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A MODEL OF OPTIMAL PUBLIC INVESTMENT IN
U.S. AGRICULTURAL RESEARCH: FURTHER RESULTS

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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. Analysts of research policy had claimed 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 developed 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

A broad concensus has emerged that public expenditures on agricultural research have generated social benefits in excess of social costs. (See Ruttan (1982, Chapter 10)). 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 increased in real terms by 10% annually until total expenditure is tripled. These estimates, while useful as preliminary indications of the magnitude of underinvestment, suffer from some important limitations. None of these studies incorporate the full opportunity cost of public funds. Fox (November 1985), has demonstrated that the costs of distortions induced by tax collection can have important consequences for 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.

In addition to claiming that research levels have been inadequate, several authors have suggested that the composition of research effort may be incorrect. Ruttan (1983) and Judd, Boyce and Evenson (1983) have suggested that the allocation of research effort among commodities 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 was unchanged. True (1937), Knoblach <u>et al.</u> (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.[1] Economic analysis of both of these claims has been limited. (See Fox, Evenson and Ruttan, 1987).

The purpose of this study is to estimate the extent to which agricultural research has been underfunded in the United States and to test for the existence of both commodity bias and the neglect of basic research in recent funding allocations. A dynamic general equilibrium optimal growth model is used as the framework for analysis. Efforts are made to reflect the true social opportunity cost of 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 gross sales in U.S. agriculture in 1982.

II. DESCRIPTION AND ESTIMATION OF MODEL

A three sector general equilibrium optimal growth model was used to study the three propositions discussed above. Consumption of the 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, and 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. A summary of the model is presented in Table 1.

The Criterion Function

The model allocates public and private resources 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[3] is

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

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

Table 1: Summary of the Growth Model

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

Subject to

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

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

$$F_{2t}(\cdot) - C_{2t} - X_{2t} - F_{1t} \geq 0$$

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

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

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

$$L_{0t} + L_{1t} + L_{2t} \leq \bar{L}_t$$

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

for $t = 0, 1, 2, \text{---} \infty$

Table 1 continued

Notation

C_{it}	- Consumption of output of sector i in period t
β	- 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
$\varepsilon_{Ai}, \varepsilon_{Bi}$	- 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

expenditure shares data.[4] The share of net national income devoted to the farm value of livestock and grain products fell systematically from 1963-1982. 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 gives a value of 0.9497 for β.

The 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]

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 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. 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 for the non-farm sector, the period by period constraints on C_{0t} can be written as

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

The coefficient τ indicates that the marginal social opportunity cost of public funds exceeds one. 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. Ballard et al. (1985) have produced estimates of τ in the range of 1.2 to 1.5 for the United States.

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 function indirectly through feed purchases.

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 $2,109 in 1982. A metric ton of dressed beef was worth $2,935. 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. This assumption is based on the observation that livestock product exports from the United States are small relative to crop exports. The largest category of livestock products exported in 1980-1984 was hides and skins, ranging from $1.0-1.4 billion annually.

(USDA, Agricultural Statistics). As a result, the constraint on C_{1t} is

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

Output of the crop sector, Y_{2t}, 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, general research, as well as capital, current purchased inputs such as pesticides, fuel and fertilizer, land, and labor. Output for this sector can either be consumed, exported or fed to livestock, so the constraint on C_{2t} is

$$F_{2t}(\cdot) - C_{2t} - X_{2t} - F_{1t} \geq 0$$

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. Capital depreciation is assumed to be 10% per annum in each sector, so $\delta = 0.90$. It follows then that

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

and,

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

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

Note that each of the four research categories has a separate rate of depreciation. 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 three sectors cannot exceed some upper limit, $\bar{L}_t$, and that total land in crops and forages cannot exceed $\bar{N}_t$. That is

$$L_{0t} + L_{1t} + L_{2t} \leq \bar{L}_t$$

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

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 estimate are independent.

Inadequate time series data on input use by sector in agriculture preclude 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. The factor shares approach to estimation of aggregate production functions has been used by 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) examined the degree to which observed factor shares correspond to equilibrium factor shares in U.S. agriculture. They found that, between 1911 and 1976, the average difference between observed and equilibrium factor shares was less than 6%, and concluded that the factor shares approach was an empirically valid technique for estimation of production function parameters.

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 and livestock. In these instances, use is made of commodity level data in the input of Economic Indicators of the Farm Sector: Costs of

<u>Production</u>. The output elasticity for capital in the non-farm sector was estimated using the national income accounts. 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. This indicates a higher factor share for labor than that estimated by Cobb and Douglas (1928) and by Douglas (1948) for the U.S. economy but is consistent with the trend of an increasing factor share for labour reported by Kravis (1959). The hypothesis of constant returns to scale was supported by this early empirical work and was later reaffirmed at a less aggregate level by Dhrymes (1965), in his work on industry level production functions.

Factor share estimates for the crop sector are based on budget data on crop input costs reported in various issues of <u>Economic Indicators of the Farm Sector: Costs of Production</u>. 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.

For the livestock sector, <u>Economic Indicators of the Farm Sector: Income and Balance Sheet Statistics</u> 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. Total acreage devoted to hay and forage production 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 assumed for this input. This results in a value of λ_1 of 0.04. This is an arbitrary 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. Finally, an estimate of the output elasticity of capital in livestock of 0.14 was derived from cost of production data for livestock products.

Efforts to estimate aggregate production functions for U.S. agriculture have a long history but are short on concensus. Griliches (1964), Peterson (1967) and Bredahl and Peterson (1976) used cross-section data to estimate Cobb-Douglas production functions at various levels of aggregation. Tyers et al. (1984) used time-series data for 1949-1981 to estimate a Cobb-Douglas and a Translog functional form of the U.S. and of regional production functions. Chambers and Lee (1986) used time-series data for 1947-1980 to estimate a translog indirect production function for U.S. agriculture. While there is considerable variation in the procedures used in each of these studies and our empirical understanding of the aggregate agricultural production function is imperfect, a few 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. Chambers and Lee (1986) and Lyn et al. (1984) 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 concensus has been achieved on the values of particular output elasticities. Variations in the definitions of categories of inputs make it difficult to compare elasticities across studies.

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

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

If time series data on sectoral inputs were available the estimation of parameters of this function would be straightforward. 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 $g(Z_t)$.

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, E_t is the level of farmer's education and W_{it} is an index of weather conditions. 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.[6] A least squares regression of multi-factor productivity (MFP) on labor productivity (LP) from 1944-1982 produced the equation

$$MFP_t = \underset{(48.5)}{56.19} + \underset{(25.5)}{0.446}\ LP_t$$

Values in parentheses are t-statistics. The value of the adjusted R^2 was 0.94. The coefficients of this equation were used to predict multi-factor productivity indexes for crops and livestock using the appropriate series of labor productivities published by the USDA.

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 applied research investment and of basic research. 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 were eliminated.

Prior to 1968, research expenditures were calculated from data reported in the annual House appropriations hearings for the Department of Agriculture. Estimates of the expenditures 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

(October, 1985). 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 Cline (1975, pp.153-158). 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 was converted to real 1982 dollars using the price deflator for State and Local government purchases of goods and services (<u>Economic Report of the President</u>, 1984, Table B-3, P.225).

Recall that AR_{it} and BR_{it} are stocks of undepreciated research expenditure. It follows, therefore, 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. 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 and crop equations are reported in Table 2. Weather and real extension expenditures did not contribute significantly to the explanation of variation of productivity in the livestock equation and these variables were deleted. Both equations were plagued

Table 2: Coefficients in the Livestock and Crop Sector Productivity Equations

Livestock

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

Crops

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

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, the procedure was not particularly effective. 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. Use of a model which separates basic and applied research has, therefore, led to significantly higher combined elasticity estimates than have been found when research expenditures 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. The findings of this study indicate that through time, the effect of the different research categories translates into sharply different effects on productivity.

The Trade Function

Export volumes of food and feed grains 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 at 1982 prices ranged from less than \$5 billion to over \$18 billion. The representation of the exchange opportunities in the world reflects a decline in the purchasing power of exports at the margin as exports increase. The U.S. is modeled 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. A linear excess demand function is assumed.

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 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.

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 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. 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.[7] Also, it is assumed that $\bar{N}_T$ and $\bar{L}_T$ 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_{0T}, 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) was used to identify an optimal solution to the model.[8] 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. 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 Values for Reference Solution

Variables in the growth model were initialized with 1982 as the base year. 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 Table 3.[9] The total labor force is assumed to remain at 100 million man-years throughout the 25-year horizon of the model. 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 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, 1983). Values of each of the two sub-sectors were determined on the basis of the share of total farm revenue generated in each sub-sector.

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

Table 3: Production Function Variables and Parameters - 1982

Non-Farm Sector

Variable	Value	Elasticity
Output	$2940 b	
Capital Stock	$3231 b	0.18
Labor	99.3 million man-years	0.82
Intercept	15.82	

Livestock Sector

Variable	Value	Elasticity
Output	19.35 m.m.t.	
Value	$56.7 b	
Capital Stock	$44.5 b	0.14
Type A Research	$0.77 b	0.087
Type B Research	$1.41 b	0.06
Feed	127 m.m.t.	0.28
Land	69.2 m. acres	0.04
Labor	0.452 million man-years	0.393
Intercept	3.39	

Table 3 continued

Crop Sector

Variable	Value	Elasticity
Output	293.3 m.m.t.	
Value	$36.66 b	
Capital Stock	$28.7 b	0.130
Type A Research	$0.346 b	0.056
Type B Research	$0.743 b	0.075
Purchased Inputs	$10.3 b	0.28
Land	$240.3 m. acres	0.300
Labor	0.256 million man years	0.159
Intercept	25.67	

will maintain approximately constant real prices for livestock and crop products over the 25-year planning horizon.

<u>Summary of the Reference Solution</u>

A comparison of the actual values of selected variables in 1982 and their corresponding values in the reference solution is presented in Table 4. The final column in the table reports the percentage deviation of the optimal solution from 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 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 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. 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 homogeneous land causes a shift away from forage production at the higher rental rate. With adjustments for variations in land quality, this change in land use patterns would be

Table 4: Comparison of Selected Variables in Reference Solution with 1982 Actual Values

Variable	1982 Actual Value	Reference Solution (t = 0)	% Deviation
Livestock Output	19.50 m.m.t.	19.50 m.m.t.	-
Crop Output	293.3 m.m.t.	252.8 m.m.t.	-13.8
Non-Farm Capital	$3529.0 b	$3523 b	- 0.1
Livestock Capital	$44.5 b	$44.5 b	-
Crop Capital	$29.7 b	$29.7 b	-
Non-Farm Labor	99.30 m.m. yrs.	99.58 m.m. yrs.	+ 0.3
Livestock Labor	0.45 m.m. yrs.	0.33 m.m. yrs.	-26.7
Crop Labor	0.26 m.m. yrs.	0.09 m.m. yrs.	-65.4
Crop Exports	127 m.m.t.	114.1 m.m.t.	-10.2
Livestock Feed	127 m.m.t.	99.9 m.m.t.	-21.3
Land in Forages	69.2 m. acres	48.8 m. acres	-29.5
Land in Crops	240.3 m. acres	260.7 m. acres	+ 8.5
Crop Sector Current Input Purchases	$10.3 b	$4.1 b	-60.2

less pronounced.

Optimal levels of livestock and crop research from 1982 to 2006 are reported in Figures 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 dynamic 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. Two important points should be recognized, however, with respect to the jump in optimal research expenditures in 1982. First, the true opportunity costs of this investment are accounted for in the model, even though adjustment costs are not included. The marginal excess burden of tax collection is charged against research investments, and these funds are obtained in competition with investment demand and consumption. Second, regardless of the true optimal phase in period, a serious problem of underinvestment in agricultural research is indicated for all of the four types of research studied. 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 capital can only leave the sector through depreciation, and until the desired capital stock is achieved the

Figure 1: Optimal Annual Expenditures for Basic and Applied Livestock Research - Reference Solution

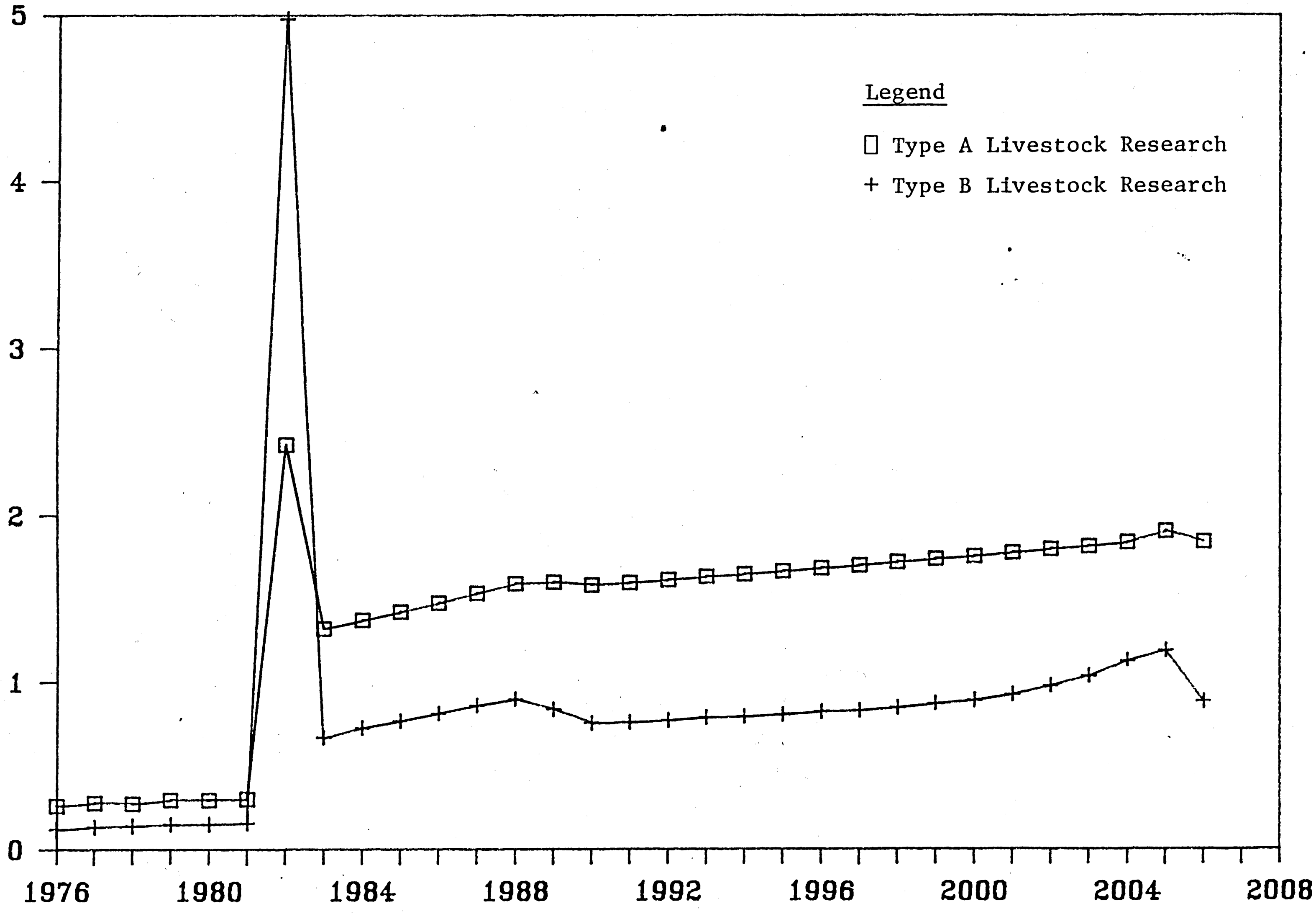
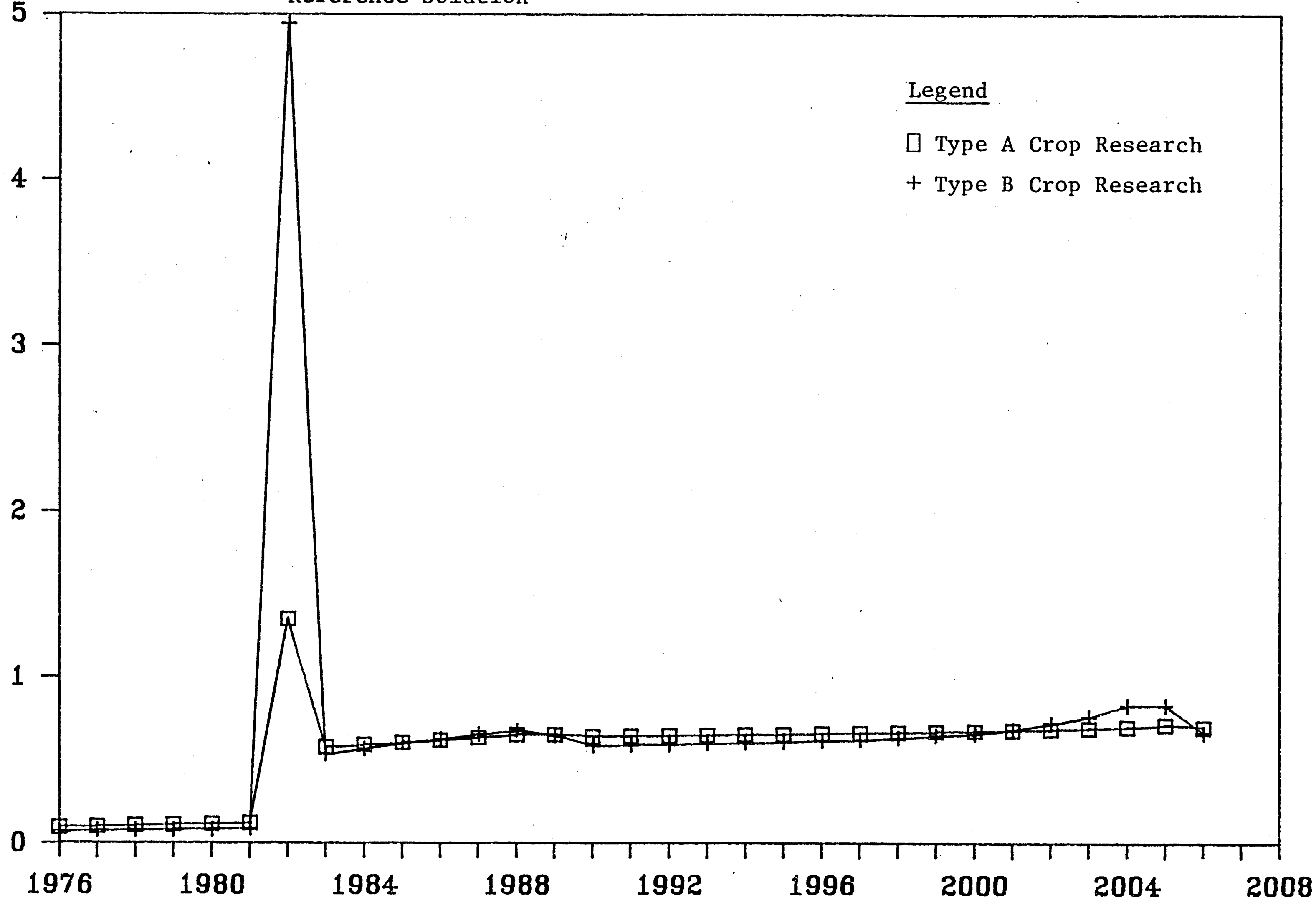


Figure 2: Optimal Annual Expenditures for Basic and Applied Crop Research - Reference Solution



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 Type A and Type B amounted to 1.0 percent and 1.8 percent of the value of the crops produced in the sector. For livestock, the corresponding figures were 3.0 percent and 2.2 percent respectively. These rates of investment can be thought of as long-run equilibrium values.

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

$$\rho = \frac{\tau R_0(\varepsilon-1) + \varepsilon\delta PY_0}{\tau R_0}$$

Values for the research stock of a particular type of research (R_0), the rate of obsolescence (ε), output elasticity (δ) and gross revenues of commodity production (PY_0) are substituted into this expression to obtain estimates for ρ. The marginal excess burden of tax collection, 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 to conventional capital in the U.S. (Fox, 1985b).

The rate of return estimates for the actual 1982 situation are higher than those reported elsewhere in the literature. In his summary of available rate of return estimates, Ruttan (1982, chapter 10) finds a cluster of rates of return at about 50%. However, Evenson (See Ruttan, 1982, p.248) found that separation of research expenditures into applied and basic catagories 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_0. Doubling R_0 goes a long way toward reconciling the rate of return estimates of this study with those obtained elsewhere.

Sensitivity Analysis

The response of the optimal pattern of research expenditures to variations in selected parameters of the growth model was examined in 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 concensus on particular values. Figures 3 through 10 report the results of the simulations. In each figure, optimal research expenditures with the modified parameter is expressed as a proportion of the corresponding optimal expenditure in the reference solution (Figures 1 and 2).

The effects of variations in the excess demand elasticity are shown in Figures 3 to 6. Figures 3 and 4 report simulations when the elasticity is increased to 2.0, and Figures 5 and 6 report the results for an elasticity of 1.0. Both basic and applied crop research change in the direction of the change in the export demand elasticity, as one

Figure 3: The Impact of Increasing the Export Demand Elasticity for Crops on Optimal Crop Research

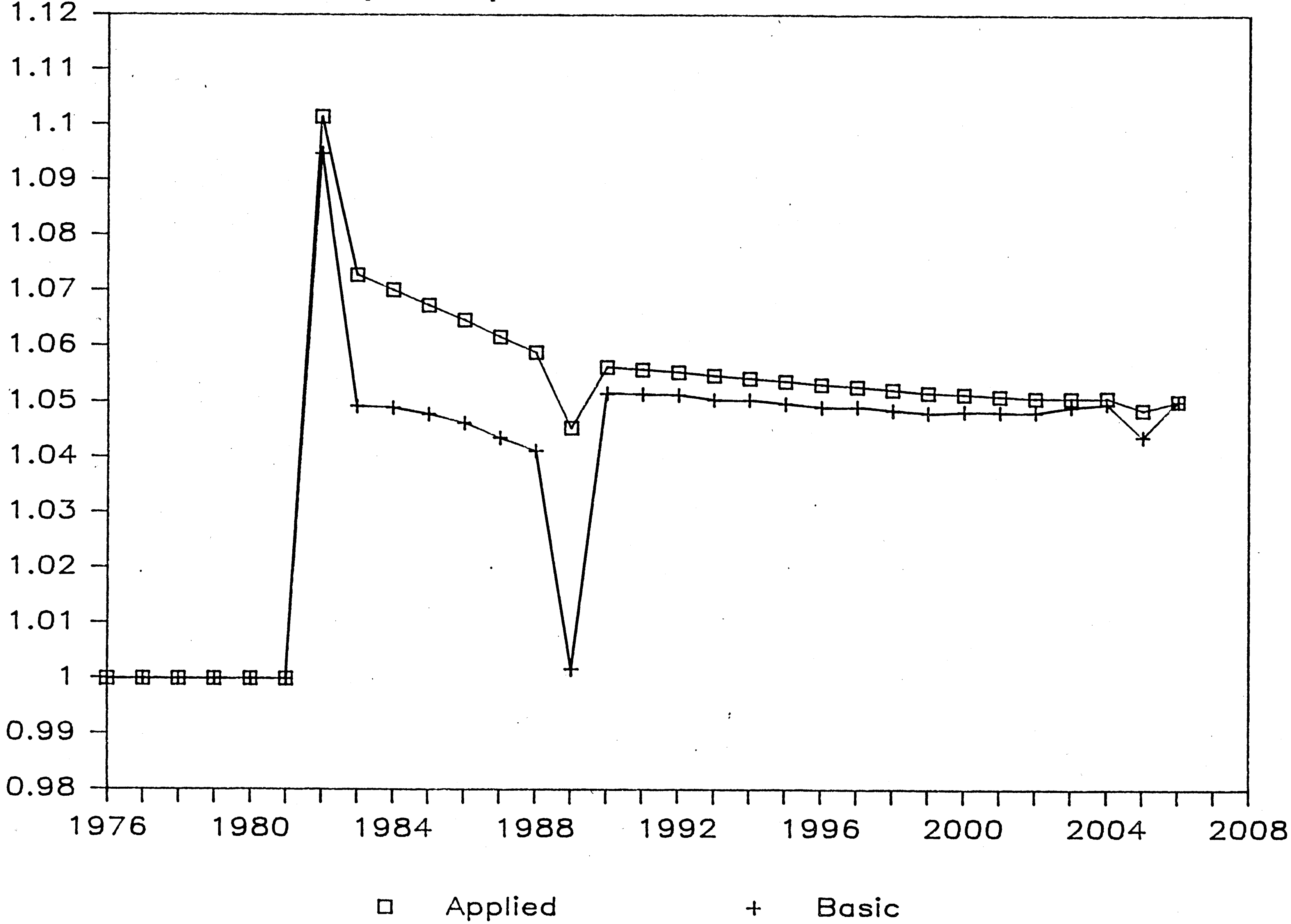


Figure 4: The Impact of Increasing the Export Demand Elasticity for Crops on Optimal Livestock Research

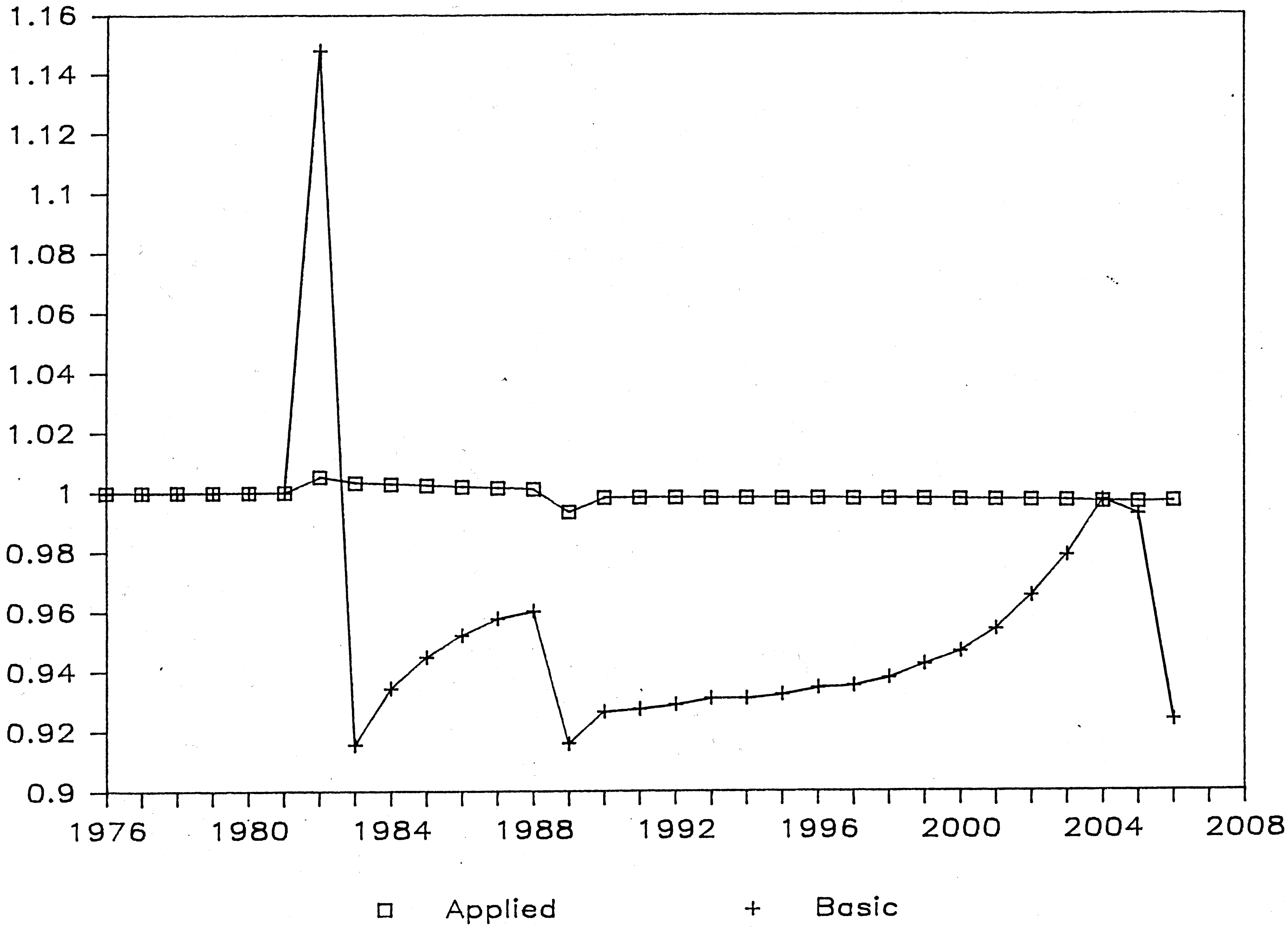


Figure 5: The Impact of Decreasing the Export Demand Elasticity for Crops on Optimal Crop Research

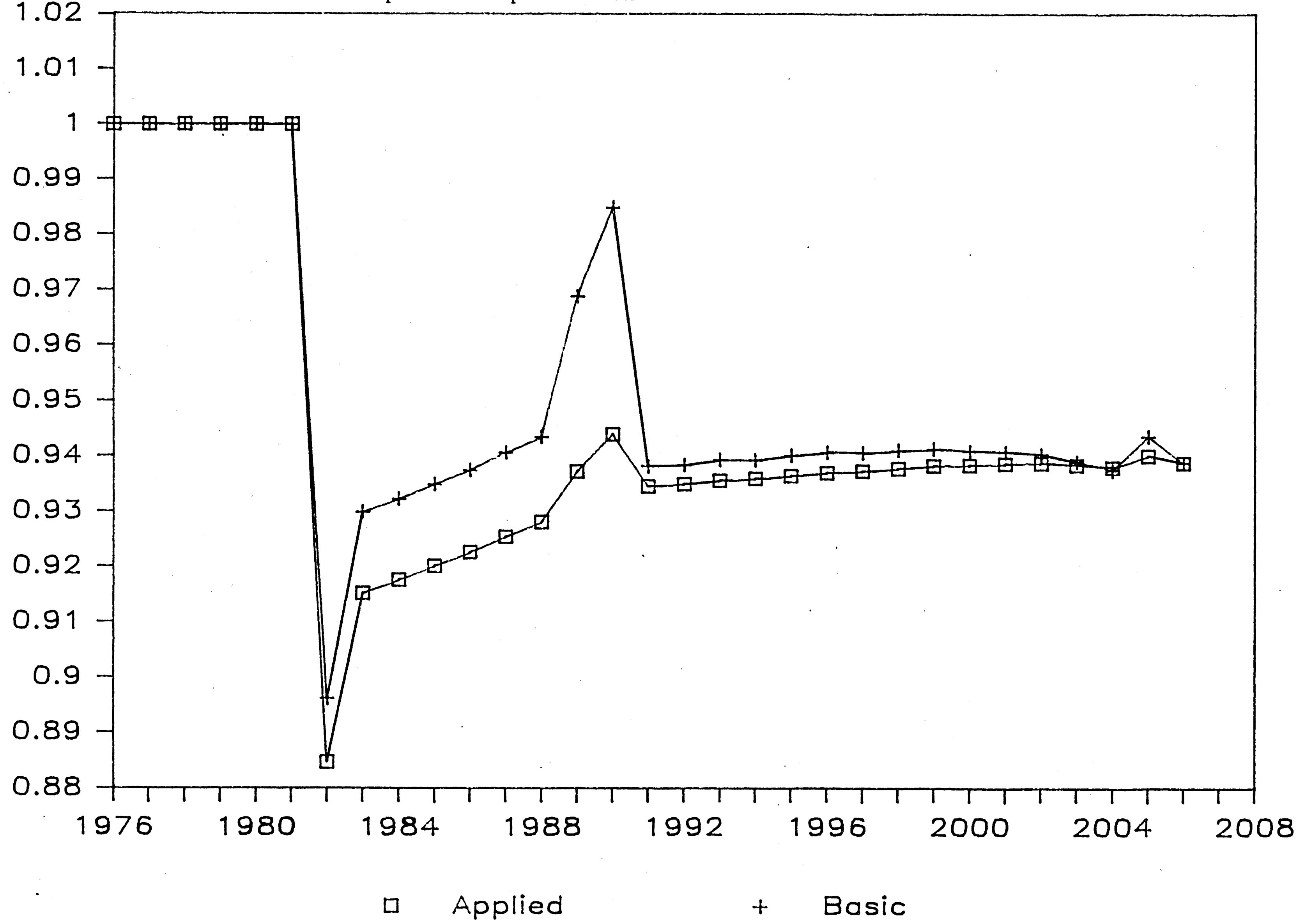
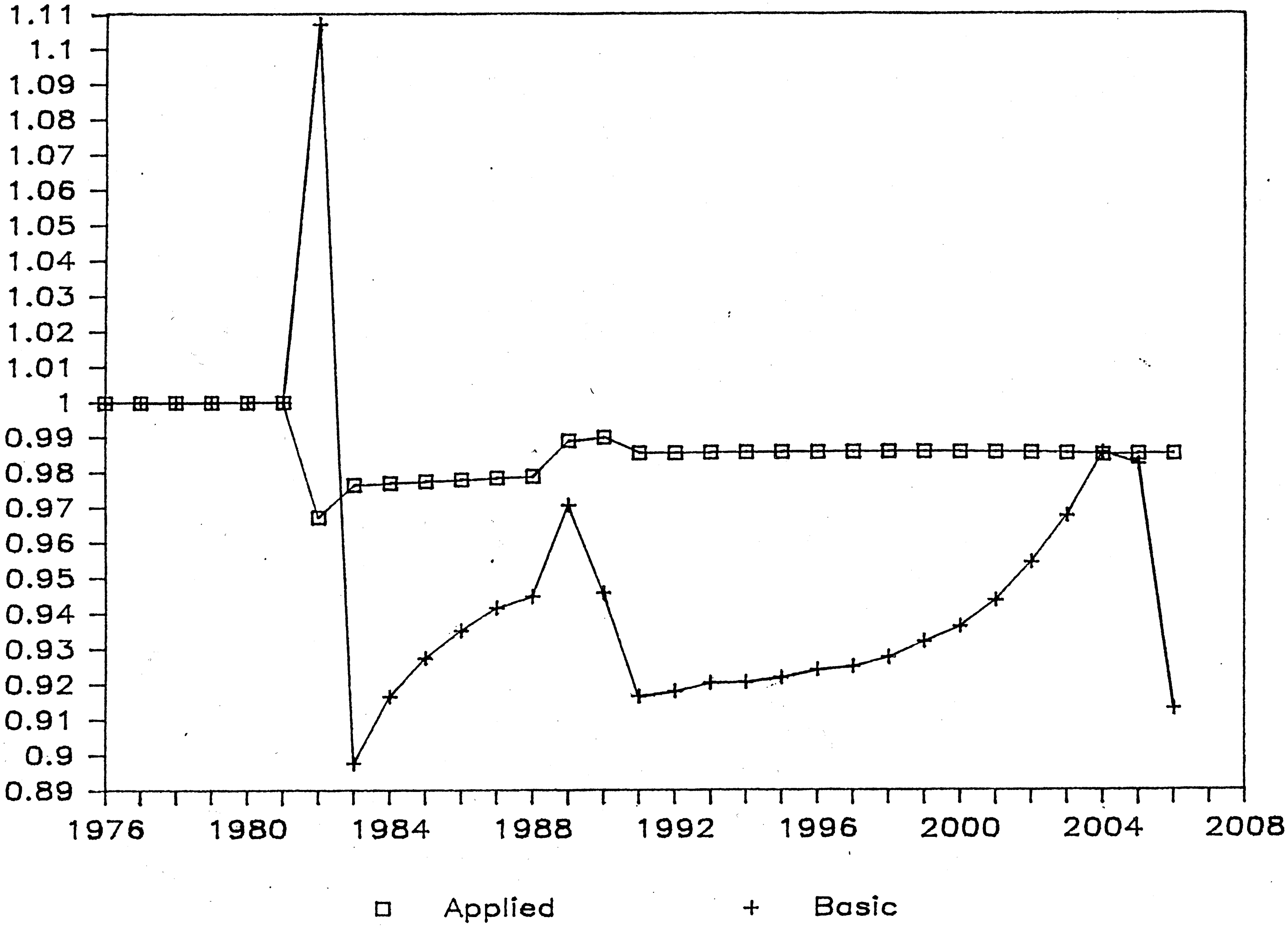


Figure 6: The Impact of Decreasing the Export Demand Elasticity for Crops on Optimal Livestock Research



would expect. 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 to 7%.

Variations in the export demand elasticity leave annual levels of applied livestock research expenditure largely unchanged (Figures 4 and 6). 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% to 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¢ per dollar of public expenditure to 50¢ reduces optimal research expenditures in all categories (Figures 7 and 8). Basic and applied crop research are reduced by 9 to 10% in each year. Basic livestock research is more seriously effected, being reduced by about 13% per year on average. Applied livestock research is reduced to the same extent as both types of crop research.

Reductions in the rate of technical change in the non-farm sector tend to reduce the optimal rate of investment in agricultural research (Figures 9 and 10). Inputs purchased from the non-farm sector become relatively more expensive over time under this regime. 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

Figure 7: The Response of Optimal Crop Research Expenditure to Increases in the Marginal Excess Burden

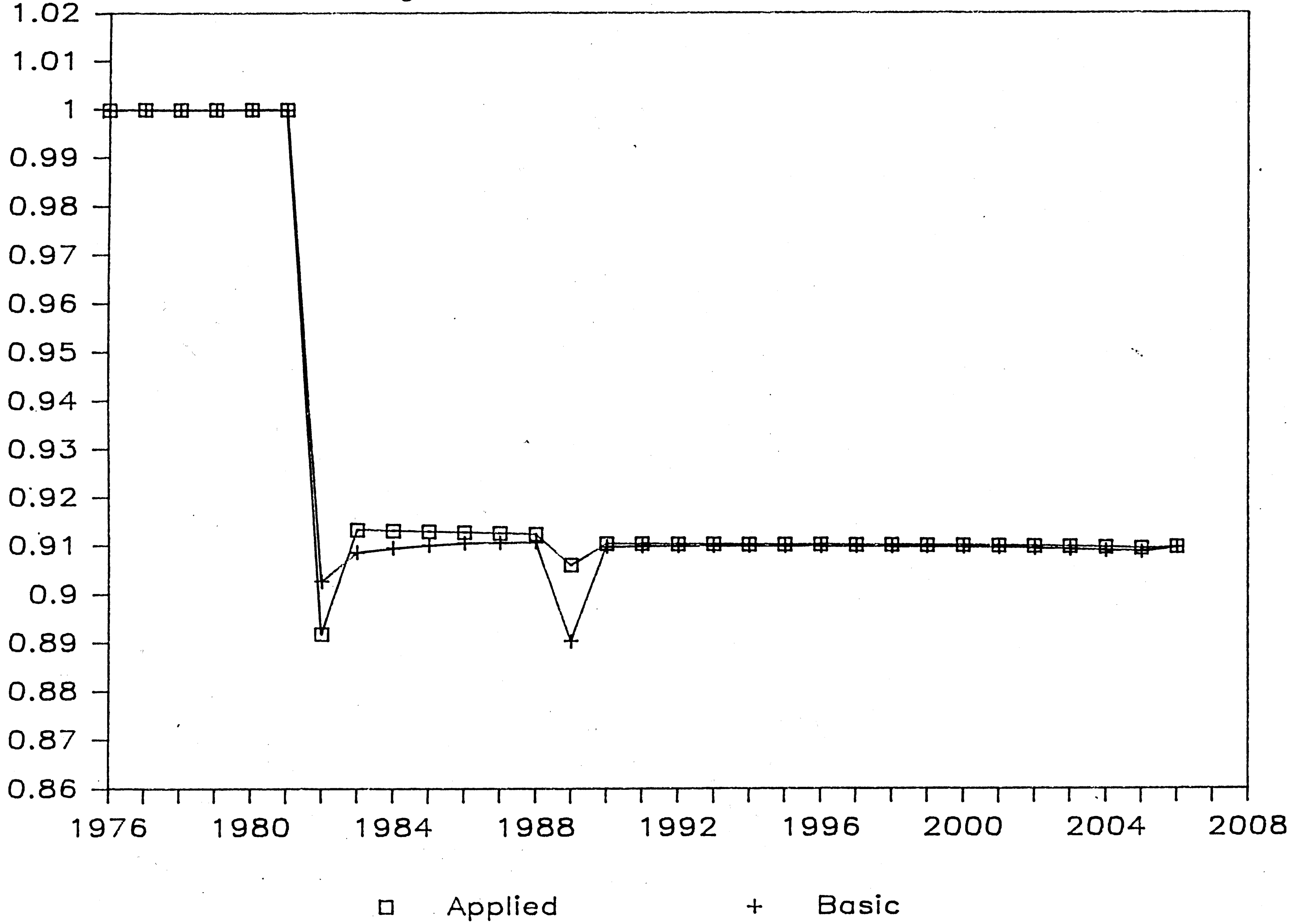


Figure 8: The Response of Optimal Livestock Research to Increases in the Marginal Excess Burden

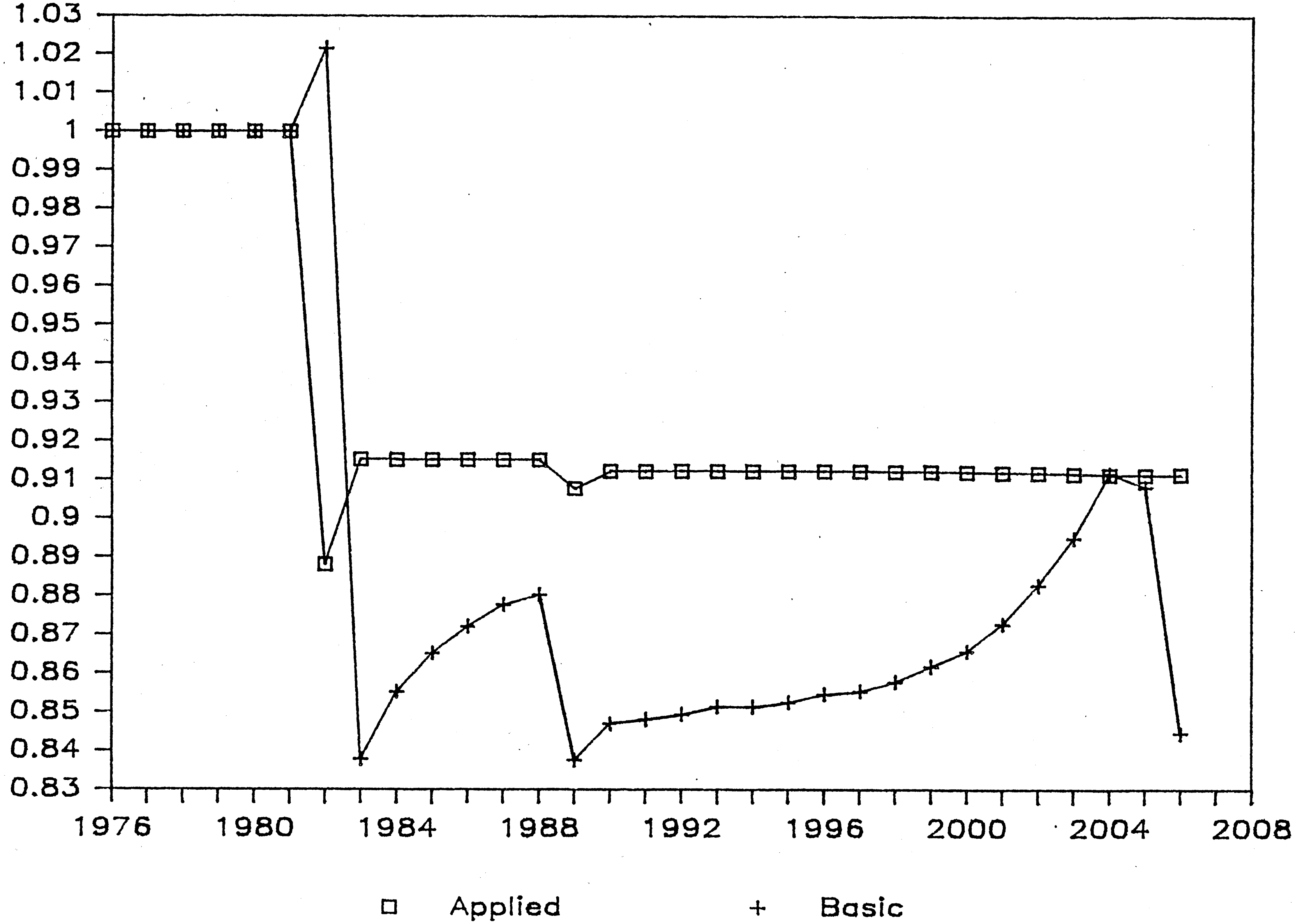


Figure 9: The Impact of Reduced Technical Change in the Non-Farm Sector on Optimal Crop Research

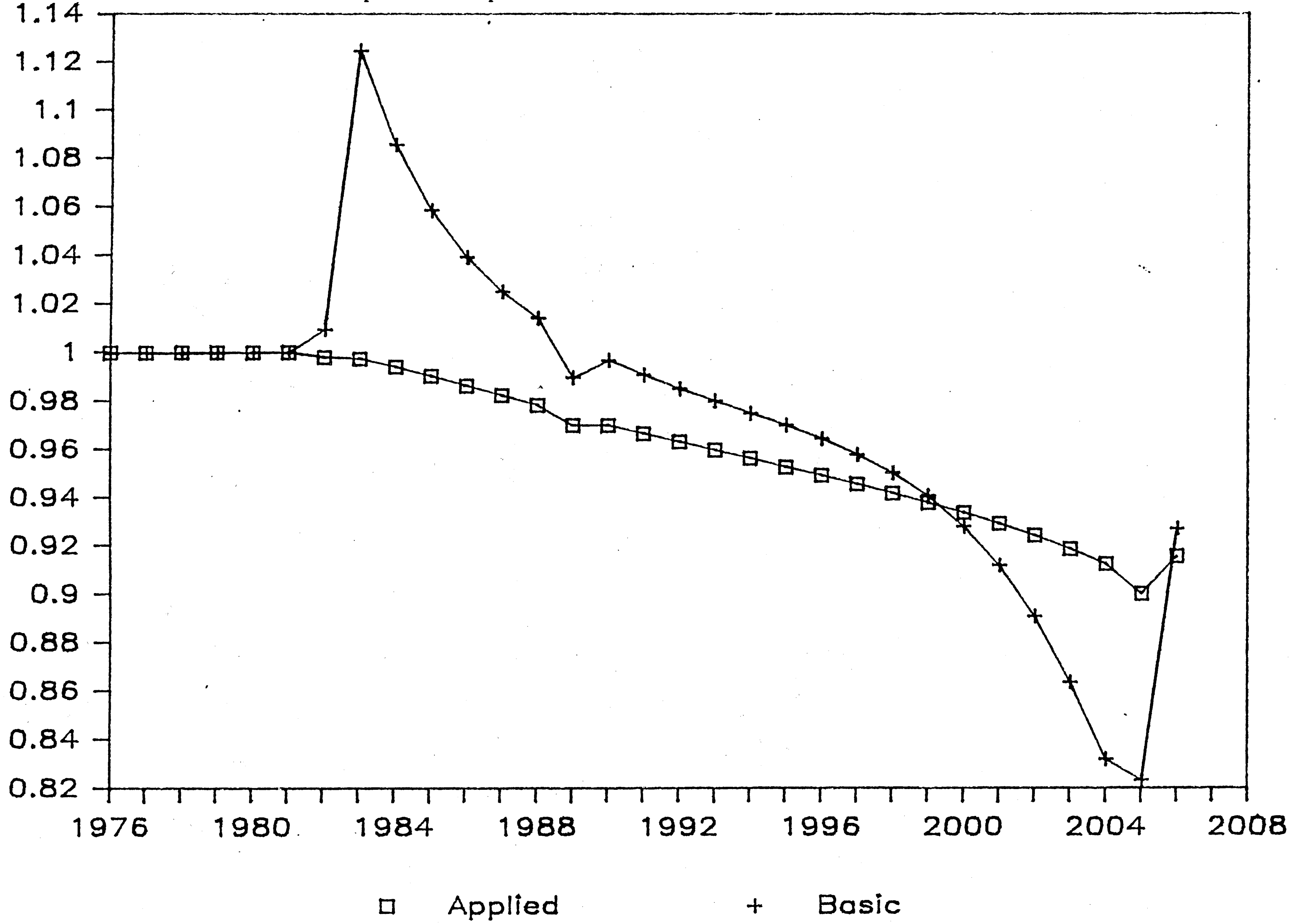
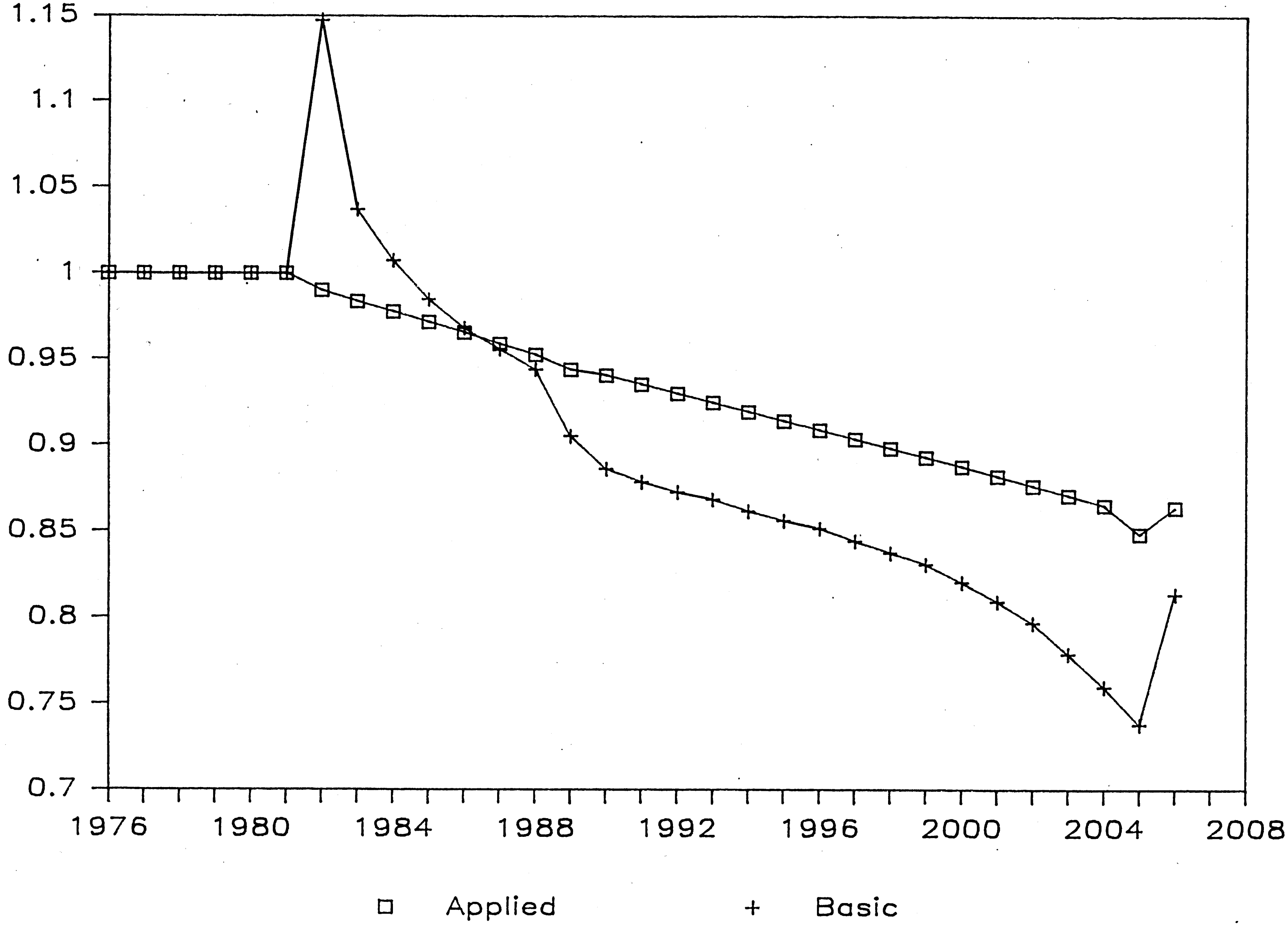


Figure 10: The Impact of Reduced Technical Change in the Non-Farm Sector on Optimal Livestock Research



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 have fallen 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. The Hypothesis of Underinvestment

There is a long history of claims that public investment in agricultural research in the United States is too meager. Fox (1985), has 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. <u>The Hypothesis of Neglect of Basic Research</u>

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. <u>The Hypothesis of Neglect of Crop Research</u>

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. 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 under-investment 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 under-investment 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. 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 that 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 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 factors. 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. 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 implicitly 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.

Footnotes

+ Thanks are due to Vernon W. Ruttan, Willis Peterson, C. Ford Runge, O.H. Brownlee, Ed Foster, Ed Prescott, and Jim Oehmke for their comments and suggestions. John Myers, director of the Current Research Information System (CRIS) of the USDA, provided data on research expenditures from 1968-1983. Phil Pardey and Michelle Hallaway helped with data collection.

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1 In this paper "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. Similar definitions of basic and applied research have been employed by Evenson (1978, p. 72).

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. in 1982. Livestock is defined to include Beef, Hogs, Sheep and Lambs, Milk, Poultry Meat and Eggs, as well as the pro-

duction of forage crops for ruminants.

3 Variations of this functional form have been used extensively in the analytical optimal growth literature. For example see Chiarella (1980), Takayama (1980) and Robson (1980).

4 Details of these calculations are reported in Fox (October, 1985).

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

6 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.

7 For further development of this optimal steady stats concept, see Fox (1986, pp. 88-101).

8 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) and Fox (1986).

9 This amounts to approximately 266 eight hour days per man year.

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