The Returns to Agricultural Research in Maine: The Case of a Small Northeastern Experiment Station

James D. Leiby and Gregory D. Adams

Estimates of the marginal internal rate of return to expenditures for research by the Maine Agricultural Experiment Station are presented. Estimates are performed using ridge regression under an array of specifications, including alternative functional forms, lag structures, costs of public funds, and variable specifications. The results are consistent with many previous results that imply an underinvestment in agricultural research.

Federal and state budget expenditures have come under increasing pressure. As a result of this pressure, in many states, funds to carry on agricultural research at state agricultural experiment stations are experiencing increased scrutiny. It is sometimes argued that since the number of farms and agricultural acreage are declining (ignoring much greater increases in agricultural income and production), public funding of agricultural research should decline as well.

In states like those of the Northeast, where agriculture's share of the total economy has become relatively small, the pressure on public funding of agricultural research is particularly severe. The critical issue is, of course, not the growth or decline of the agricultural sector, but the rate of return to expenditures for public agricultural research.

It has been argued for many years that there is significant underinvestment in agricultural research. This argument is based largely on many estimates of the rate of return to agricultural research that invariably show much higher returns than those that we observe in the private sector. Table 1 provides an overview of some of these estimates. There have been, however, a number of criticisms of such estimates. The criticisms focus on a number of issues, including accounting for extension activities, accounting for the effects of research expenditures from sources other than the aggregate considered, the appropriate length of time over which the research provides benefits, the appropriate aggregation with which to evaluate research expenditures, and the cost of public funds for the research.

The purpose of this paper is to estimate the rate of return to state investments in agricultural research in Maine over the period 1951 to 1985. We present an array of estimates resulting from the various assumptions and specifications implied by the criticisms listed above. The approach followed here is the ex post estimation of a state-level aggregate agricultural production function. We follow closely the work of Norton, Coffey, and Frye, who estimated the rate of return to agricultural research in Virginia.

Background and Approach

The empirical study of returns to research in agriculture begins with Schultz 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. There have been many subsequent estimates of these returns, many of which follow the basic Griliches methodology (see Norton and Davis for a more-thorough review of this literature).

Most studies of the returns to agricultural re-

James D. Leiby is an assistant professor, University of Maine, and Gregory D. Adams is a graduate student, University of California at Berkeley. Appreciation is expressed to Wallace Huffman, Michele Marra, James McConnen, and Alan Kezis. Anonymous reviewers provided a number of useful suggestions. MAES Publication 1522.

search have been conducted on either a national, single commodity, or single research area level. There have been several studies of the returns to research on a state level. Of these, many follow the production function approach, often using the parameter estimates from national studies to derive state-level marginal products (see, for example, Bredahl and Peterson or Babb and Pratt). Norton, Coffey, and Frye derived an explicit state-level production function.

Following the production function methodology of Griliches (1964), suppose some output is produced with the production technology

$$(1)\qquad Q = f(z_1, \ldots, z_n),$$

where Q is agricultural production and $z_1, \ldots, z_n$ are factors of production.

Although we normally consider production functions in terms of units of quantity, deflating agricultural income or expenditures on inputs by appropriate price indices yields the equivalent of a quantity index. This approach allows aggregation across different commodities for purposes of estimation. In this way, we rewrite equation (1) as

$$(2)\qquad Y = g(x_1, \ldots, x_n),$$

where Y is the real value of agricultural production and the x_i's represent the real expenditure on any factor i.

A distinct advantage of the use of revenue and expenditures in the production function is that $\partial Y/\partial x_i$ is the marginal revenue from a marginal expenditure of one dollar on factor i. This leads directly to the rate of return. For our purposes, if Y is the revenue from agricultural production in Maine, and $x_i = r$ is the expenditure for research, $\partial Y/\partial r$ is the marginal value of research in Maine.

Because the resulting extra revenue from research generally occurs over many years after the research is actually completed, the productive effects of the research must be allocated over time by a weighted lagging scheme and an internal rate of return must be calculated. That is, given weights w_j, the marginal internal rate of return (ρ) may be found as the solution to

$$(3)\qquad \frac{\partial Y}{\partial r} \sum_{j=1}^{t} [w_j/(1 + \rho)^j] - 1 = 0,$$

where j is the number of years over which the research results contribute to income.

Thus for this study we estimate a function of the form

$$(4)\qquad Y_t = f(r_t, s_t, e_t, l_t, n_t, v_t),$$

where Y_t is the value of agricultural output in Maine during year t (per farm); r_t is a polynomial lag-weighted allocation of agricultural research expenditures at the Maine Agricultural Experiment Station; s_t is a polynomial lag-weighted adjustment for the effects of research from sources other than the Maine Agricultural Experiment Station during year t; e_t is a polynomial lag-weighted allocation of agricultural extension expenditures by the Maine Cooperative Extension Service (per farm); l_t is the value of land services used in Maine agricultural production during year t (per farm); n_t is the value of hired labor services used in Maine agricultural production during year t (per farm); and v_t is the value of capital services used in Maine agricultural production during year t: the sum of expenditures on feed and livestock purchases, seed, fertilizer and lime, fuels and oil, electricity, pesticides, repair and operation, machine hire and custom, fire,

Table 1. Selected Results from Past Studies of Returns to Agricultural Research

Author	Research Coefficient	Marginal Product ($)	Rate of Return (%)	Lag Length (Years)	Aggregate[a]
Griliches	0.059	13.00	600	—	(1)
Peterson	0.062	18.00	33	10	(3)
Evenson	0.210	40.00	—	12	(1)
Bredahl and	0.041	14.09	36	10	(2)
Peterson	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)

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

wind, and hail insurance, miscellaneous, depreciation, property taxes, and non–real estate interest (per farm).

Estimation of the parameters of this model poses some significant difficulties. First is the difficulty of collecting state-level data with enough detail and frequency to be useful. Details of the data and variable specification are provided in the next section. Perhaps the most important difficulty is the relatively severe multicollinearity to be expected among several of the regressors. A detailed discussion of our approach to the multicollinearity problem follows the data description.

The Data

The dependent variable for this study is the real value of Maine farm output per farm (Y_t). This is the sum of "Cash Marketing Receipts," "Nonmoney Items and Related Income" (on-farm consumption of farm output), and "Inventory Change" for the years 1951 to 1984 from Lucier, Chesley, and Ahearn. Data for 1985 were obtained from *Economic Indicators of the Farm Sector, 1985* (U.S. Department of Agriculture). These figures were deflated by the Index of Prices Paid by Farmers, All Items (1977 = 100)(USDA 1986).

Maine per farm real revenue has shown less year-to-year variability than the national figures, with a strong upward trend from the early 1950s to the middle 1970s, then a sharp decline to the middle 1980s. Real per farm revenue increased from a minimum of $9,316 in 1951 to a maximum of $67,818 in 1976, then declined to $39,590 in 1985 (Lucier, Chesley, and Ahearn).

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. Since MAES conducts research in areas other than agriculture, it is necessary to account for only those expenditures that apply to agriculture.[1]

Following Griliches, most studies of this type have considered the public-expenditures variables in total, while considering the traditional production inputs and output on a per farm basis. The reason is that the public expenditures are viewed as noncongestable; that is, all of the research is available to all farmers without diminution. While this view is theoretically appealing, its realism may be somewhat problematic. There may be some congestability of research results if the costs of transmitting research results depend on the number of farms or if the research is of a highly specific nature. If research results are completely congestable or specific to individual farms, then research should be considered at the farm level like other inputs. If it is a pure public good, it should be considered in total. Since truth lies somewhere between the two extremes, we consider research expenditures both in total and on a per farm basis in our analysis.

Maine total real agricultural research expenditures (r_t) increased steadily from $1.4 million in 1952 to $2.9 million in 1971. Expenditures then fell to between $2.2 million and $2.4 million until the early 1980s, after which they increased to about $3 million in 1985. The general pattern of research expenditures per farm is similar to total state expenditures. However, because of a steady decline in the number of farms in Maine during the period, per farm, real research expenditures increased more quickly and smoothly than total real research expenditures, particularly during the 1951 to 1971 period.

There is an important complication for defining the expenditures-for-research variable. Our interest is in the returns to expenditures of the Maine Agricultural Experiment Station, but agricultural production also will be affected by both private research and research carried on by other agricultural experiment stations.

Data on expenditures for private research are not generally available, so ad hoc adjustments or assuming the effects to be zero are the common approaches to this problem. We follow the latter approach under the assumption that at least a portion of private research is concerned with results that can be captured by the price of a product (or is strictly proprietary). Its effects, therefore, are somewhat reflected in the costs of the factors of production. Since the factor costs are considered explicitly in this analysis, some of the effects of private research should be already accounted for in the production function.

The problem of "spillover" from other public research is considerably more difficult. Since there is considerable interaction among the research and extension personnel of different states, it is clear that the spillover effects are important. Thus, to consider the agricultural revenue effects of research

[1] These data were collected from several sources, including the Current Research Information System (CRIS) and various annual reports of the Maine Agricultural Experiment Station. Research expenditures, spillover, and extension expenditures are deflated by the Implicit Price Deflator for Gross National Product: Government Purchases of Goods and Services (1977 = 100) (USDA) to obtain real research expenditures. To allow for the lagged effects and conserve degrees of freedom, MAES expenditures were collected beginning with 1941.

without making an adjustment for this spillover would be to overstate the effectiveness of the Maine research.

Several previous studies—including Latimer and Paarlberg; Evenson; Bredahl and Peterson; Norton; White and Havlicek; and Sundquist, Cheng, and Norton—all found significant effects from the spillover of research from other state agricultural experiment stations. We create a research-spillover adjustment by first calculating the total research expenditures by other experiment stations on commodities that are closely related to those produced in Maine (in 1977 dollars), then applying a geographic weighting scheme. Under this scheme the most distant states and those with the least production in common with Maine receive the least weight, while those that are closest and produce many similar products receive the greatest weight.[2]

The issue of whether or not to aggregate the spillover variable is the same as for the research variable. Since our spillover variable is specified as an index, the meaning of per farm spillover is unclear, and since the magnitude of the spillover parameter is not of interest to this study, we consider only total spillover in our regressions. The patterns of weighted spillover expenditures (s_t) are very similar to the pattern of MAES research expenditures. The primary difference is of magnitude. Weighted spillover expenditures are larger and increase more rapidly than MAES expenditures during the 1951 to 1985 period. Our measure increased from \$4.0 million in 1951 to \$7.7 million in 1971. It then fell slightly until 1973 and increased to a maximum of \$9.6 million, with a slight decline during the 1980 to 1983 period. Total weighted spillover expenditures average about \$7.0 million over the period.

In the study by Griliches (1964), research and extension expenditures are considered as a single variable. Later studies note the fundamental difference between these two activities and include them as separate inputs. The measure of expenditures on agricultural extension services (e_t) used in this study is the annual real expenditures of the University of Maine Cooperative Extension (UMCE). While not all expenditures of the UMCE are devoted to agricultural extension, there are no complete data that relate the proportion of extension expenditures dedicated to agriculture. We assume the proportion to be relatively constant over the period of the study and use "total real UMCE expenditure" from 1951 through 1985 to account for cooperative extension activities, recognizing that overcounting extension expenditures will bias the extension coefficient toward zero. Since most extension activities are clearly congestable, it seems most reasonable to consider extension on a per farm basis, as we do in our regressions.

The pattern of real UMCE expenditures is similar to that of the research-expenditures and spillover variables. They rose from a minimum of \$1.6 million in 1951, fell slightly in the early 1960s, and rose steadily from the mid-1960s to the mid-1970s to a level just over \$4.0 million. Since the mid-1970s, real UMCE expenditures have averaged about \$3.5 million. On an annual basis, real UMCE expenditures rose from about \$50 per farm in the early 1950s to more than \$500 per farm in the mid-1970s, and they have averaged around \$450 per farm since the late 1970s.

Because adequate land price data are not available to us, we use acres of land in agricultural use as our land variable (l_t). However, because the land in farms in Maine has fallen from about 4.4 million acres in 1950 to about 1.6 million acres in 1985, it is probable that the quality of the land in use will have changed dramatically. The lack of land price data makes adjustments for quality changes difficult. To adjust for quality changes, we assume that the land in different uses represents different land quality and adopt the weights from Hoover, used by Norton, Coffey, and Frye for their Virginia study. For each year our land variable is calculated as: *Land* = *Harvested Cropland* + 0.5(*Land in Pasture*) + 0.075(*Total Woodland*) + 0.25(*Land in Farms* − *Total Cropland* − *Total Woodland*). Data for this acreage 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.

For Maine, adjusted acres average about 800,000 acres per year and ranged from a high in 1951 of almost 1.3 million acres to a low in 1985 of about 565,000 acres. On a per farm basis, the trend was quite different, beginning with a low in 1951 of about 40 acres, reaching a high in 1975 of about 88 acres, then declining to around 72 acres per farm in 1985, with an average of about 64 acres per farm over the whole thirty-five years.

Because most Maine farms are primarily family owned and operated, a very large proportion of farm labor is family labor, much of which is unpaid and thus is not recorded in any statistical series. Reasonably good data exist for the wages paid to hired labor, but for unpaid family labor in Maine we have only the average numbers of family farm

[2] The geographic weights are calculated by the approximate degrees east and north, of one degree west of Hawaii, to the center of each state, standardized to sum to one. Expenditures are deflated by the Implicit Price Deflator for Gross National Product: Government Purchases of Goods and Services (1977 = 100) (USDA).

workers with no annual information as to the number of hours worked or the quality of the farm labor. National data for the ratio of total to hired labor are available annually and hired labor is multiplied by this value to create our labor variable. Our variable for labor (n_t) is "hired labor expenses" from Lucier, Chesley, and Ahearn and *Economic Indicators of the Farm Sector, 1985* (USDA 1986) multiplied by the ratio of total to hired farm labor for the United States (USDA). Per farm labor expenditures are deflated by the Index of Prices Paid by Farmers; Wages, 1977 = 100 to obtain the real expenditures for labor.

Hired labor expenses on Maine farms have been extremely variable over the thirty-five years studied. For the state as a whole, real wages paid by farms were about \$50 million in 1951 and rose to a high of about \$70 million in 1958. From the 1960s through the middle 1980s labor expenses fell to between \$30 million and \$40 million per year. Real wages paid per farm were lowest in 1951, about \$1,500, then rose to a high of about \$7,000 in 1971, after which they averaged about \$5,000 per year from the 1970s through 1985. Our per farm real labor expenditures, adjusted to account for family labor, range from a low of about \$5,600 in 1954 to a high of almost \$25,000 in 1970, averaging slightly less than \$13,000.

For this study, capital (v_t) includes 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 to account for short-term capital, and depreciation, property taxes, and non–real estate interest to account for long-term capital. Data are from Lucier, Chesley, and Ahearn and *Economic Indicators of the Farm Sector, 1985* (USDA 1986). Per farm capital expenditures were deflated by the Index of Prices Paid by Farmers; Production Items, Total, 1977 = 100.

Our measure of the real flow of capital services per year for the state as a whole begins at just less than \$250 million in 1951, increases to about \$350 million in 1975, and then declines to about \$270 million in 1985, averaging just under \$300 million. Per farm capital use rose from a low of about \$7,200 per farm in 1951 to a high of about \$52,000 in 1975, then declined to less than \$34,000 per farm in 1985, averaging just less than \$28,000 per farm per year for the thirty-five-year period.

Since few agricultural production functions are estimated without some adjustment for weather, we considered a number of representations of weather, including "average July rainfall in Maine" (U.S. Department of Commerce) following Norton, Coffey, and Frye. No specification for weather was significant in any of the models that were tested. Weather is thus not considered here.

Empirical Issues

Because of the nature of these data, we expect a high degree of multicollinearity. Research expenditures at the state level are highly correlated across states, perhaps through mutual response to federal policies. Traditional factors of production, particularly at the level of aggregation required by the available data, would be expected to be highly correlated. Preliminary examination of the data reveals severe multicollinearity among several of the variables. All variables are highly (and significantly at a 99% level of confidence) positively correlated. Research expenditures are correlated with all other regressors with correlation coefficients exceeding 0.67.

Multicollinearity can be thought of as a problem of sparse data or poor experimental design. Thus, the preferred solution to collinearity problems is the collection of more data. As in most economic studies, this is not reasonably possible here. The next-best solution to such problems is the imposition of exact linear restrictions on the parameters. In the absence of theoretical restrictions, this is generally the restriction of some parameters to zero, which may trade the multicollinearity problem for an omitted-variables problem.

Since the appropriate solutions for multicollinearity are not available to us, we are left with a choice between no analysis and the application of some ad hoc approaches to its solution. Here we follow one such technique known as ridge regression (Hoerl and Kennard 1970a, 1970b). This technique is employed and described in great detail by Norton, Coffey, and Frye in their similar study.

Ridge regression imposes increasing bias to the parameter estimates while at the same time increasing the precision of those estimates. Hoerl and Kennard condition the $X'X$ matrix by the addition of a small positive scalar (k) to the diagonal elements so that

$$\hat{\beta} = [X'X + kI]^{-1} X'Y. \tag{5}$$

There are no a fortiori criteria for the selection of the scalar. The general practice is to continue adding small increments to k until the coefficient estimates stabilize. Since a definition of stability is left to the researcher, it is possible to "choose the results" of the estimate. To avoid this form of pretesting, we imposed our own a fortiori convergence criteria based on the maximum iterative percent change of any parameter estimate (5% and

1%), with fixed increments to k (0.005) over a fixed range (0 to 0.25). The restrictions that we impose on our estimates, while arbitrary, are an effective approach to eliminating the researcher bias.

The ordinary least squares (OLS) results from multicollinear data are unbiased, but inefficient estimates. OLS parameter estimates are very sensitive to changes in specification or data. Therefore, the individual parameter estimates are not reliable estimates of the true parameters. The ridge regression procedure approaches this difficulty by deliberately trading bias for more precision of parameter estimates, thereby attempting to more closely approximate the true parameter. Monte Carlo studies performed by Hoerl and Kennard (1970a, 1970b) suggest that ridge estimators may be a closer approximation to the true parameters than those from OLS under conditions of severe multicollinearity.

While biased, there are certain attributes of the ridge estimates that make them more attractive in a study such as this. Because the direction of bias of ridge regression is known to be toward zero, ridge regression may be thought of as the imposition of the Bayesian prior that all parameters are zero (Hoerl and Kennard 1970a, 1970b; Johnson and Wallace).[3] Since the prevailing result of previous returns-to-research estimates is that returns to research are quite high, the zero prior imposed by ridge analysis is appropriately conservative.

While the ridge regression technique provides an approach to addressing the multicollinearity problem, it is clearly not a perfect fix. Our predisposition is that the less collinearity addressed by the ridge regression, the more acceptable are the results of the application. That is, wherever possible, impose restrictions on parameters rather than estimate them, then test among restrictions, rather than parameters. This implies that the most, rather than the least, restrictive functional forms are favored unless there is clear evidence that they are inferior. It also implies aggregating variables whenever that seems reasonable, restricting lags to the shortest possible length to preserve data, and eliminating higher-order coefficients unless the model including them is significantly superior. Details of these restrictions are provided in the sections relating the data and estimation results.

Estimation and Specification

Functional Form

Most studies of this type follow a Cobb-Douglas specification. This specification was tested by Griliches (1964) and found not to be overly restrictive. Besides the computational ease of the log-linear formulation, the parameters of the Cobb-Douglas specification are particularly amenable to interpretation in the framework of this study since the coefficients represent the elasticity of agricultural revenue with respect to the various right-hand-side variables. However, since this application is somewhat different from that of Griliches and for much more recent data, we perform nested tests to determine the restrictiveness of the Cobb-Douglas form.

Estimates of all specifications of the model were performed as both translog and Cobb-Douglas functions. Because of the limited degrees of freedom, the only second-order terms of the translog that were considered were between research and other regressors. Nested likelihood ratio tests of the restrictions that the higher-order terms were zero were performed.

In ridge regression, at different levels of the biasing parameter k, there are different error sums of squares. This results not only from different parameter estimates, but differently conditioned data. Therefore, across-model comparisons should be made at the same value of k. For these tests, the level of k was chosen as the level at which the translog model converged to the 5% and 1% criteria described above. In no case were the results of the translog estimates significantly different from those of the Cobb-Douglas; that is, the restriction that the six extra translog parameters were zero had no significant effect on the performance of the model. We therefore report only the Cobb-Douglas results here.

Lag Structure

Three variables included in the regressions imply some lag structure since their benefits may be spread over a long period: research, spillover, and extension. Because of limited degrees of freedom and the already poorly conditioned information matrix, it is neither possible nor reasonable to estimate these lag structures directly. We thus impose, rather than estimate, the lag structures. Various imposed lags are tested sequentially using likelihood ratio tests to determine the most appropriate lag structure.

Some of the earliest studies, like that of Griliches (1964) and Peterson, use the simple averages from two arbitrarily chosen previous years to account for the lagged effects of research. Evenson applies several different lag structures and determines that an inverted "V" lag of mean length of 6.5 to 7.0 years is most appropriate to his data. Since Evenson's study, most estimates have relied on similar lag structures, but of varying lag lengths. Pardey

[3] Alternatively, Johnson and Wallace suggest that ridge regression can be thought of as combining data with an exact restriction on β.

and Craig cite evidence that long lags of more than thirty years may be appropriate to capture all of the research benefits. Bredahl and Peterson, on the other hand, suggest that for commodity-specific research and some types of commodities, the effects of research may be relatively short-lived.

Without clear guidance as to the appropriate lag length, to allow for the allocation of research effects over time, eight- to sixteen-year polynomial (quadratic) lags are imposed (in two-year increments) for our estimation. This range is selected based on the results of Evenson and the procedures of White and Havlicek. As a smaller experiment station, MAES tends to focus on a larger proportion of applied research which should reduce the life span of research products, so we expect shorter lags than those suggested by Pardey and Craig.

We expect a similar, although perhaps somewhat longer, effect of spillover; thus, specifications for spillover include lags of eight to eighteen years (in two-year increments). Previous studies by Davis and Norton suggest that the parameter estimates for studies such as this are not sensitive to lag specification. Since the spillover variable represents a relatively smooth, stationary series, it is likely that different lag specifications will have little effect. Because of this possibility, with the hope of conserving degrees of freedom, we also test unlagged spillover expenditures in our estimates.

We expect that extension expenditures should have a considerably shorter life span than either research or spillover, and thus impose shorter lags for analysis. Polynomial lags, like those for research and spillover for zero through six years (one-year increments), are imposed on extension expenditures.

The different imposed lags imply 180 estimates for the Cobb-Douglas form.[4] Likelihood ratio tests are performed in a sequential fashion, testing the restriction that the parameters for the longer lags are zero, as suggested by Judge. As before, it is necessary to perform each test at a single level of the biasing parameter k for both estimates. Since several of the longer lag structures fail to converge to both of our criteria, we use the convergence levels for the shortest lags considered, eight years for research, zero years for both spillover and extension. The sequential tests of the lag length for either spillover or extension indicated no statistically significant differences among these specifications. This is consistent with the results of Norton and Davis.

Because of the reduced information in the data, the longest lag structures (spillover, eighteen-year lag) failed to converge at either of our criteria prior to the a fortiori imposed upper limit of $k = 0.25$. Our convergence criteria are not met with any spillover lag of greater than ten years. As the spillover lag is increased from zero, the output elasticity of research increases (for any given research lag), thus imposing no lag on spillover yields the most conservative estimator of returns and allows the most information to be applied to the model.[5]

If the effects of spillover were a focus of this research, it would be important to incorporate lags into the specification of the spillover variable, as with research. Since spillover is not of direct interest, to preserve information and because of the more conservative nature of our estimates with a zero spillover lag, we report only the results from the estimates conducted with no imposed lag on spillover.

The results of the tests for extension lags are very similar to those for spillover. Changing the lag on extension expenditures had no significant effect on the model (the estimates of the research coefficient increased very slightly with longer extension lags). Likelihood ratio tests showed no significant difference between any pair of estimates with different extension lags. We therefore report only the results that use unlagged extension expenditure.

Although likelihood ratio tests do not select a "correct" length of lag for the research expenditures variable, the estimated output elasticities for different lag specifications appear to significantly differ, and the differences are not monotonic with the length of lag. Since the estimate of the rates of return to research is very sensitive to the estimate of the output elasticity, we present the results of all five lag specifications for research expenditure.

Ridge Regression Results

Ten ridge regressions are presented with k values of 0 to 0.25 in increments of 0.005. For all regressions, approximate R^2 values are greater than 0.95, and F tests of the significance of the whole model indicate significance at a greater than 99% level of confidence for all regressions. All parameter estimates are of positive sign in all regressions (at convergence).

For all regressions, the dependent variable is per farm real revenue. Land, labor, capital, and extension expenditures are all considered as per farm.

[4] For each of these, both the translog and the Cobb-Douglas are estimated and the Cobb-Douglas restrictions tested. As previously noted, in no case were the restrictions rejected.

[5] Note that the longest lags show a significant difference from the shortest lags, however the estimates of returns to research are larger. It is not clear whether this difference is the result of the different model or a less well conditioned information matrix.

Table 2. Ridge Regression Results, Research Specified as Total, 5% Convergence

Research Lag in Years (k)	Variable					
	Research	Extension	Spillover	Land	Labor	Capital
8 ($\hat{}$0.045)						
β	0.272	0.107	0.234	0.629	0.116	0.284
t^a	1.44	2.71	1.76	5.26	1.65	6.19
10 ($\hat{}$0.045)						
β	0.336	0.010	0.218	0.601	0.116	0.277
t^a	2.25	2.53	1.66	4.90	1.68	6.18
12 ($\hat{}$0.05)						
β	0.419	0.096	0.208	0.561	0.119	0.261
t^a	3.84	2.67	1.64	4.99	1.77	6.34
14 ($\hat{}$0.05)						
β	0.380	0.93	0.212	0.557	0.130	0.266
t^a	4.83	2.69	1.67	5.00	1.93	6.25
16 ($\hat{}$0.05)						
β	0.270	0.097	0.230	0.579	0.141	0.280
t^a	3.31	2.98	1.79	5.12	2.09	6.19

[a] $\hat{\beta}$/approximate standard error.

Spillover is considered as state total. Neither extension expenditures nor spillover are lagged. Research expenditures are considered both as total state expenditures and as per farm expenditures. Research expenditures are considered with imposed polynomial lags of eight to sixteen years in two-year increments. The results presented in Tables 2 through 5 are for the a fortiori convergence criteria that no parameter changes by more than 5% or 1%.

Tables 2 and 3 present the results of the five ridge regression estimates that treat research as noncongestable; that is, research is considered as total state expenditures. The t ratios presented in the tables represent the ratio of the parameter estimate to its approximate standard error. The exact sampling distribution of this statistic is unknown, but common practice, following Hoerl and Kennard, is to consider a ratio greater than 2.0 as significant.

At the 5% convergence criterion (Table 2), no model has all parameter estimates that are more than twice their standard error. The research coefficient is significant for all but the eight-year lag specification. At the 1% convergence criterion (Table 3), all coefficients in all models are more than twice their standard error. The estimated output elasticities of research increase as the lag structure increases from eight to twelve years and decreases for lag structures longer than twelve years. Estimates of the output elasticity of research range from 0.27 to about 0.42 for these specifications.

The results of the estimates with the assumption that research is congestable (research considered as per farm expenditure) are qualitatively quite distinct from those from the noncongestable assumption (Tables 4 and 5). For lag lengths of less than fourteen years, all coefficients are more than twice their approximate standard error. For research lags of more than twelve years, neither the research nor the spillover coefficients were more than twice their standard error for the 5% criterion. The estimated output elasticity of research decreased monotonically from the shortest to the longest lag structures. For the per farm research specification, the estimated output elasticity of research ranged from 0.045 to 0.099.

Interpretation of Results

To convert the regression results to rates of return by equation (3), first calculate the marginal products of research (MP_r) as $\hat{\beta}_r\bar{Y}/\bar{r}$, where $\hat{\beta}_r$ is the coefficient for research and $\bar{Y}/\bar{r}$ is the arithmetic average of the ratio of revenue per farm to research expenditure as it is defined for the particular model. The estimated marginal product of research is then allocated over the imposed lag structure prior to solving equation (3).[6] For the total-expenditure specification, the ratio $\bar{Y}/\bar{r}$ is multiplied by the average number of farms since the raw marginal product is the per farm marginal product of one dollar's worth of total research. Marginal products are expressed in dollars of revenue per dollar of research expenditure. Table 6 presents the estimated marginal products of research and marginal internal rates of return (IRR) to research for all five lag structures, two research specifications, and two convergence criteria.

[6] Equation (3) is solved using numerical approximation.

Table 3. Ridge Regression Results, Research Specified as Total, 1% Convergence

Research Lag in Years (k)	Variable					
	Research	Extension	Spillover	Land	Labor	Capital
8 (0.11)						
$\hat{\beta}$	0.349	0.126	0.252	0.566	0.132	0.231
t^a	3.086	5.85	2.33	7.56	2.23	9.71
10 (0.105)						
$\hat{\beta}$	0.387	0.119	0.239	0.545	0.133	0.227
t^a	4.93	5.53	2.20	7.23	2.24	9.55
12 (0.105)						
$\hat{\beta}$	0.422	0.114	0.233	0.522	0.135	0.222
t^a	7.12	5.44	2.17	7.21	2.30	9.45
14 (0.105)						
$\hat{\beta}$	0.393	0.112	0.235	0.518	0.145	0.224
t^a	9.06	5.56	2.18	7.24	2.46	9.27
16 (0.115)						
$\hat{\beta}$	0.333	0.114	0.246	0.522	0.157	0.227
t^a	7.65	6.32	2.31	7.60	2.69	9.47

[a] $\hat{\beta}$/approximate standard error.

For both specifications, estimated marginal internal rates of return decrease monotonically as the length of the imposed lag structure increases. Estimates range from a high of more than 700% (total research, eight-year lag) to a low of less than 42% (per farm research, sixteen-year lag). Note that three of the estimates are less than twice their estimated standard error. Estimated rates of return are always higher for the 1% criterion than for the 5% criterion because the ridge estimators are still increasing (they eventually fall to zero). The estimated rates of return for the total-research-expenditure specification are substantially higher than the per farm expenditure specification.

Figures 1 and 2 provide traces of the estimated rates of return for the total-research-expenditure and per farm research expenditure specifications for all values of the biasing parameter k. Notice that the estimates based on the total-expenditure specification stabilize very quickly but are much greater than the estimates from the per farm expenditure specification.

The Extra Cost of Public Funds

Alston and Hurd point out "that the opportunity cost of a dollar of government spending is not one dollar is generally well known to economists . . ."

Table 4. Ridge Regression Results, Research Specified as per Farm, 5% Convergence

Research Lag in Years (k)	Variable					
	Research	Extension	Spillover	Land	Labor	Capital
8 (0.075)						
$\hat{\beta}$	0.077	0.111	0.262	0.567	0.160	0.260
t^a	2.86	4.92	2.17	6.31	2.53	7.48
10 (0.085)						
$\hat{\beta}$	0.063	0.117	0.266	0.570	0.166	0.260
t^a	2.33	5.79	2.26	6.82	2.70	7.91
12 (0.09)						
$\hat{\beta}$	0.062	0.118	0.266	0.565	0.170	0.256
t^a	2.31	6.08	2.29	7.03	2.81	8.09
14 (0.085)						
$\hat{\beta}$	0.057	0.121	0.204	0.516	0.181	0.223
t^a	1.96	5.63	1.64	8.61	3.45	10.08
16 (0.115)						
$\hat{\beta}$	0.045	0.125	0.221	0.570	0.167	0.265
t^a	1.60	5.97	1.57	6.71	2.66	7.44

[a] $\hat{\beta}$/approximate standard error.

Table 5. Ridge Regression Results, Research Specified as per Farm, 1% Convergence

Research Lag in Years (k)	Variable					
	Research	Extension	Spillover	Land	Labor	Capital
8 (0.140)						
$\hat{\beta}$	0.099	0.117	0.271	0.514	0.172	0.223
t^a	5.66	7.92	2.64	8.30	3.10	10.26
10 (0.165)						
$\hat{\beta}$	0.088	0.120	0.275	0.511	0.180	0.220
t^a	5.057	9.18	2.82	8.96	3.40	10.92
12 (0.17)						
$\hat{\beta}$	0.085	0.120	0.275	0.510	0.184	0.220
t^a	4.78	9.42	2.84	9.11	3.52	11.00
14 (0.165)						
$\hat{\beta}$	0.080	0.122	0.219	0.516	0.181	0.223
t^a	4.11	8.95	2.11	8.61	3.45	10.08
16 (0.215)						
$\hat{\beta}$	0.067	0.124	0.230	0.515	0.180	0.229
t^a	3.55	8.91	1.94	8.537	3.30	9.81

[a] $\hat{\beta}$/approximate standard error.

(p. 149). Although it is clear that the cost of a one dollar research expenditure is more than one dollar, prior estimates of the rate of return to research fail to consider the extra costs associated with public funding. Fox provides a thorough review of the issue of the extra burden of public funds as it applies to the public funding of agricultural research. He cites evidence from other studies that suggests that the marginal opportunity cost of public funds may be as high as $1.56. In that review, an extra social burden of tax collection is incorporated to adjust previously estimated internal rates of return to agricultural research. This process implied that previous estimates of internal rates of return were substantially biased upward.

To account for such undercounting of the cost of public funds, we recompute our IRR based on the assumption that there is significant social cost in the collection and distribution of public funds. Of the studies cited by Fox, the extra burden of taxes ranges to greater than $0.50 per dollar of taxes collected. To be conservative by allowing for

Table 6. Summary of Estimates of Internal Rates of Return, Marginal Products, and Convergence Levels for All Reported Models

Research Lag in Years	Total Research Expenditure		Per Farm Research Expenditure	
	5% Convergence	1% Convergence	5% Convergence	1% Convergence
8 years				
IRR	578.45%[a]	729.68%	174.85%	219.39%
MP_r	$48.84	$62.76	$12.81	$16.58
(k)	(0.045)	(0.110)	(0.075)	(0.140)
10 years				
IRR	465.20%	525.41%	104.42%	138.67%
MP_r	$60.69	$69.51	$10.49	$14.73
(k)	(0.045)	(0.105)	(0.085)	(0.165)
12 years				
IRR	405.39%	408.65%	79.33%	102.41%
MP_r	$75.29	$75.94	$10.29	$14.15
(k)	(0.050)	(0.105)	(0.090)	(0.170)
14 years				
IRR	287.01%	295.71%	60.50%[a]	77.80%
MP_r	$68.54	$71.03	$9.50	$13.13
(k)	(0.050)	(0.105)	(0.085)	(0.165)
16 years				
IRR	175.83%	207.28%	41.74%[a]	57.26%
MP_r	$48.79	$60.06	$7.37	$11.09
(k)	(0.050)	(0.115)	(0.115)	(0.215)

[a] Less than two approximate standard errors from zero.

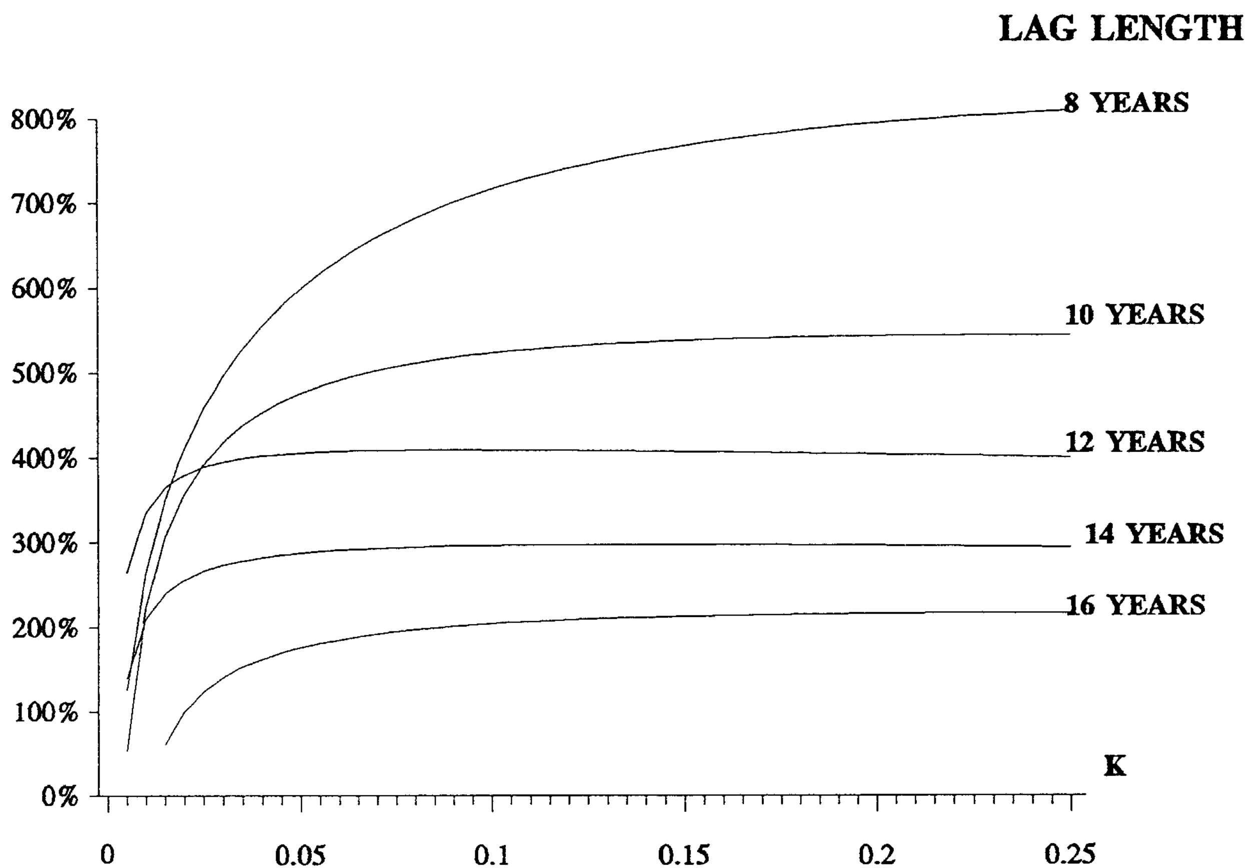

Figure 1. Estimated Internal Rate of Return (Total Expenditure Research Specification)

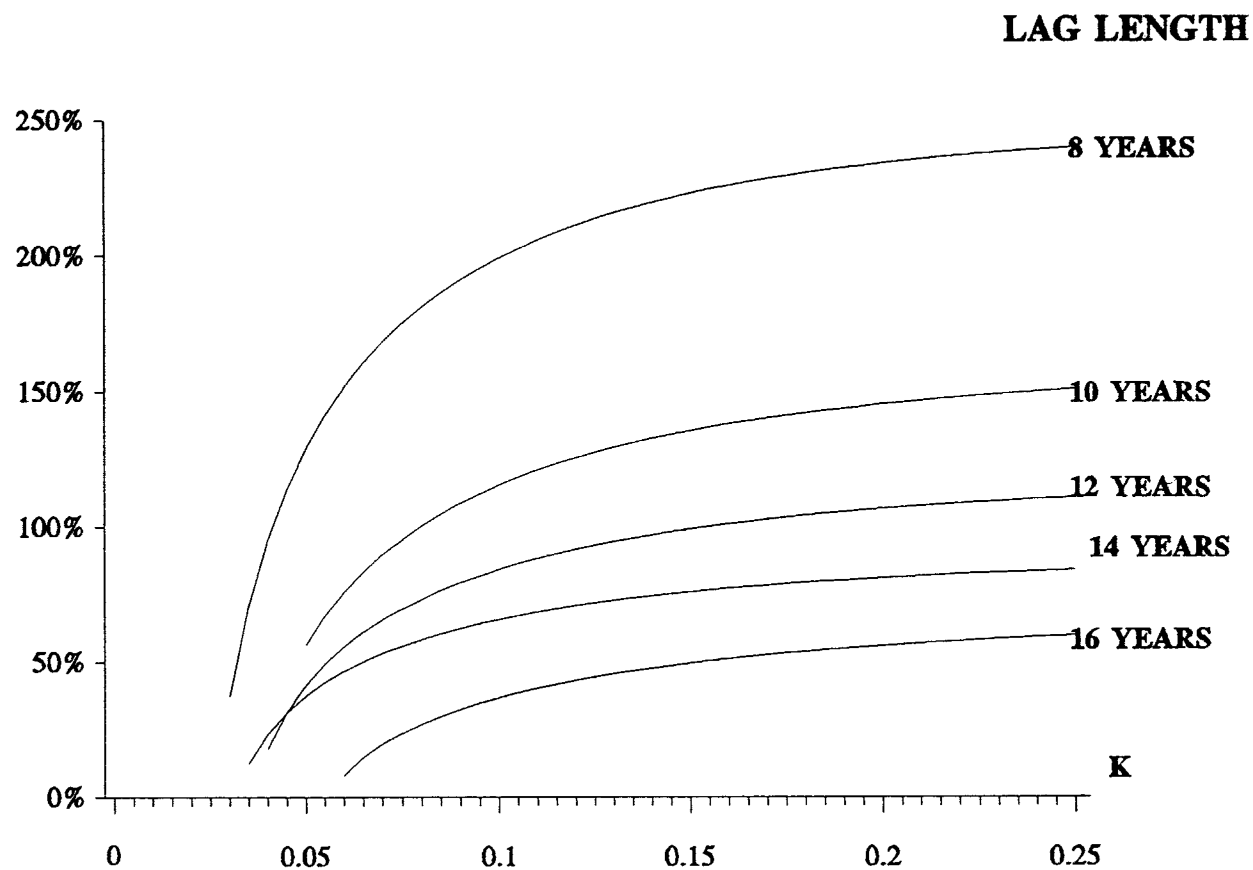

Figure 2. Estimated Internal Rate of Return (Per Farm Expenditure Research Specification)

Table 7. Summary of Estimates of Internal Rates of Return with Two Assumptions Relating the Cost of Public Research Expenditures

Research Lag in Years	Extra Marginal Cost of Public Funds ($)	Total Research Expenditure		Per Farm Research Expenditure	
		Convergence Criterion (%)		Convergence Criterion (%)	
		5%	1%	5%	1%
8	0.00	578.45[a]	729.68	174.85	219.39
	1.00	309.02	386.71	93.71	118.77
10	0.00	465.20	525.41	104.42	138.67
	1.00	254.14	285.50	56.87	77.25
12	0.00	405.39	408.65	79.33	102.41
	1.00	270.09	272.05	44.04	58.25
14	0.00	287.01	295.71	60.50[a]	77.80
	1.00	162.29	168.21	33.78	44.80
16	0.00	175.83	207.28	41.74[a]	57.26
	1.00	103.41	120.96	22.61	32.92

[a]Less than two approximate standard errors from zero.

further costs of distribution of the public funds (for example, the portion of administrative costs dedicated to the allocation of the funds), we assume that each dollar of experiment station expenditure has an extra burden of one dollar. Table 7 provides estimates of the rates of return for each of our specifications using a two dollar social cost for each dollar of research expenditures.

Fox also cites estimates of the range of returns to private research of up to 36%.[7] In Table 7, only three of the point estimates of the rate of return to public expenditures on agricultural research in Maine fall below 36%.[8] While the imposition of the assumption of a 100% extra burden of public funding greatly reduces our estimates of the internal rates of return, they are, for the most part, still greater than estimates of the rates of return to private research.

Summary and Conclusions

Following previously used procedures, but with a large number of alternative specifications for estimation, the marginal internal rates of return to agricultural research are estimated. Estimates are performed with research benefits spread from eight to sixteen years following initial research expenditures. Two extreme assumptions regarding the public goods nature of agricultural research are imposed. Estimates of the IRR are calculated assuming either a 0% or a 100% extra burden of collecting and distributing public funds.

Estimates of the rate of return to MAES research expenditures decrease as the imposed lag length increases and if the research results are considered congestable. The point estimates of the marginal internal rate of return to research expenditure range from almost 42% to more than 700%, well above reasonable assumptions about the opportunity rate of interest of public funds. Doubling the cost of public funds, while significantly reducing the estimates of the rates of return, still indicates high rates of return. Calculations of the internal rate of return that used a two dollar total cost for each one dollar research expenditure ranged from over 22% to almost 400%.

Thirty-four of forty estimates of IRR are greater than two approximate standard errors from zero, and all point estimates are greater than 20%. Since opportunity rates of return are normally taken to be well below 20%, we regard this as substantial evidence that there is underinvestment in public agricultural research in Maine. Thus, despite the decline in the number of farms and individuals on farms, expenditure on agricultural research continues to be a worthwhile investment.

[7] The production function approach followed here assesses only the private returns to the public research expenditures and thus does not account for any external benefits or costs.

[8] Note that if the returns to private research expenditures are indeed in this range, it is evidence of underinvestment in private research as well.

References

Alston, Julian M., and Brian Hurd. "Some Neglected Social Costs of Government Spending in Farm Programs." *American Journal of Agricultural Economics* 72 (1990):149–59.

Babb, E. M., and J. E. Pratt. "Changes in Agricultural Productivity and Funding for Research and Extension Education in Indiana, 1964 to 1977." *Station Bulletin no. 205*. Purdue University, Department of Agricultural Economics and Agricultural Experiment Station, West Lafayette, IN, October 1978.

Barnard, Charles H., and John Jones. *Farm Real Estate: Historical Series Data, 1950–85*. Statistical Bulletin no. 738. U.S. Department of Agriculture, Economic Research Service, National Resource Economics Division, 1986.

Bredahl, Maury, and Willis Peterson. "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations." *American Journal of Agricultural Economics* 58 (1976):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. "A Note on the Use of Alternative Lag Structures for Research Expenditure in Aggregate Production Function Models." *Canadian Journal of Agricultural Economics* 28 (1980):72–76.

Evenson, Robert. "The Contribution of Agricultural Research to Production." *Journal of Farm Economics* 48 (1967):1415–25.

Fox, Glenn. "Is the United States Really Underinvesting in Agricultural Research?" *American Journal of Agricultural Economics* 67 (1985):806–12.

Griliches, Zvi. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." *Journal of Political Economy* 66 (1958):419–31.

———. "Research Expenditures, Education and the Aggregate Agricultural Production Function." *American Economic Review* 54 (1964):961–74.

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

———. "Ridge Regression: Applications to Nonorthogonal Problems." *Technometrics* 12 (1970b):67–82.

Hoover, Dale. "Land Prices in United States Agriculture." Ph.D. diss., University of Chicago, 1961.

Johnson, T., and T. D. Wallace. "Multicollinearity and NO-FLIRP." *Journal of Economic Development* 1 (1976):29–35.

Latimer, Robert, and Don Paarlberg. "Geographic Distribution of Research Costs and Benefits." *Journal of Farm Economics* 47 (1965):234–41.

Lucier, Gary, Agnes Chesley, and Mary Ahearn. *Farm Income Data: A Historical Perspective*. Statistical Bulletin no. 740. U.S. Department of Agriculture, Economic Research Service, National Economics Division, 1986.

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

Norton, George W. "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations, Revisited." *North Central Journal of Agricultural Economics* 3 (1981):1–12.

Norton, George W., Joseph D. Coffey, and E. Berrier Frye. "Estimating Returns to Agricultural Research, Extension, and Teaching at the State Level." *Southern Journal of Agricultural Economics* (1984):121–28.

Norton, George W., and Jeffrey S. Davis. "Evaluating the Returns to Agricultural Research: A Review." *American Journal of Agricultural Economics* 63 (1981):685–99.

Pardey, P. G., and Barbara Craig. "Causal Relationships between Public Sector Agricultural Research Expenditures and Output." *American Journal of Agricultural Economics* 71 (1989):9–19.

Peterson, Willis L. "Return to Poultry Research in the United States." *Journal of Farm Economics* 49 (1967):656–69.

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

Sundquist, W. B., Cheng Ge Cheng, and George W. Norton. "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, April 1981.

U.S. Department of Agriculture. *Agricultural Statistics*. Washington, DC: U.S. Government Printing Office, various years.

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

U.S. Department of Commerce. *Climatological Data: New England*. Ashville, NC: National Climatic Center, various issues.

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

White, Fred C., and Joseph Havlicek, Jr. "Interregional Spillovers of Agricultural Research Results and Intergovernmental Finance: Some Preliminary Results." In *Evaluation of Agricultural Research*, edited by G. W. Norton, W. L. Fishel, A. A. Paulsen, and W. B. Sundquist, 60–70. Miscellaneous Publication 8-1981. Minnesota Agricultural Experiment Station, University of Minnesota, April 1981.