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THE ESTIMATION OF THE RETURNS TO AGRICULTURAL RESEARCH AND EXTENSION IN MAINE: 1951-1985

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INTRODUCTION

The number of individuals involved in agricultural production and the number of farms in the United States have been shrinking since before the turn of the century. From 1947 to 1984, the total number of farms in the United States declined from about 5.9 million to about 2.3 million, a decline of more than 60% (Lucier, Chesley, and Ahearn 1986). Since 1947, the number of persons employed in agriculture has declined from more than 7.8 million to about 3.2 million, an almost 60% reduction (*Economic Report of the President* 1988). This has sometimes been cited as evidence of the decline of agriculture in the United States.

While the decline of the number of farms and the number of individuals who farm for a living seems to indicate an industry in poor health, other figures suggest that agriculture is a healthy industry. While the farm population has declined, the United States has experienced huge increases in the productivity and profitability of the agriculture sector. For example, from 1965 to 1985, the productivity of agricultural labor more than tripled in the Northeast (*Agricultural Statistics* various years), while the average improvement in non-agricultural industries merely doubled during the same time period (*Economic Report of the President* 1988). It is well known that one of the primary reasons for such increased productivity of the agricultural sector is in large part derived from the results of agricultural research carried on at state agricultural experiment stations and communicated to producers by extension services.

Because of the public nature of many types of knowledge used in agriculture, we expect significant private under-investment in agricultural research and extension, thus these functions are considered important roles for government. As is often the case, the appropriate level of public expenditures on these activities is not obvious and is subject to debate.

Recent changes in the structure of agriculture and calls for fiscal austerity have resulted in increasing pressure to reduce the level of public expenditure for agricultural research and extension. New technologies have improved the likelihood of private provision of some of these activities. The decline of the number of farms and the agricultural share of the total economy suggest to some that the amount of public provision for agricultural research and extension should decline. Concerns about both public budget deficits and the relative size of the government have increased pressure to reduce real public financial support for research and extension activities.

Although all of the above reasons for reduced public agricultural activities are valid, they do not necessarily imply that a reduction in public spending for agricultural research and extension is appropriate. Such expenditures are appropriately viewed as investments in the productive infrastructure of the whole economy. As such, the level of investment should be evaluated like any other investment, whether private or public. In particular, if the rate of return to the research and extension activities is greater than the interest cost of public funds, then levels of investments in these activities should be increased.

The purpose of this paper is to determine a statistical estimate of the returns to agricultural research at the Maine Agricultural Experiment Station during the period 1950 through 1986. The approach taken here follows most of the recent literature regarding the estimation of returns to agricultural research, by estimating an econometric production function and deriving an internal rate of return on both research and extension expenditures within the state of Maine. This estimate is derived using ridge regression techniques. The approach taken here differs somewhat from much of the returns to research literature in that it focuses on a single state, while most other work in this area considers the country as a whole. In addition the estimates here take explicit account of benefits accruing from outside of the state.

BACKGROUND AND THEORETICAL MODEL

THEORETICAL BACKGROUND

The empirical study of returns to research in agriculture begins with Schultz (1953) and Griliches (1958). Both authors estimated these returns using consumer surplus measures to estimate the social gains from agricultural research. Because of difficulties with the consumer surplus method, Griliches (1964) took the approach of modelling the aggregate agricultural production function for the U.S. in which he included education, agricultural research and extension, as well as the standard productive inputs, as right-hand side variables. With this approach, Griliches could form an estimate of the marginal product of research, which in turn yielded a statistical rate of return on research expenditures. Since Griliches's 1964 paper, there have been many subsequent estimates of these returns, all of which followed the basic Griliches methodology. Table 1 presents some summary results of several of the more important studies in this area.

Until recently, there have been few attempts to study the returns to research on a state level, the most notable exception is the Virginia Study of Norton, Coffey, and Frye of 1984. The Norton, Coffey, and Frye study found a state level internal rate of return of about 58%, significantly higher than the rate of return expected for most investments. This study closely follows the methods used in the Norton, Coffey, and Frye study.

Table 1. Estimated Returns to Agricultural Research From Selected Studies

AUTHOR	DATE	TYPE	RESULT	APPROACH
Schultz	1953	Aggregate	32% saving of inputs	Consumer Surplus
Griliches	1958	Hybrid Corn	IRR* 35-40%	Consumer Surplus
Griliches	1964	Aggregate	Gross Social Rate of Return of 300%	Production Function
Peterson	1967	Poultry	IRR 33%	Production Function
Evenson	1967	Aggregate	Marginal Product of Research $40.00	Production Function
Bredahl & Peterson	1976	Grains Poultry Livestock Dairy	IRR 36% IRR 37% IRR 46% IRR 43%	Production Function
Norton	1981	Grains Poultry Livestock Dairy	IRR 85% — IRR 88% IRR 51%	Production Function
Norton, Coffey & Frye	1984	State Level	IRR 58%	Production Function

* Internal Rate of Return

THEORETICAL MODEL

Following the production function methodology first used by Griliches (1964) and used in virtually all studies of returns to agricultural research since, suppose some product is produced with the production technology:

$$Q = f(z_1, z_2) \qquad (1.$$

where Q is agricultural production and z_1 and z_2 are factors of production.

$$\frac{\partial Q}{\partial z_i} = \text{the marginal physical product of factor } z_i. \qquad (2.$$

If the value of output and the cost of a unit of the factor are known, a rate of return to the factor may be determined.

Production functions are most commonly measured in quantity units, but in order to aggregate across goods, it is necessary to consider the production function in monetary units, that is:

$$Y = g(x_1, x_2, ...) \qquad (3.$$

where $Y = PQ$, P is the price of output, and the x_i represents the expenditure on any factor i.[1]

A distinct advantage of the use of revenue and expenditures in the production function is that $\partial Y/\partial x_i$ is the value of additional output resulting from an increased expenditure of $1 on the factor, which leads easily to the rate of return. For our purposes, if Y is the state of Maine revenue from agricultural production and $x_i = r$ is the expenditure for research, $\partial Y/\partial r$ is the additional agricultural revenue generated in Maine from a $1 increase in research expenditures. If the additional output occurs during the same period as the research, then:

$$\frac{\partial Y}{\partial r} - 1 = R, \qquad (4.$$

where R is the rate of return to the research.

Because the resulting extra revenue from research generally occurs over many years after the research is actually completed, we are not able to calculate the rate of return as simply as in Equation 4. To determine the rate of return, a means must be devised to allocate the returns across time. Once the allocation of the returns over time is determined, then a marginal internal rate of return (R') may be found as the solution to:

$$\frac{\partial Y}{\partial r} \sum_{i=1}^{j} [\, w_i/(1 + R')^i] - 1 = 0 \qquad (5.$$

where w_i is the weight assigned to the year's agricultural revenues, and j is the number of years considered.

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[1] The use of revenue and expenditures as we normally use quantities in production analysis is appropriate, since if the prices of the output and the inputs specified as expenditures are each converted to constant dollars by a reasonable price index, it can be easily shown that the result is equivalent to a quantity index.

Thus, for purposes of this study, it is necessary to estimate a function of the form:

$$Y_t = f(r_t, s_t, e_t, l_t, n_t, k_t, c_t), \qquad (6.$$

where:

Y_t =Total revenue to Maine agriculture during year t;

r_t = A lag-weighted allocation of agricultural research expenditures (at the Maine Agricultural Experiment Station) to year t;

s_t =A weighted adjustment for the effects of research from sources other than the Maine Agricultural Experiment Station, during year t;

e_t = A lag-weighted allocation of agricultural extension expenditures (by the Maine Cooperative Extension Service) to year t;

l_t = The value of land services used (in Maine agricultural production) during year t;

n_t = The value of labor services used (in Maine agricultural production) during year t;

k_t = The value of capital services used (in Maine agricultural production) during year t;

and

c_t = a weather adjustment.

Descriptions of the variables used to estimate Equation 7 and the details of the estimation are presented in the following section of this paper.

VARIABLES INCLUDED IN THE MODEL

For estimation of Equation 7, agricultural revenue, input, and a weather variable for the 35 years from 1951 through 1985 are considered. In order to consider the lagged effects of research and extension, an additional ten years of observations for research expenditures, and five years for extension expenditures are included. For adjustments to the research variable, it is necessary to gather research expenditures for all states during the 35 year period.

All values, except land and rainfall, are expenditure values expressed in dollars. Each of these is adjusted by the most appropriate available price index to 1977 dollars.[2] Analysis is on a per-farm basis so that these variables are also divided by the number of farms in Maine from *Farm Real Estate: Historical Series Data 1950-1985* (USDA 1986a).

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[2] All price indices are from *The Economic Report of the President* (1988).

Because of the long time series used here, it is impossible to find values for each of the variables that are measured consistently over time and precisely match the theoretical definitions of the variables listed in Equation 7. It is therefore necessary to make a number of assumptions about and some adjustments to the data. Some descriptive summary statistics of the revenue, research expenditure, and extension expenditure variables are presented in Table 2. The same statistics for other variables are presented in Table 3. Details of the construction of the major variables used in this study are discussed below and in Appendix B.[3]

Table 2 Sample Statistics Real Agricultural Revenue, Research and Extension Expenditures for Maine, 1951–1985 (1977 Dollars)

Variable	Mean	Std. Dev.	Maximum	Minimum
Revenue[a] (1951–85)				
Total	395,981,351	48,353,658	512,320,000	285,700,000
Per-Farm	36,134.24	16,377.83	67,817.87	9,315.63
Research[b] (1941–85)				
Total	2,037,223	560,762.75	3,035,245	1,069,662
Per-Farm	174.48	124.45	379.41	26.15
Extension[c] (1946–85)				
Total	2,838,122	76,8704.86	4,090,679	1,623,024
Per-Farm	285.91	173.77	554.89	49.79

[a] Cash Marketing Receipts + Non-money Items and Related Income + Inventory Change, 1951–1985 (Lucier, Chesley and Ahearn 1986).

[b] Agricultural research expenditures at the Maine Agricultural Experiment Station, 1941–1985.

[c] Total expenditures of Maine Cooperative Extension Service, 1946–1985.

FARM REVENUE: (Y)

The dependent variable, "The value of Maine farm output," Y, must measure the total value of goods and services produced on the farm during a given year. The figure used here to represent this value is the sum of "Cash Marketing Receipts," "Non-money Items and Related Income" (on-farm consumption of farm output) and "Inventory Change," for the years 1951 to 1984 from Lucier, Chesley, and Ahearn (1986). Data for 1985 were obtained from *Economic Indicators of the Farm Sector, 1985* (USDA 1986b).[4] This measure of farm revenue is de-

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[3] A more detailed description of all of the variables used may be found in Adams (1988).

[4] These two series are consistent since Lucier, Chesley, and Ahearn is a compilation from historic "Economic Indicators of the Farm Sector."

flated by the Index of Prices Received by Farmers; All Items, 1977=100. Farm revenue is converted to a per-farm basis. Thus, the left-hand-side variable for the analysis, Y is the per-farm, real value of farm output in Maine.

For Maine as a whole, the real value of farm output rose sharply from the pre-1955 period to the post-1955 period (see Figure 1). Since 1955, this figure averaged about $400,000,000 a year with much inter-year variation. Maine per-farm real revenue shows less year-to-year variability and a strong upward trend from the early 1950s to the middle 1970s, then a sharp decline to the middle 1980s (see Figure 2). Real per-farm revenue increased from a low of $9,316 in 1951 to a high of $67,818 in 1976, then declined to $39,590 in 1985 (Lucier, Chesley, and Ahearn 1986).

RESEARCH AND EXTENSION

The variables of primary interest to this report, research and extension expenditures, are somewhat different from variables normally included in a production function (or revenue function in the present case). Although these are values that can be controlled, they are controlled not by individual farms, but by governmental policy. As such, their values are not as responsive to economic conditions as are the values of the more traditional factors of production. Because these expenditures are policy variables, they tend to be highly correlated and subject to the same long trends (See Figures 3 through 6). Both research and extension expenditures are deflated by the "Implicit Deflator for Gross National Product; Government Purchases of Goods and Services: Total" (*Economic Report of the President* 1988).[5]

Research and Spillover

Research (r)

It is commonly understood that agricultural output is affected by certain off-farm, non-purchased inputs such as agricultural research. Agricultural research is in many respects fundamentally different from conventional agricultural inputs such as land and fertilizer, however. Research outcomes affect agricultural production in two ways. First, they provide new or improved inputs to production. Second, they provide new or improved ways to combine other inputs.

In many cases, the results of research are embodied in the factors of production purchased at the farm and are accounted for in the expenditures on more traditional inputs to production. These cases are not the primary interest of this study, our concern is with the public research results that are embodied in improved knowledge which is freely available and will not be captured in the prices of the traditional factors because the results are easily imitated. Because it is difficult to capture returns to this sort of research outcome, the private sector

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[5] The published series uses a 1982 = 100 base. For data consistency, this is adjusted to a 1977 base.

FIGURE 1
Annual Real Farm Revenue in Maine 1950–1985 (Millions of 1977 Dollars)

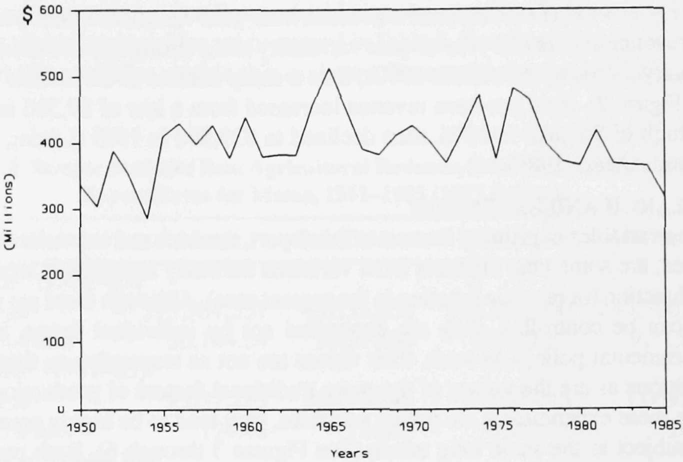
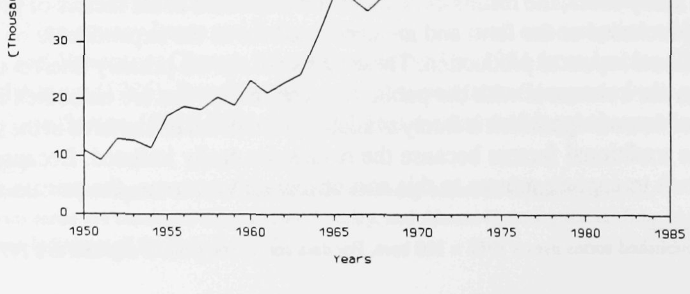


FIGURE 2
Annual Real Farm Revenue (Per-Farm) in Maine 1950–1985 (Thousands of 1977 Dollars)



systematically under-invests in research of this type, and it has become a role of the public sector to provide much of this. In the case of agriculture, state agricultural experiment stations are the primary providers of such research.

The investment in public agricultural research in the state of Maine is primarily through the Maine Agricultural Experiment Station (MAES), thus the essential measure of the level of investment is the level of expenditures at MAES for agricultural research. The exclusion of non-agricultural research expenditures from the research variable is straightforward for the years 1951 onward. Data from the Current Research Information System (CRIS) on research expenditures by "Commodity, Resource or Technology not Associated with a Particular Commodity" enabled the exclusion of non-agricultural research expenditures for the years 1968 to 1985. Similar data from the Cooperative States Research Service (CSRS) are available for the years 1951 to 1964. No data are available for the years 1965 to 1967, and these observations are completed by linear interpolation.

Because of the necessity of allocating research expenditures to future revenue, a longer time series for the research expenditures variable than for other variables in the analysis is required. Since values for research expenditure prior to 1951 are not available from the CSRS data, it is necessary to find another source. For this purpose, the total annual expenditures from issues of the *Annual Report* of the Maine Agricultural Experiment Station are used to provide information for research expenditures for the years 1941 to 1950. Because the total expenditures data from the annual reports are not consistent with the data from CSRS, several adjustments are made to them. Further details of these adjustments to this variable are presented in Appendix B.

Maine total real agricultural research expenditures increase steadily from $1,368,866 in 1952 to $2,800,877 in 1971, then fall to between $2.2 million and $2.4 million until the early 1980s after which they increase to $3,035,245 in 1985 (see Figure 3). The pattern of research expenditures per-farm is similar to the total expenditure. Because of a steady decline of the number of farms in Maine during the period, per-farm real research expenditures increase more quickly and smoothly than total real research expenditures, particularly during the 1951 to 1971 period.

Spillover (s)

Knowledge is not consumed as it is used and it is easily copied; it is not usually bought and sold in the marketplace, except as it is embodied in other products. Because of this, research conducted in one place or applied to one commodity frequently adds to the knowledge for the production of other commodities at other places. This phenomenon is referred to as research spillover. Because of spillover, the research product of a single experiment station will

FIGURE 3
Maine Agricultural Experiment Station Real Expenditures for Agricultural Research, 1940–1985 (Millions of 1977 Dollars)

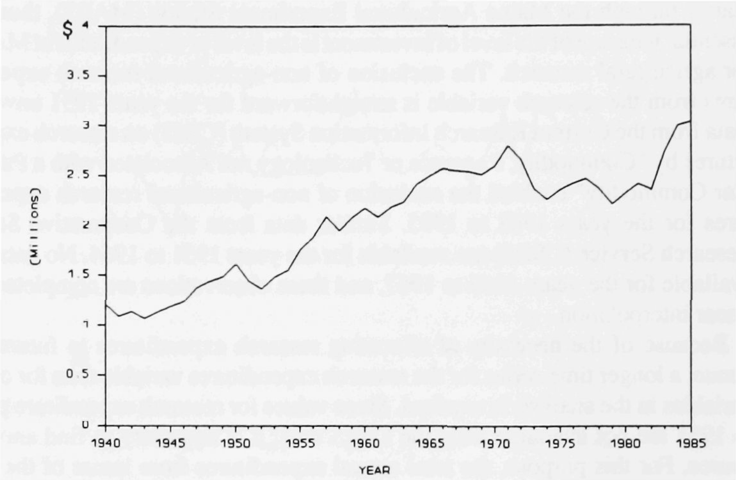
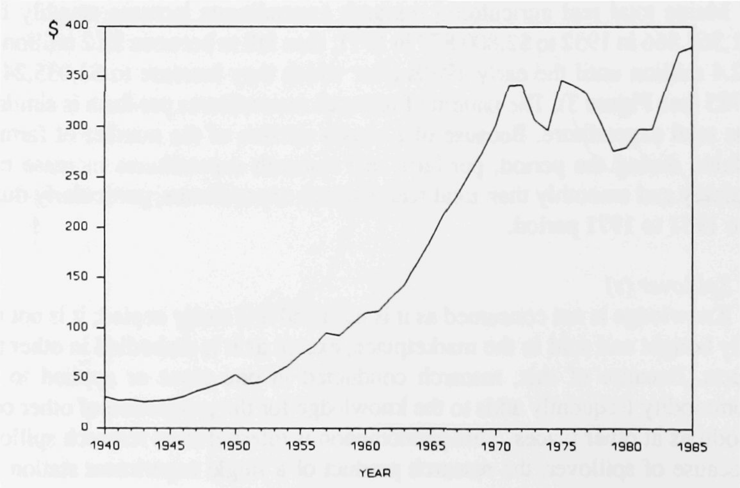


FIGURE 4
Maine Agricultural Experiment Station Real Per-Farm Expenditures for Agricultural Research, 1940–1985 (1977 Dollars)



benefit and be benefitted by the research products of other experiment stations. Thus, gains in the agricultural production of a single state from research cannot be attributed solely to the research investment within that state. Several previous studies, including Latimer and Paarlberg (1965), Evenson (1967), Bredahl and Peterson (1976), Norton (1981), White and Havelicek (1981), and Sundquist, Cheng, and Norton (1981) all find significant spillover effects. None of these, except White and Havelicek, utilizes an explicit adjustment for research spillover in estimates of the returns from research.

In our case, Maine agricultural production benefits not only from the investments made at the Maine Agricultural Experiment Station (MAES), but also from research conducted at other experiment stations and within other disciplines, "research spill-in." It is of course also true that the research conducted at MAES spills-out to other disciplines and states, and previous studies such as this assume that spill-in and spill-out cancel one another and can be ignored (Bredahl and Peterson 1976). In this study we do not make such an assumption for three reasons. First, the within-state returns seem to be the most appropriate for state level policy since returns captured in other states do not directly benefit the people of Maine. Second, as a relatively small and somewhat isolated agricultural state, Maine seems more likely to gain from research elsewhere than the reverse. Third, ignoring spill-out but deducting for spill-in is consistent with our approach of choosing more conservative means to measure returns. We thus add a variable that attempts to account for spill-in effects, while ignoring spill-out.

Aside from some *ad hoc* attempts in other studies to adjust the final estimated rate of return, there is no methodology to account for spillover, either between states or among disciplines. There is no information that will reflect such transfers because there is no explicit market for this sort of knowledge. Since there is reason to believe that the returns to private research are captured by factor prices, we ignore private research expenditures altogether. We also ignore spillover from non-agricultural research because there are neither data available nor any theory of how this takes place. We do make adjustments, however, for expenditures by other U.S. public agricultural research organizations. In this study, spillover is accounted for by the sum of other states' research expenditures on commodity aggregates most similar to those of Maine, then weighting these using a geographic scheme. The details of our spillover variable are presented in Appendix B.

The pattern of weighted spillover expenditures, both total and per-farm, is extremely similar to that of MAES research. The primary difference is of degree and magnitude. Weighted spillover expenditures are larger and increase more rapidly than MAES expenditures during the 1951 to 1985 period. Total real weighted spillover expenditures increase from $4,018,014 in 1951 to

$7,771,976 in 1971. Total weighted spillover expenditures fall slightly until 1973 and then increase to a maximum of $9,608,517 with a slight decline during the 1980 to 1983 period. Total weighted spillover expenditures have a mean of $7,093,500 and a standard deviation of $1,419,034. Per-farm weighted spillover expenditures have a mean of $686.34 and a standard deviation of $362.79.

Extension (e)

If the results of research are to affect production, the results must first be transmitted to producers. This is the function of the Cooperative Extension Service. In the study by Griliches (1964), research and extension are aggregated into a single variable. Later studies note the fundamental difference between these two activities and include them as separate inputs in the production function.

Agricultural extension services will attempt to transmit all useful knowledge to farmers, regardless of the origin of the knowledge. In a single state analysis, where spillover effects are likely to be large, extension services may play a large role in increasing agricultural productivity. Agricultural extension is complementary to both in-state and spillover research. If precise estimates of the productive effect of both of these individual activities are desired, there must be explicit consideration of the effects of the extension function.

The measure of expenditures on agricultural extension services used in this study is the total yearly real expenditures of the Maine Cooperative Extension Service (MCES). Not all expenditures of the MCES are devoted to agricultural extension. No reliable data exist, however, on the relative allocation of expenditures to agricultural and non-agricultural uses for this entire time series. If the ratio of these two activities has remained relatively constant throughout the time series, then the parameter estimates for the production function should be unbiased, but the estimates of the rate of return to extension will be biased downward.

It is very probable, however, that the proportion of extension activities devoted to agriculture has declined in Maine during the time period under consideration. If this is true, then the more recent years' measures of agricultural extension expenditures will be biased upward. This will further bias the coefficient on extension downward, *ceteris paribus*.

We are unable to adjust for these biases in this study, but note that they will cause an underestimate of the extention contribution. The variable used here is "total real MCES expenditure" from 1951 through 1985. Although this bias is unfortunate, it is consistent with our conservative approach.

The pattern of real Maine Cooperative Extension Service expenditures is similar to that of the research expenditures and spillover variables (see Figure 5). Real state total MCES expenditures rise from a minimum of $1,623,025 in 1951, fall slightly in the early 1960s, and rise steadily from the mid-1960s through mid-1970s to a level slightly greater than $4 million. Since the mid-1970s, MCES expenditures average roughly $3.5 million. On a per-farm basis MCES expenditures rise from about $50 per-farm in the early 1950s to more than $500 per-farm in the mid-1970s then fall to around $450 per-farm since the late 1970s (see Figure 6).

OTHER VARIABLES (l,n,k,c)

Traditional production function specifications include only the physical, on-farm inputs that affect agricultural production. While the level of aggregation of these diverse physical inputs varies from study to study, they can all be grouped into the broad categories land, labor, capital, and weather.[6]

Aggregation of inputs into physical units is difficult for at least two reasons. First, quantity measures of inputs do not reflect differences in quality. Second, since different factors of production are measured in different units, even within quite narrow aggregates, there is no single, satisfying unit of measure for any of the aggregates.

The use of expenditures data, for labor and capital, addresses both of these problems. On average, we expect that differences in the quality of factors of production, over time, will be reflected as changes in their real price. It is possible to estimate some representation of the price of both labor and capital, thus dollars are a convenient common unit of measure for these. Adequate expenditures data for land are not available so a weighting scheme is adopted as a measure of the land input.

Because the aggregates land, labor, and capital are quite broad and somewhat arbitrary, our estimates will not provide particularly meaningful information regarding the physical production processes for Maine, but this is not the purpose of this study. Because we are principally concerned with the effects of the research and extension expenditures, we require only satisfactory accounting of the production effects of these standard production variables. In the estimations for this study, all values for these variables are considered as real, per-farm values. Table 3 presents some summary statistics for the land, labor, capital, and rainfall variables, and details of their construction are presented below.

Land (l)

Specification of the land variable would seem to be straight-forward since land is generally measured in acres. Without adequate price data, however,

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[6] It is a common practice to include some education variable in estimates such as these. It is appropriately assumed that greater education implies faster adaptation to research results and better management. The only education data available to us are for the entire rural population of Maine (as opposed to farmers) and are only available once for each decade. These data show very small changes for the period of analysis and the necessary interpolation for annual figures yields a variable that is so stable that it is probably not meaningful for this analysis. For these reasons, a variable representing education is not included in this analysis.

FIGURE 5
Maine Cooperative Extension Service Expenditures 1950–1985 (Millions of 1977 Dollars)

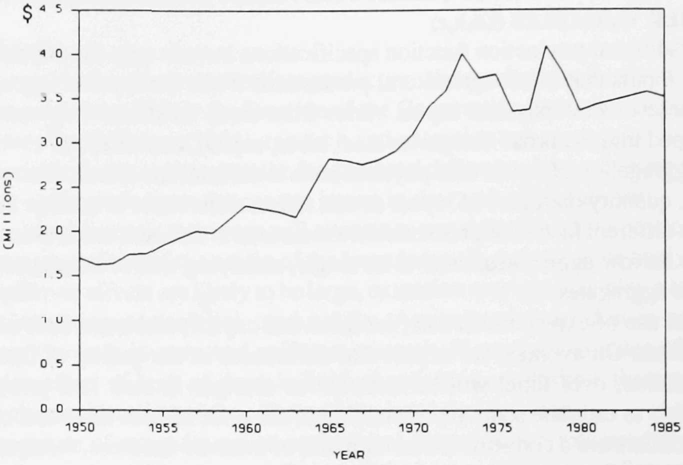

FIGURE 6
Maine Cooperative Extension Service Expenditures Per-Farm, 1950–1985 (1977 Dollars)

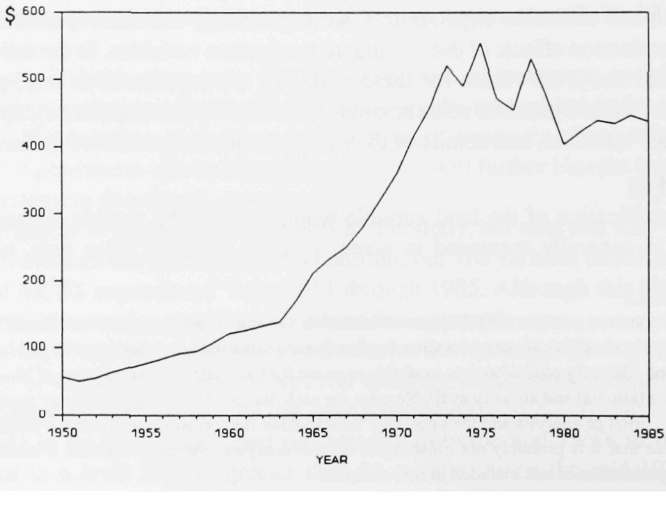

Table 3. Sample Statistics: Land, Real Expenditures for Labor and Capital, and Mean July Rainfall for Maine, 1951–1985 (1977 Dollars)

Variable	Mean	Std. Dev.	Maximum	Minimum
Land[a] (Acres)				
Total	794,591	226,857	1,296,908	565,367
Per-Farm	63.7	14.2	88.7	39.8
Labor[b] ($)				
Total	42,177,228	8,665,435	70,096,552	25,695,833
Per-Farm	3,668.46	1,454.05	6,422.24	1,345.22
Capital[c] ($)				
Total	299,956,334	30,752,065	353,665,060	236,802,128
Per-Farm	27,957.54	13,322.48	48,501.45	7,263.87
Rain[d] (Inches)	3.528	1.237	6.38	0.97

[a] Land = Harvested Cropland + .5(Pasture land) + .075(Total Woodland) + .25(Land in Farms - Total Cropland - Total Woodland). (U.S. Department of Commerce 1983)

[b] Hired Labor Expenses for Maine Agriculture. (Lucier, Chesley, and Ahearn 1986)

[c] The sum of expenditures on Feed, Livestock Purchased, Seed, Fertilizer and Lime, Fuels and Oil, Electricity, Pesticides, Repair and Operation, Machine Hire and Custom, Fire, Wind and Hail Insurance and Miscellaneous, Depreciation, Property Taxes and Non-Real Estate Interest. (Lucier, Chesley, and Ahearn 1986)

[d] Average July Rainfall for Maine.

acreage cannot reflect quality differences. Included in acreage are all acres in farms, regardless of land type or use. Clearly, woodland is not the same as cropland and will have neither the same value nor the same effect on production. An acreage measure must somehow be weighted to reflect these differences.

We follow the weighting scheme of Norton, Coffey, and Frye (1984), used in the evaluation of agricultural research in Virginia. For each year land is calculated by the formula; Land = Harvested Cropland + .5(Pasture land) + .075(Total Woodland) + .25(Land in Farms – Total Cropland – Total Woodland). Data on these acreages were obtained from the 1982 *Census of Agriculture* for the years 1950, 1954, 1959, 1964, 1969, 1974, 1978, and 1982. Observations for the missing years were estimated by linear interpolation.

Labor (n)

The labor variable should include the total costs of labor inputs for a given year. Total costs include both implicit and explicit costs. Explicit costs are both the wages paid to hired labor and expenses associated with perquisites provided to hired labor. The primary implicit costs are the opportunity costs of non-wage labor, family labor in particular.

Reasonably good data exist for the explicit costs but not for the implicit costs. Family-farm labor statistics do exist but these statistics are of limited use. The only available data of this sort are the average numbers of family farm workers. No sufficient information is available on the number of hours worked, age, educational level, or any other variable that could enable a reliable calculation of the opportunity cost of these labor services.

It is reasonable to assume, however, that family labor is relatively stable, in the aggregate. It is assumed here that most of the variation in labor inputs is represented by variations in the amount of hired labor. There is no attempt to impute a cost for non-wage labor services. "Hired labor expenses" is the only measure of labor inputs used here.

Data for labor are from Lucier, Chesley, and Ahearn (1986) for the years 1951 to 1985 and from *Economic Indicators of the Farm Sector, 1985* (USDA 1986b) for 1985. Labor expenditures are deflated by the Index of Prices Paid by Farmers; Wages, 1977=100.

Capital (k)

The factor capital includes all purchased inputs except land and labor. Capital is often disaggregated into variable or non-durable capital, such as seed and fertilizer, which is used in the year that it is purchased, and fixed or durable capital, such as buildings or machinery, which is used for many years. The relevant measure for durable capital is the service flow from the piece of that capital during a particular year.

The capital variable used here is the additive aggregation of expenditures on all physical inputs except land and labor. As such, it represents both non-durable and durable capital. The costs of variable capital are represented by expenditures on "Feed," "Livestock Purchased," "Seed," "Fertilizer and Lime," "Fuels and Oil," "Electricity," "Pesticides," "Repair and Operation," "Machine Hire and Custom," "Fire, Wind, and Hail Insurance" and "Miscellaneous." Data for expenditures on all these categories are from Lucier, Chesley, and Ahearn (1986) for the years 1951 to 1984 and from *Economic Indicators of the Farm Sector, 1985* (USDA 1986b) for 1985. Total capital expenditures were deflated by the Index of Prices Paid by Farmers; Production Items, Total, 1977=100. The total costs of these services of durable capital are the opportunity cost of the capital stock, its depreciation, and any explicit expenses associated with it, such as property taxes. To calculate these costs, data on the yearly capital stock are necessary, but not available. Lucier, Chesley, and Ahearn (1986) report annual figures for depreciation, property taxes and non-real estate interest. We sum these as an approximation for the services of durable capital.

Climate (c)

Traditional production function specifications usually include some variable to represent weather. A correct specification of the weather variable is not clear, however, since there is no single, quantitative weather measure that reflects the effect of climate upon agricultural output. Also, any measure, such as mean rainfall or temperature in a given month, may affect different products in different ways. With no clear guide for a weather variable, we follow Norton, Coffey, and Frye (1984), using average July rainfall. These data are from *Climatological Data for New England* (U.S. Department of Commerce). For the years 1951 to 1960, statewide average rainfall is reported, and these figures are used for these years. For the years 1960 to 1985, statewide averages are not reported so the average of three regional averages ("Northern," "Southern Interior," and "Costal") are used.

EMPIRICAL SPECIFICATION

Most previous studies of returns to agricultural research, beginning with Griliches (1964), use a generalized Cobb-Douglas production function as the specification. This functional form has been criticized as too restrictive because it imposes a unitary elasticity of substitution among inputs and constant returns to scale. The Cobb-Douglas is convenient because it is easy to estimate and requires less data than common, more flexible functional forms. Griliches tested the importance of the restrictions imposed by the functional form and concluded that the bias imposed by the use of the Cobb-Douglas was not significant, hence, the Cobb-Douglas has been used for almost all similar studies.

With the Cobb-Douglas specification, equation 6 is rewritten as:

$$Y_t = \alpha\, r_t^{\beta r}\, s_t^{\beta s}\, e_t^{\beta e}\, l_t^{\beta l}\, n_t^{\beta n}\, k_t^{\beta k}\, c_t^{\beta c}, \qquad (7.$$

recalling that:

Y_t =the value of agricultural output per-farm in Maine during year t;

r_t = a lag-weighted allocation of agricultural research expenditures at the Maine Agricultural Experiment Station from the ten years prior to year t, to year t(a polynomial lag structure imposed) (per-farm);

s_t =a weighted adjustment for the effects of research from sources other than the Maine Agricultural Experiment Station during year t (per-farm);

e_t = a lag-weighted allocation of agricultural extension expenditures per-farm by the Maine Cooperative Extension Service from the five years prior to year t, to year t(a polynomial lag structure imposed);

l_t = the value of per-farm land services used in Maine agricultural production during year t;

n_t = the value of hired labor services per-farm used in Maine agricultural production during year t;

k_t = the value of capital services per-farm used in Maine agricultural production during year t, the sum of expenditures on: feed livestock purchases; seed, fertilizer, and lime; fuels and oil; electricity; pesticides; repair and operation; machine hire and custom; fire, wind, and hail insurance; miscellaneous; depreciation; property taxes and non-real estate interest;

and

c_t = mean July rainfall in Maine.

Also, $\beta_i = \partial \ln Y / \partial \ln x_i$ is the percentage change of revenue from a 1% increase in the expenditure on factor i. The marginal product of research is:

$$\frac{\partial Y}{\partial r} = \beta r \ \frac{Y}{r} \qquad (8.$$

Both research and extension are considered on a per-farm basis. The lag structure in the variable r_t is specified as a 10-year polynomial ("inverted V") lag, following the procedure of White and Havelicek (1981). Details of the lag structure are presented in Appendix A.

ESTIMATION AND RESULTS

Preliminary examination of the data reveals severe multicollinearity among several of the variables. All variables except mean July rainfall are highly (and significantly at a 99% level of confidence) positively correlated. Without extreme modification of the data, reasonable ordinary least squares analysis is impossible under these conditions. Following Norton, Coffey, and Frye, ridge regression (Hoerl and Kennard 1970a & b) is used as the estimation technique. Since ridge regression is a somewhat unfamiliar estimation technique, a brief description of ridge regression and more details of the estimates are presented in Appendix C. The model is estimated using the SAS procedure RIDGEREG with *a fortiori* convergence criteria of 5% and 1% for the ridge regression parameter "k."

Although standard hypothesis testing is not possible with ridge regression results, a standard measure of parameter significance is if the parameter is more than twice its standard error. The ridge regression estimates for k = .105 (5% criterion) and k = .205 (1% criterion) are presented in Tables 4 and 5. For the 5% criterion, all estimated coefficients are at least twice their standard error except for rain and research. For the 1% criterion, all coefficients except rain are more than twice their standard error. For both criteria, the coefficients are of the expected sign.

Table 4. Ridge Regression Results:Estimates based on 5% Convergence Criterion (k=0.105)

Variable	Coefficient	Standard Error of the Estimate	Ratio of Coefficient to Standard Error
Intercept	-2.155	—	—
Land	0.479	0.087	5.51
Labor	0.163	0.060	2.71
Capital	0.242	0.031	7.81
Rain	-0.042	0.045	-0.93
Research	0.045	0.027	1.67
Spillover	0.129	0.030	4.30
Extension	0.103	0.017	6.06

F = 121.90
$R^2 = 0.9644$

Table 5. Ridge Regression Results:Estimates based on 1% Convergence Criterion (k=0.205)

Variable	Coefficient	Standard Error of the Estimate	Ratio of Coefficient to Standard Error
Intercept	-1.655	—	—
Land	0.438	0.056	7.82
Labor	0.171	0.044	3.88
Capital	0.203	0.019	10.68
Rain	-0.039	0.042	-0.93
Research	0.071	0.016	4.44
Spillover	0.125	0.018	6.94
Extension	0.107	0.011	9.73

F = 112.99
$R^2 = 0.9617$

INTERPRETATION OF RESULTS AND CONCLUSIONS

Of primary interest to this study are the estimated coefficients of the research and extension expenditures. These coefficients represent the elasticity of agricultural revenue with respect to expenditures for either research or extension activities. Each of these indicates the percentage increase of farm production resulting from a 1% increase in the expenditure on that activity. For example, the coefficient of total research spending on per-farm production for the 5% criterion is approximately .045. This means that a 1% increase in the per-farm expenditures on research at MAES will result in slightly less than 1/20th of 1% increase in revenue per-farm in Maine. Since total MAES expenditure for research is a small proportion of total Maine farm revenue, a small change in MAES expenditure will result in a surprisingly large increase in Maine farm revenue, adjusted for other things.

Such numbers by themselves are not sufficient to determine the appropriateness of the level of research expenditures. For comparison to other investments, it is necessary to calculate the rate of return to such investments.

RETURNS TO RESEARCH

Because the returns to research sometimes occur many years after the research takes place, the benefits of research must be allocated across time, then reconverted to a single rate of return. Recall that this was the reason that a 10-year lag structure is imposed on the research expenditures data prior to the estimation. As is discussed previously and in Appendix A, this is a somewhat shorter than usual lag, but there is reason to expect that the true MAES lag may be shorter than normal. Since MAES is a relatively small agricultural experiment station conducting a high proportion of applied research to specific problems (approximately 56% from 1978 through 1987), it seems reasonable that the benefits from this type of research would occur sooner than the benefits of research on more basic, non-specific topics.

Recall, from Equation 5, that the rate of return commonly calculated and reported for investments in agricultural research is the marginal internal rate of return (MIRR). The MIRR is the rate of return that solves the equation:

$$\frac{\partial Y}{\partial r} \sum_{i-1}^{j} [w_i/(1 + R')^i] - 1 = 0$$

where R' is the marginal internal rate of return to research, $\partial Y/\partial r$ is the marginal product of research, and j is the number of years.[7]

The marginal internal rate of return can be computed by a two step procedure. First the regression coefficient on research is used to calculate the marginal product of research ($MPR = \partial Y/\partial r$). The MPR is then distributed over time and the value of this product is discounted into an annualized internal rate of return.

The marginal product of research for the Cobb-Douglas is:

$$MPR = \partial \bar{Y}/\partial r = \beta_r(\bar{Y}/\bar{r}) \qquad (9.$$

where:
β_r = the regression coefficient on research;
$\bar{Y}$ = the geometric mean of the value of agricultural output;
$\bar{r}$ =the geometric mean of agricultural research expenditures;

This marginal product is then allocated over the imposed lag period and then discounted to obtain the rate of return by Equation 5. The MIRR is the rate of return which, when used to discount a stream of net future benefits and costs, results in a discounted value of zero.

By equation 9, using the 5% criterion results, the marginal product of research is $10.77. Since product is expressed as dollars of revenue, this means that one dollar of expenditures on research generates $10.77 revenue during the ten-year period considered. Marginal products for research and extension for both versions of the regression are presented in Table 6.

Table 6. Estimated Marginal Products of Research and Extension from the 5% and 1% Convergence Criteria

	Convergence Criterion	
	5%	1%
Research	$10.77	$17.00
Extension	$15.36	$15.62

Marginal products are then converted to internal rates of return by Equation 5. From the results using the 5% criterion, the marginal internal rate of return

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[7] There are several methods of calculating a MIRR and estimates are sensitive to the method. In applications to a single case, Davis (1979, 1980) found that the MIRR ranged from 23.9% to 49.7% depending on the type of estimation procedure used and the length of the estimated or assumed lag. Davis concludes that great care and attention must be paid to the MIRR estimation procedure when computing or comparing rates of return. While assumptions about the length and form of the lag of research benefits are relatively unimportant in the production function estimation, the resulting MIRR is quite sensitive to these assumptions (see Norton 1981 as well).

to expenditures for research at the Maine Agricultural Experiment Station is 82% and 118% with the 1% criterion. Marginal internal rates of return for both research and extension are presented in Table 7.

Table 7. Marginal Internal Rates of Return to Expenditures for Research and Extension by the Maine Agricultural Experiment Station and the Maine Cooperative Extension Service Using 5% and 1% Convergence Criteria

	Convergence Criterion	
	5%	1%
Research (10-year lag)	82%	118%
Extension (5-year lag)	258%	262%

The results of these estimations are particularly high rates of return when compared with rates of return to most private investments. A typical estimate of the real, long-term rate of return on private investments is about 2.5% to 3.5% for most U.S. investments although they have been in the neighborhood of 6% to 9% recently. The estimates here indicate significant under-investment in both agricultural research and extension activities in Maine. Large estimated rates of return for activities such as these are not surprising since under-investment in public goods-producing activities is generally predicted by theoretical models.

Because estimation procedures, scale of aggregation, method of calculation, and lag structures vary from study to study, direct comparisons of marginal internal rates of return from different studies are inexact, but are somewhat instructive. Table 8 provides estimates of production function coefficients, marginal products, and marginal internal rates of return for research, as well as the length of lag from selected past studies and this study. While the estimated coefficient for research from the 5% criterion is somewhat lower than in most other studies and the 1% criterion estimate is reasonably within their range, the marginal product and rate of return are somewhat higher. This apparent inconsistency is caused by the relatively large average product of research in Maine. Since expenditures at the Maine Agricultural Experiment Station are relatively small, the resulting average product is quite large. This large average product results in a large marginal product and subsequently a large internal rate of return.

Of the studies cited in Table 8 all but 2 of the estimated coefficients on research are within 2 standard errors of the estimate of this study and all but 1 are larger. A rigorous statistical comparison of these is not possible. We are unaware of relevant comparisons for the extension expenditures results. Only the Gril-

Table 8. Selected Results from Past Studies of Returns to Agricultural Research

Author	Research Coefficient	Marginal Product $	Rate of Return %	Lag Length (years)	Aggregate*
Griliches	0.059	13.00	600	—	(1)
Peterson	0.062	18.00	33	10	(3)
Evenson	0.210	40.00	—	12	(1)
Bredahl and Peterson	0.041	14.09	36	10	(2)
	0.054	19.58	37	12	(4)
	0.061	25.93	43	12	(3)
	0.099	41.76	46	14	(5)
Norton	0.091	42.00	44-85	10-18	(2)
	0.057	27.00	33-62	10-18	(4)
	0.108	81.00	66-132	10-18	(5)
Norton, Coffey and Frye	0.064	8.94	58	12	(6)
This Study CRITERION					
(5%)	0.045	10.77	82	10	(6)
(1%)	0.071	17.00	118	10	(6)

*Types of research evaluated: (1) U.S. aggregate, (2) cash grains, (3) poultry, (4) dairy, (5) livestock, and (6) state level aggregate.

iches study shows an unambiguously higher rate of return, and the Norton livestock study includes our estimate within its range.

Despite the high estimates of this study, we consider them to be conservative for several reasons. It is a common practice for these studies to use total rather than per-farm research expenditures. These estimates are based on the use of per-farm research expenditures. Estimated coefficients and rates of return from models with total research expenditures were much larger than those reported here. Our estimates have adjusted more carefully for spill-in, but take no credit for spill-out, thus will result in a lower rate of return. Other studies ignore extension expenditures, thus overstate the revenue attributable to research expenditures.

There are several reasons that we might expect the returns to be greater in the case of Maine. First, because the agricultural products are less diverse than in the country in general, or in the states for which we have estimates, there may be more focus to the research. Because the producers of the different commodities tend to be concentrated in particular regions of the state, both delivery and the focus of the research may be more directed and efficient. Finally, since research expenditures at MAES are relatively small with respect to other State Agricultural Experiment Stations, it is expected that the marginal product of the research would be higher at MAES because of the law of diminishing marginal productivity.

We are unaware of any studies relating the returns to other forms of public expenditure. This is probably because data appropriate to this form of analysis are not as available to other sectors as they are for agriculture. Other sectoral studies focus on specific forms of returns and cannot measure as broad a set of returns as can agriculture.

CONCLUSIONS

Estimated rates of return from 82% to 118% for agricultural research and 258% to 262% for extension indicate strongly that there is substantial under-investment in agricultural research and extension in the state of Maine, despite the declining agricultural sector. Maine has a relatively small agricultural sector, and this sector has experienced substantial decline in the past thirty-five years. These conditions may lead one to conclude initially that agricultural research would have low returns in such a situation. The current results suggest, however, that the returns to agricultural research are quite high, even in small sub-sectors of the agriculture industry.

Since even the least of these estimated rates is considerably higher than the opportunity cost of public monies, the results indicate that increased expenditures for agricultural research would be a profitable use of public monies.

LITERATURE CITED

Adams, Gregory. 1988. Evaluation of the Returns to Agricultural Research at the Maine Agricultural Experiment Station. Master's thesis, University of Maine.

Bredahl, Maury, and Willis Peterson. 1976. The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations. *Amer. J. Agr. Econ.* 58:684–92.

Cooperative States Research Service. "Experiment Station Research Expenditures, by State 1951–64." Unpublished USDA-CSRS Records.

Current Research Information System. *Inventory of Agricultural Research.* U.S. Department of Agriculture, Cooperative States Research Service. Various Issues.

Davis, Jeffrey S. 1979. A Comparison of the Alternative Procedures for Calculating the Rate of Return to Agricultural Research Using the Production Function Approach. Staff Paper P79-19, University of Minnesota, Institute of Agriculture, Forestry and Home Economics.

Davis, Jeffrey S. 1980. A Note on the Use of Alternative Lag Structures for Research Expenditure in Aggregate Production Function Models. *Can. J. Agr. Econ.* 28:72–76.

Economic Report of the President, 1988. 1988. Washington DC: United States Government Printing Office.

Evenson, Robert. 1967. The Contribution of Agricultural Research to Production. *J. Farm Econ.* 48:1415–25.

Griliches, Zvi. 1958. Research Costs and Social Returns: Hybrid Corn and Related Innovations. *J. Polit. Econ.* 66:419–31.

Griliches, Zvi. 1964. Research Expenditures, Education and the Aggregate Agricultural Production Function. *Amer. Econ Rev.* 54:961–74.

Hoerl, Arthur E., and Robert W. Kennard. 1970a. Ridge Regression: Biased Estimation for Nonorthogonal Problems. *Technometrics* 12:55–67.

Hoerl, Arthur E., and Robert W. Kennard. 1970b. Ridge Regression: Applications to Nonortogonal Problems. *Technometrics* 12:67–82.

Judge, George G., William E. Griffiths, R. Carter Hill, and Tsoung-Chao Lee. 1980. *The Theory and Practice of Econometrics.* New York: John Wiley and Sons.

Latimer, Robert, and Don Paarlberg. 1965. Geographic Distribution of Research Costs and Benefits. *J. Farm Econ.* 47:234–41.

Lucier, Gary, Agnes Chesley, and Mary Ahearn. 1986. *Farm Income Data: A Historical Perspective.* National Economics Division, Economic Research Service, USDA. Statistical Bulletin No. 740.

Maine Agricultural Experiment Station. *Annual Report* Various Issues.

Norton, George W. 1981. The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations, Revisited. *No. Cent. J. Agr. Econ.* 3:1–12.

Norton, George W., Joesph D. Coffey, and E. Berrier Frye. 1984. Estimating Returns to Agricultural Research, Extension, and Teaching at the State Level. *South. J. Agr. Econ.* 16(2):121–28.

Peterson, Willis L. 1967. Return to Poultry Research in the United States. *J. Farm Econ.* 49:656–69.

Schultz, T.W. 1953. *The Economic Organization of Agriculture.* New York: McGraw-Hill Book Co.

Sundquist, W. B., Cheng Ge Cheng, and George W. Norton. 1981. Measuring Returns to Research Expenditures for Corn, Wheat, and Soybeans. In *Evaluation of Agricultural Research* Miscellaneous Publication 8-1981, Minnesota Agricultural Experiment Station, University of Minnesota.

USDA. Various Issues. *Agricultural Statistics*. Washington DC: U.S. Government Printing Office.

USDA. 1986a. *Farm Real Estate: Historical Series Data, 1950–85.* Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, Statistical Bulletin No. 738.

USDA. 1986b. *Economic Indicators of the Farm Sector: State Financial Summary, 1985.* Agriculture and Rural Economy Division, Economic Research Service, U.S. Department of Agriculture. ECIFS 6-4.

U.S. Department of Commerce *Climatological Data: New England.* Ashville N.C.: National Climatic Center. Various Issues.

U.S. Department of Commerce. 1983. *1982 Census of Agriculture, Volume 1, Part 19.* Washington DC: U.S. Government Printing Office.

Vinod, Hrishikesh D. 1978. A Survey of Ridge Regression and Related Techniques for Improvements Over Ordinary Least Squares. *The Review of Economics and Statistics.* 60:121–131.

White, Fred C., and Joseph Havelicek, Jr. 1981. Interregional Spillovers of Agricultural Research Results and Intergovernmental Finance: Some Preliminary Results. In *Evaluation of Agricultural Research* Miscellaneous Publication 8-1981, Minnesota Agricultural Experiment Station, University of Minnesota.

APPENDIX A: DETAILS OF THE LAG STRUCTURE

Most conventional inputs affect production in the time period in which they are used. Planting more acres or using more fertilizer this year will increase current yield. While it may be argued that fertilizer or pesticide use this year will affect yield in following years through changes in soil quality, these effects will usually be small. The effects of research felt in a current year's production, however, are largely the result of research conducted in previous years, and the current year's research will not have a significant effect on production until some future year. To correctly apportion the research expenditure to the appropriate increase in output for a given year, expenditures on research must be lagged when entered into the production function.

The early studies of Griliches (1964) and Peterson (1967) used simple averages from two arbitrarily chosen previous years. Estimating the same production function using several different lags, Evenson determined that an inverted "V" lag of $6^1/2$ to 7 years mean length is most appropriate. All subsequent studies have adopted a similar inverted "V" lag of mean length from five to seven years. In their evaluation of commodity specific research, Bredahl and Peterson speculate that research on commodities such as crops have a shorter lag than research on more long term agricultural enterprises such as livestock.

Ideally one would like to include in the production function individual variables for expenditures on research for each previous year. If as many previous years expenditures are included as are relevant, then the regression technique can estimate a parameter for each variable and thus estimate the length and structure of the lag.

This approach is very difficult in terms of data requirements and multicollinearity. Evidence from previous research indicates that expenditures from at least 12 previous years are needed to correctly capture all lagged effects. The inclusion of 12 additional variables in the model would make estimation quite difficult. Methods of specifying polynomial distributed lags that require many fewer parameters do exist but even these require the addition of three variables to the equation, and these three variables are likely to be extremely collinear.

Because of these problems, it may be necessary to impose, rather than estimate, the structure of the lag relationship. Previous research has found that the production function coefficient for research is not sensitive to alternate specified lag structures and, further, that the use of current research expenditures or a simple average is appropriate (Davis 1980; Norton 1981).

Many previous studies have estimated the lag structure of research and reported the individual parameter estimates. These results can be used to compute a weighted average of current and past research expenditures giving a more precise measure of research than by using a simple average.

The empirical model was originally estimated using a 10-year Almon polynomial lag. Muliticollinearity problems precluded satisfactory estimation of this model, however, and the Almon lag was thought to be contributing to the multicollinearity. The model was therefore re-estimated with a weighted 10-year lag imposed on research expenditures. Figure A.1 presents a graphical representation of the lag weights for the 10-year distributed lag, and Table A.1 the actual weights.

FIGURE A.1
Lag Distribution Imposed for Maine Agricultural Experiment Station Agricultural Research Expenditures

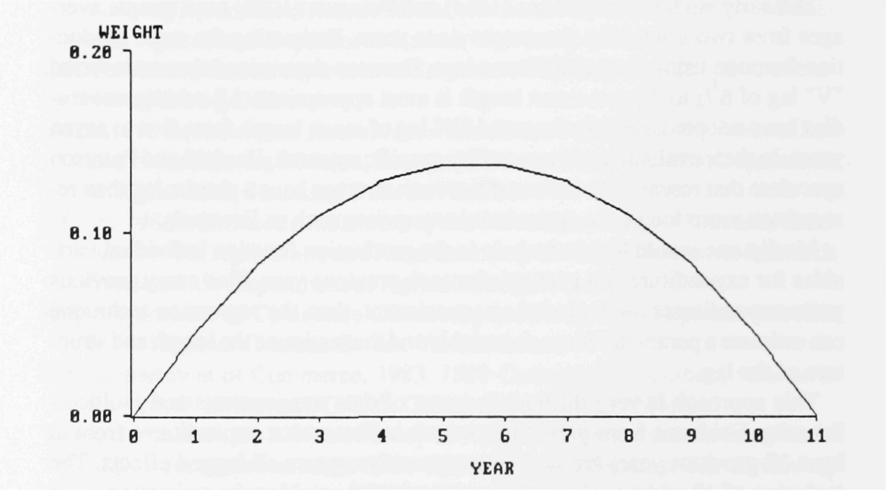


Table A.1. Weights for the 10-Year Distributed Lag Structure Imposed on the Research Variable

Yr :	1	2	3	4	5	6	7	8	9	10
Wght :	.0454	.0818	.1091	.1273	.1364	.1364	.1273	.1091	.0818	.0454

To generate the research variable used in the regression, for any year t:

$$r_T = \sum_{j=T-1}^{10} \Phi_j r_j,$$

where ϕ represents a weight from above.

APPENDIX B: ADDITIONAL DETAILS OF VARIABLE SPECIFICATION

RESEARCH EXPENDITURES

For the years 1941 to 1950, the only data available for research expenditures at MAES are "Total Expenditures" from the Annual Report of the Maine Agricultural Experiment Station. There are at least two problems with these data.

First, "Total Expenditures" includes all expenditures of MAES, not solely those devoted to agricultural research. Since only agriculture-related research expenditures have been included in the research variable for the years 1951 to 1985, the use of total expenditures for the years 1941 to 1950 would be incorrect and lead to bias and inconsistency in the data series.

Second, the CSRS data do not coincide exactly with the Annual Report data. Specifically, "Total Expenditures" in the CSRS data are consistently lower, and lower by a constant proportion, than Total Expenses from the Annual Report, for the overlapping years. Conversations with Mark Anderson, Assistant Director of the Maine Agricultural Experiment Station, revealed that the Annual Report figures for the period under question contain expenditures on non-research projects, potato inspections in particular. Potato inspections were performed during this period as a service to the agricultural sector of the state, and the expenses incurred are reported in the Annual Report figure of "Total Expenses," but were not reported to the CSRS as a component of research expenditures. Because of the existence of these type programs, it was decided that the CSRS data better represented the correct level of agricultural research expenditures.

Because both of these problems distorted the data in the same way, making the 1941 to 1950 observations abnormally large, it was necessary to adjust the 1941 to 1950 observations. Data from both sources for the years 1951 to 1960 were compared. It was found that the CSRS "Total Expenditures" were consistently about 87% of the Annual Report "Total Expenses." The Annual Report based expense figures were therefore multiplied by .87 to obtain an estimate of total research expenditures.

The ratio of agricultural research expenditures to total research expenditures for the years 1951 to 1960 were then calculated using the CSRS data. This ratio was quite stable during this period at about 93%. The adjusted Annual Report figures were, therefore, further multiplied by .93 to arrive at the estimated annual expenditure on agricultural research.

SPILLOVER

Data from the Current Research Information System (CRIS) on State Agricultural Experiment Station (SAES) research expenditures by "Commodity, Resource or Technology not Associated with a Specific Commodity" allowed for the exclusion of all expenditures for non-agricultural research or for research on commodities not produced in Maine for the years 1970 to 1985.

Similar data from the Cooperative States Research Service allow the exclusion of all expenditures on "non-spillover" research for the years 1951 to 1964. For the years 1965 to 1969, 1972, 1975, and 1976 no data are available. Spillover research expenditures for these years were estimated by interpolating between existing observations.

The remaining expenditures are weighted by state, with the weights linearly decreasing with increasing distance from Maine. Distance is hypothesized to capture two effects, transferability due to similarity in soils and climates, and transfer costs. Greater distance implies greater soil and climatic differences making the research results less applicable to Maine agriculture. Also the greater the distance a state is from Maine the more difficult and costly will be the transmission of research results, *ceteris paribus*.

Distance is calculated by determining the approximate latitude and longitude coordinates for the middle of each state and the approximate latitude and longitude for the center of Maine. Triangulation is used to determine the relative distance of each state from Maine. The resulting measure adjusts for climatic similarity with Maine both through elimination of research on commodities not produced in Maine and with the distance weighting.

As discussed earlier, the productivity effects of agricultural research usually do not occur in the year that the research is undertaken. This makes it necessary to lag research expenditures before entering them into the equation to be estimated. Since spillover is simply out-of-state agricultural research, the same considerations apply. In fact, the lag between spillover expenditures and in-state benefits is probably longer than the lag between in- state research expenditures and in-state benefits.

The problems associated with lagging research expenditures (degrees of freedom and multicollinearity) also apply to spillover. In the case of spillover, the degrees of freedom problem is particularly troublesome. Data constraints are a particular problem in this study and data on State Agricultural Experiment Station (SAES) research expenditures before 1951 are unavailable. Assuming a 10-year lag, 1961 would be the earliest year in which the time series could begin. Such a series does not contain enough observations to permit statistical estimation of the hypothesized model.

Research by Davis and Norton indicates, however, that it is not necessary to lag research expenditures when using the production function approach to evaluate returns to agricultural research. Davis found production function coefficients estimates showed little difference when the lag structure on research was changed or omitted.

In light of these results and the unavailability of data on SAES research expenditures before 1951, it was decided not to lag spillover research expenditures. Thus, the spillover variable for a given year is the distance weighted amount of expenditures on agricultural research at other SAES that is thought to be applicable to Maine agriculture, in that year.

The above specification of spillover does not capture all spillover effects, and several significant omissions quickly come to mind; foreign research, research done at 1890 Institutions and veterinary schools, private research, and the spill-out of research effects from Maine. Foreign research, particularly some Canadian research, may have a significant spillover effect, but data on these research expenditures are not available thereby precluding the inclusion of these expenditures in spillover variable.

Similarly, adequate data on research expenditures at 1890 Institutions and veterinary schools are unavailable. The available data indicate that these expenditures tend to be small, however, and it is felt that their exclusion will not seriously affect the results.

Research done by private firms clearly has a large effect on agricultural production, but because of the private nature of this research, there are no reliable data on this type of research expenditure. Most private research is concerned with improving the quality of purchased inputs, and it is expected that a large portion of the returns to this research will be captured in increased input prices. The effect of this research, while large, will not significantly bias the results; while the returns to this research are not captured in the spillover variable, they are captured in expenditures on conventional inputs.

The above omissions are omissions of non-MAES research expenditures which may be affecting Maine agricultural production. Their omission will bias the effect of in-state research upward. There are other spillover effects, however, that may bias the returns to in-state research downward. Most importantly, the spillover variable is really a spill-in variable. The coefficient on this variable measures the effect that other research has had on agricultural production in Maine. There is no variable that measures the effects of Maine research on agricultural production elsewhere, or spill-out. Thus the total social returns to agricultural research at MAES will be underestimated by this amount. It is believed, however, that this amount is small, and furthermore, that out-of-state returns to research are of less importance to state policy makers.

The pattern of real spillover expenditures is extremely similar to that of MAES agricultural research (Figure B.1). Real weighted spillover expenditures increase steadily from a minimum of $4,018,014 in 1951 to $7,771,976 in 1971. Real spillover expenditures then fall to $6,930,408 in 1973, then rise sharply for seven years, reaching $8,942,440 in 1980, before declining for two years, to $8,077,786 in 1982. From 1983 onward, real spillover expenditures increase sharply, to a maximum value of $9,608,517 in 1985. The per-farm spillover figures are represented in Figure B.2.

FIGURE B.1
Real Total Spillover Research Expenditures, 1951–1985
(1977 DOLLARS)

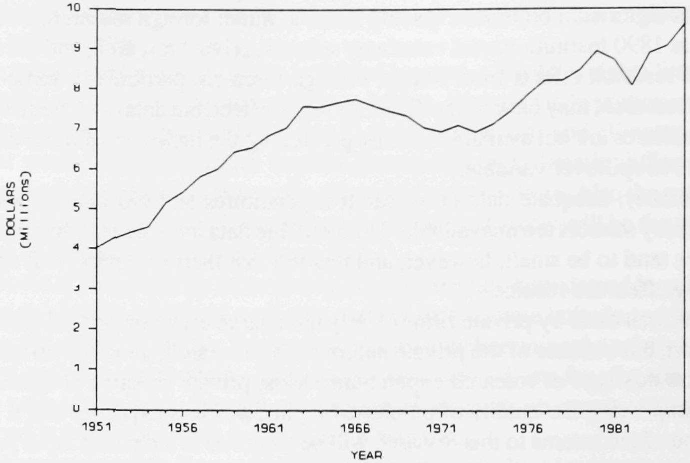
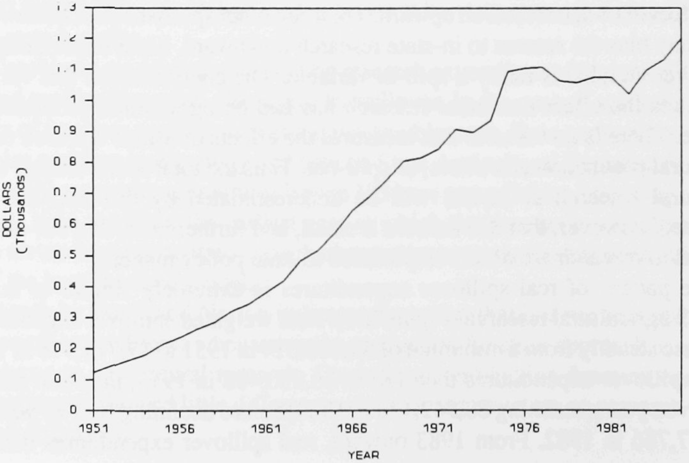


FIGURE B.2
Real Per-Farm Spillover Research Expenditures, 1951–1985
(1977 DOLLARS)



APPENDIX C: A BRIEF DESCRIPTION OF THE RIDGE REGRESSION TECHNIQUE

Ridge regression was first proposed by Hoerl and Kennard (1970a) as an alternative, and possibly superior, estimation technique to ordinary least squares (OLS) when severe multicollinearity between the independent variables exists. The ridge regression procedure involves adding small positive amounts to the diagonal element of the X'X matrix, and estimating the model using these new data. The ridge regression estimator, B*, can thus be written as $B^*=(X'X + kI)^{-1} (X'Y)$, for $k>0$. Notice that OLS is a special case of ridge regression where $k=0$. For $k>0$, B* is a biased estimator of B, with the bias an increasing function of k. Also, as k approaches infinity, B* approaches 0, so the direction of the bias is known; ridge regression estimates are "conservative," they are biased toward 0. This is an appealing property since OLS estimates tend to be too large, in absolute value, when multicollinearity is present (Hoerl and Kennard 1970b; Norton, Coffey, and Frye 1984).

The chief advantage of ridge regression in the presence of multicollinearity is that the mean square error (MSE) of the estimates is often reduced (Vinod 1978). Hoerl and Kennard (1970a) show that there always exists a $k>0$, such that B*(k) has a smaller MSE than B, the OLS estimate. Since the bias in B* is an increasing function of k, and the variance of B* is a decreasing function of k, the MSE gain is achieved by choosing a k such that the reduction in variance is greater than the increase in bias.

Ridge regression is, however, controversial in the econometric literature. The improvement of ridge regression estimates over OLS, measured in terms of MSE reduction, are contingent on the choice of k. Specifically, Hoerl and Kennard (1970a) show that ridge regression estimates are superior to OLS estimates, in terms of MSE, for $k < \sigma^2/\theta^2_{max}$, where θ^2_{max} is the largest orthonormal characteristic vector of X'X. Judge et al. (1980) point out that this property implies a MSE improvement over only a limited parameter space and this space is defined by B, the true parameter value, and σ^2, both unknown parameters. If a value for k is chosen outside this parameter space, the estimates will be inferior to OLS.

A common practice is to use the sample data to estimate the parameters B and σ^2, and thus determine the correct value for k. As Judge et al. (1980) point out, this makes the choice of k dependent on the sample data and thus non-stochastic. Therefore, the Hoerl and Kennard result of MSE improvement no longer holds. Furthermore, the sampling distributions of the ridge regression estimator are unknown, making hypothesis tests and confidence intervals invalid (Judge et al. 1980).

Despite these rather formidable theoretical problems, numerous Monte Carlo studies have been performed in which ridge regression almost always returned better estimates from collinear data than OLS (Vinod 1978). These results have led to some authors giving qualified recommendations for use of the procedure under conditions of multicollinearity (Norton, Coffey, and Frye 1984; Vinod 1978).

Once it is decided to adopt the method of ridge regression, one faces the task of choosing a value for k. Hoerl and Kennard (1970b) suggest the use of a ridge trace to determine the correct value of k. Since 1970 several alternative methods of selecting k have been proposed; the most important of these are detailed in Judge et al. (1980). None of these proposals has been shown to dominate the ridge trace method, however, and all have the cost of additional complexity. It was therefore decided to adopt the ridge trace method for this study.

A ridge trace is simply a two dimensional plot of the estimated parameter values (and sometimes standard errors) against increasing values of k. The standard process is to estimate the model repeatedly, using successively higher values of k, and to then use the ridge trace to select the proper value of k. Hoerl and Kennard (1970b) suggest that k should be selected on the basis of stability of the estimates, *a priori* expectations (reasonable signs and magnitudes of the parameter estimates) and the sum of squared errors. For more detail about the application of ridge regression techniques, see Hoerl and Kennard (1970 a & b) Vinod (1978), and Judge et al. (1980).

The estimates for this study used values for k were from 0 to .35 with iterations of .005. The ridge trace of these results is presented in Figure C.1 and Figure C.2. Using *a fortiori* stability criteria of greatest parameter change less than 5% and 1% for two subsequent iterations, convergence was achieved at k = .105 and k = .205.

FIGURE C.1
Ridge Trace Coefficient Magnitudes vs. k
(Research, Spillover, Extension)

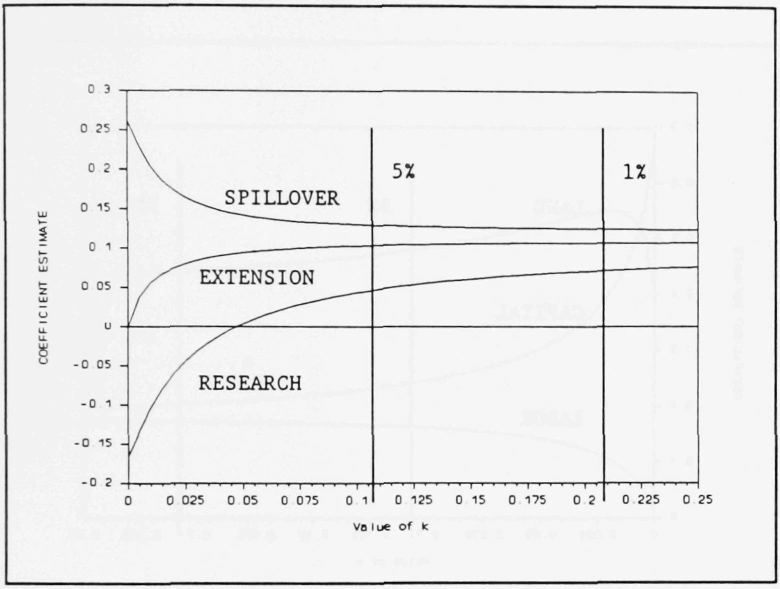
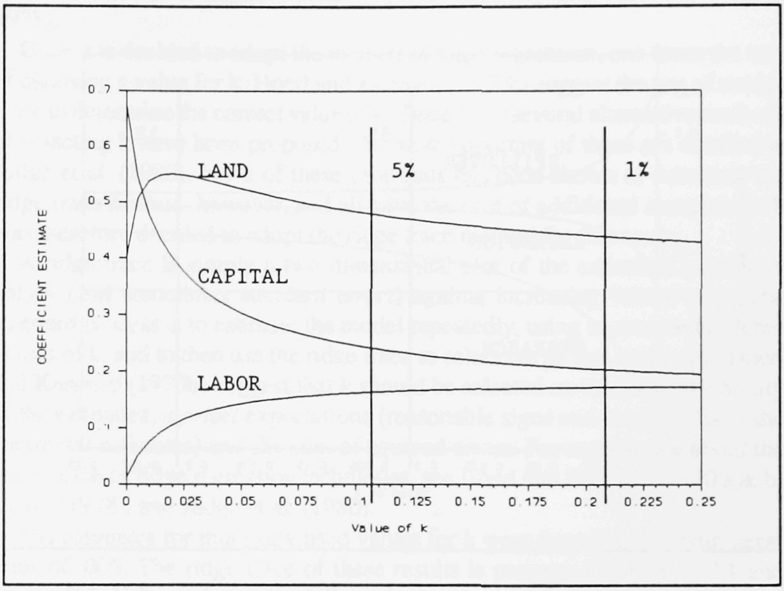


FIGURE C.2
Ridge Trace Coefficient Magnitudes vs. k
(Land, Labor and Capital*)



* The trace for rainfall is omitted because the value is approximately constant at about - 0.04.