535	5.70000	32.6614
1951	13.9000	73.2461	13.9000	73.2461	6.40000	33.7248	5.90000	31.0901
1952	14.8000	74.8054	14.7000	74.3000	7.10000	35.8864	6.00000	30.3265
1953	17.6000	86.7929	17.7000	87.2861	7.60000	37.4788	6.60000	32.5473
1954	20.4000	97.7884	20.6000	98.7471	8.10000	38.8277	7.10000	34.0342
1955	23.1000	108.172	23.6000	110.513	8.70000	40.7401	7.70000	36.0574
1956	25.9000	115.002	26.5000	117.666	9.20000	40.8502	8.20000	36.4100
1957	28.7000	121.620	29.5000	125.010	9.70000	41.1051	8.80000	37.2913
1958	29.5000	122.222	33.7000	139.623	9.80000	40.6026	10.5000	43.5029

(continued)

Table A-2

Nominal and Real Expenditures on Research Categories (1949-1983)*
(million $)

	Livestock Research				Crop Research			
Year	Type A Nominal	Type A Real	Type B Nominal	Type B Real	Type A Nominal	Type A Real	Type B Nominal	Type B Real
1959	30.3000	122.575	37.8000	152.915	9.80000	39.6446	12.2000	49.3535
1960	31.1000	122.694	42.0000	165.696	9.90000	39.0568	13.9000	54.8373
1961	39.5000	151.803	40.2000	154.493	11.6000	44.5800	14.5000	55.7250
1962	47.8000	177.282	38.4000	142.419	13.3000	49.3273	15.0000	55.6323
1963	56.2000	203.360	36.6000	132.437	15.0000	54.2776	15.5000	56.0869
1964	64.5000	227.845	34.7000	122.577	16.7000	58.9926	16.0000	56.5198
1965	72.6000	249.346	39.3000	134.976	18.8000	64.5689	18.2000	62.5082
1966	80.7000	263.754	43.9000	143.480	20.9000	68.3081	20.3000	66.3471
1967	78.8000	242.604	42.9000	132.077	22.3000	68.6557	21.7000	66.8084
1968	80.5000	234.862	39.3000	114.659	21.6000	63.0188	26.1000	76.1478
1969	82.5000	224.259	41.4000	112.537	23.6000	64.1517	27.1000	73.6657
1970	90.2000	226.925	42.8000	107.676	27.5000	69.1845	23.5000	59.1213
1971	97.6000	229.726	46.5000	109.449	31.5000	74.1431	25.2000	59.3145
1972	105.100	234.268	49.6000	110.558	35.7000	79.5753	27.5000	61.2975
1973	112.300	233.941	54.1000	112.700	38.7000	80.6190	30.8000	64.1619

(continued)

Table A-2

Nominal and Real Expenditures on Research Categories (1949-1983)*
(million $)

	Livestock Research				Crop Research			
Year	Type A Nominal	Type A Real	Type B Nominal	Type B Real	Type A Nominal	Type A Real	Type B Nominal	Type B Real
1974	127.600	241.034	58.4000	110.317	43.4000	81.9819	33.0000	62.3364
1975	141.900	244.432	64.3000	110.761	50.8000	87.5063	36.2000	62.3569
1976	162.000	261.098	75.3000	121.362	59.7000	96.2193	43.9000	70.7542
1977	186.400	279.977	91.4000	137.285	67.4000	101.236	52.9000	79.4569
1978	196.400	274.124	102.800	143.482	77.2000	107.751	59.2000	82.6279
1979	231.500	297.072	118.500	152.065	86.7000	111.258	63.8000	81.8712
1980	256.500	298.558	133.855	155.855	99.8000	116.164	71.5000	83.2238
1981	284.000	304.198	150.200	160.882	113.000	121.037	82.4000	88.2603
1982	291.500	291.500	161.500	161.500	123.100	123.100	86.8000	86.8000
1983	307.800	289.977	167.100	157.424	134.100	126.335	95.0000	89.4992

*Source: See Fox (1985a, Chapter 3)

Table A-3

Time Series Data for Extension Expenditures, Education Index, Weather Index and Real Expenditure Index, 1944-1983

Year	Extension Expenditure (m $)	Education Index	Weather Index	Real Expenditure Index
1944	36.3	101.6	100.093	8.99
1945	38.2	103.0	100.094	8.64
1946	44.6	104.4	100.068	7.82
1947	53.7	105.8	100.037	6.88
1948	60.2	107.2	100.043	6.12
1949	67.2	108.6	99.9569	5.90
1950	74.6	110.0	99.9775	5.73
1951	77.6	113.0	99.9391	5.27
1952	81.8	116.0	99.9561	5.05
1953	86.8	118.0	99.8993	4.93
1954	91.6	119.0	99.9018	4.79
1955	100.7	120.0	99.9217	4.68
1956	110.1	121.0	99.9327	4.44
1957	118.2	122.0	99.9588	4.24
1958	128.7	124.4	100.065	4.14
1959	136.0	129.5	99.9485	4.05
1960	141.7	129.2	100.008	3.95
1961	149.4	131.0	100.013	3.84
1962	159.2	133.0	100.028	3.71
1963	168.6	134.0	100.025	3.62
1964	177.9	135.0	99.9652	3.53
1965	188.9	138.0	100.059	3.43
1966	201.2	142.6	100.022	3.27
1967	213.7	146.4	100.019	3.08
1968	225.5	150.3	100.063	2.92
1969	242.0	153.7	100.104	2.72
1970	290.7	157.2	99.9961	2.52
1971	331.9	161.6	100.11	2.35
1972	354.4	166.0	100.122	2.23
1973	385.1	169.2	100.046	2.08

(continued)

Table A-4

Time Series Data for Extension Expenditures,
Education Index, Weather Index and Real
Expenditure Index, 1944-1983
(continued)

Year	Extension Expenditure (m $)	Education Index	Weather Index	Real Expenditure Index
1974	417.8	173.2	99.8160	1.89
1975	453.3	180.0	99.9641	1.72
1976	491.9	188.1	99.9174	1.61
1977	533.7	196.1	99.9819	1.50
1978	579.1	204.1	100.007	1.40
1979	628.3	212.0	100.101	1.28
1980	681.7	207.9	99.8861	1.16
1981	739.6	203.8	100.034	1.07
1982	802.5	199.7	100.072	1.00
1983	870.7	195.6	99.8497	0.94

Sources: Extension - Peterson and Fitzharris (1977)
Education - Cline (1975)
Weather - See Fox (1985a, Chapter 3)
Real Expenditure Index - Calculations based on Index of Prices Paid by State and Local Governments, <u>Economic Report of the President</u> (1984).

Footnotes

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1/ Hirshleifer (1971) has shown that knowledge as an intermediate input has important qualities that differ from knowledge as a consumption good. When knowledge is an input, the relevant question is not if any one agent's acquisition of knowledge reduced the pool of knowledge available, but rather if the ability of any agent to exploit that knowledge in related factor or product markets is influenced by who else possesses that knowledge.

2/ The technology of exclusion has improved dramatically since 1862, as techniques have become available to identify the genetic heritages of plant material suspected of infringing on plant breeder's proprietary rights. Such enforcement mechanisms undergird legislation such as the

Plant Variety Protection Act of 1970. See Ruttan (1982; pp. 195-196) for a more extended discussion.

3/ See Ruttan (1982, Chapter 10) for a review of studies that have estimated social rates of return to publicly funded agricultural research.

4/ See R.W. Howard (1985) The Vanishing Land and W. Jackson, W. Berry and B. Zolman (eds.) (1985) Meeting the Expectations of the Land.

5/ Dr. Michael Saunders of the Systems Optimization Laboratory was most helpful in the implementation of MINOS.

6/ Davis (1979) reports elasticities in the range 0.008 to 0.069 (Table 4.6, p. 68) but his model is estimated with cross-section data and employs a considerably different lag structure than the present study.

References

Ballard, C. L., J. B. Shoven, and J. Whalley. "General Equilibrium Calculations of the Marginal Welfare Costs of Taxes in the United States." American Economic Review 75(1)(March 1985): 128-138.

Beach, C. M. and J. G. MacKinnon. "A Maximum Likelihood Procedure for Regression with Autocorrelated Errors." Econometrica 46 (1)(Jan. 1978):51-88.

Bonnen, J. T. "Historical Sources of U.S. Agricultural Productivity: Implications for R&D Policy and Social Science Research." American Journal of Agricultural Economics 65(5)(Dec. 1983): 958-66.

Boyce, J. K. and R. E. Evenson. National and International Agricultural Research and Extension Programs. New York: Agricultural Development Council, 1975.

Bredahl, M. E., W. H. Meyers and K. J. Collins. "The Elasticity of Foreign Demand for U.S. Agricultural Products: The Importance of the Price Transmission Elasticity." American Journal of Agricultural Economics 61(1)(Feb. 1979):58-69.

Browning, E. V. "The Marginal Cost of Public Funds." Journal of Political Economy 84(2)(April 1976):283-98.

Carson, R. Silent Spring. Boston: Houghton Mifflin, 1962.

Cline, P. L. "Sources of Productivity Change in United States Agriculture." Ph.D. dissertation, Oklahoma State University, 1975.

Davis, J. S. "Stability of the Research Production Coefficient for U.S. Agriculture." Ph.D. dissertation, University of Minnesota, 1979.

Economic Report of the President. Washington, D.C: U.S. Government Printing Office, February 1984.

Ellingson, D. and W. Peterson. "The Allocation of Research Personnel: Administrators' Response to Expected Rates of Return." Staff Paper P81-29, Department of Agricultural and Applied Economics, University of Minnesota, Nov. 1981.

Evenson, R. E., P. E. Waggoner and V. W. Ruttan. "Economic Benefits from Research: An Example from Agriculture." Science 205 (14 Sept. 1979):1101-7.

Fox, G., "Optimal Public Investment in U.S. Agricultural Research: A Study in the Management of Technical Change" Ph.D. Dissertation, University of Minnesota, 1985a.

Fox, G. "Is the United States Really Underinvesting in Agricultural Research? American Journal of Agricultural Economics, forthcoming, 1985b.

Garren, M. M. "The Efficient Allocation of Agricultural Research Investment with Externality Considerations." Ph.D. disseration, University of Georgia, 1981.

Garren, M. M. and F. C. White. "An Analytical Framework for the Efficient Allocation of Agricultural Research Expenditures by States." Agricultural Administration 8(4)(July 1981):279-87.

Gill, P. E., W. Murray and M. H. Wright. Practical Optimization. New York: Academic Press, 1981.

Hadwiger, O. F. The Politics of Agricultural Research. Lincoln: University of Nebraska Press, 1982.

Havlicek, J. "Interregional Transfer of Agricultural Research Results: The Case of the Northeast." Journal of the Northeastern Agricultural Economics Council 12(2)(Fall 1983):19-30.

Hightower, J. Hard Tomatoes, Hard Times. Cambridge, Mass.: Schenkman Publishing Co., 1978.

Hirshleifer, J. "The Private and Social Value of Information and the Reward to Inventive Activity." American Economic Review 61(4) (Sept. 1971):561-74.

Howard, R. W. The Vanishing Land. New York: Villard Books, 1985.

Jackson, W., W. Berry and B. Colman, eds. Meeting the Expectations of the Land. San Francisco: North Point Press, 1985.

Johnson, P. R. "The Elasticity of Foreign Demand for U.S. Agricultural Products." American Journal of Agricultural Economics 59(4) (Nov. 1977):735-36.

Judd, M. A., J. K. Boyce and R. E. Evenson. "Investing in Agricultural Supply." Discussion Paper No. 442, Economic Growth Center, Yale University.

Knoblach, M. C., E. M. Law and W. P. Meyer. State Agricultural Experiment Stations: A History of Research Policy and Procedure. Miscellaneous Publication No. 904, U.S. Department of Agriculture 1962.

Kula, E. "Derivation of Social Time Preference Rates for the United States and Canada." Quarterly Journal of Economics 99(4) (Nov. 1984):873-82.

Murtagh, B. A. and M. A. Saunders. MINOS User's Guide. Systems Optimization Laboratory, Stanford University, Stanford, Calif., 1977.

__________. MINOS/Augmented User's Manual. Systems Optimization Laborabory, Stanford University, Stanford, Calif., 1980.

__________. MINOS 5.0. User's Guide. Technical Report SOL 83-20, Systems Optimization Laboratory, Department of Operations Research, Stanford University, Stanford, Calif., 1983.

Peterson, W. L. and J. C. Fitzharris. "Organiztion and Productivity of the Federal-State Research System in the United States." In Resource Allocation and Productivity in National and International Agricultural Research, edited by T. M. Arndt, D. G. Dalrymple and V. W. Ruttan, Minneapolis: University of Minnesota Press, 1977.

Ruttan V. W. Agricultural Research Policy. Minneapolis: University of Minnesota Press, 1982.

__________. "Agricultural Research Policy Issues." Hort Science 108 (6)(Dec. 1983):809-18.

Salmon, D. C. "Congruence of Agricultural Research in Indonesia, 1974-1978." Bulletin 83-1, Economic Development Center, University of Minnesota, 1983.

Stuart, C. "Welfare Costs per Dollar of Additional Tax Revenue in the United States." American Economic Review 74(3)(June 1984):352-62.

Takayama, A. Mathematical Economics. Hinsdale, Ill.: Dryden Press, 1974.

True, A. C. A History of Agricultural Experimentation and Research in the United States 1607-1925. Miscellaneous Publication No. 251, U.S. Department of Agriculture, Washington, D.C., 1937.

Tweeten, L. "The Demand for United States Farm Output." Food Research Institute Studies 7(3)(1967):343-69.

__________. "The Elasticity of Foreign Demand for U.S. Agricultural Products: Comment." American Journal of Agricultural Economics 59(4)(Nov. 1977):737-38.

U.S., Department of Agriculture. A National Program of Research for Agriculture. Report of a study by the Association of State Universities and Land Grant Colleges and the U.S. Department of Agriculture, October 1966.

________. Economic Indicators of the Farm Sector: Income and Balance Sheet Statistics, 1983, Sept. 1984.

________. Economic Indicators of the Farm Sector: Production and Efficiency Statistics, 1983, Feb. 1985.

________. Food Consumption, Prices and Expenditures, 1963-1983. Statistical Bulletin No. 713, Nov. 1984.

White, F. C. and J. Havlicek, Jr. "Interregional Spillover of Agricultural Research Results and Intergovernmental Finance: Some Preliminary Results." In Evaluation of Agricultural Research, edited by G. W. Norton, et al., Miscellaneous Publication 8-1981, Minnesota Agricultural Experiment Station, University of Minnesota, 1981.

Ziemer, R. F., F. C. White and P. L. Cline. Regional Welfare and Agricultural Research and Extension in the U.S." Agricultural Administration 9(3)(March 1982):167-78.