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Spillovers and the Returns to Agricultural Research for Potatoes

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Returns to investments in potato research were estimated for the United States and six subregions. The study combines time-series and cross-sectional data to estimate the supply response for potatoes. Two research variables, research within the state and within the region, were included as exogenous variables to identify spillovers of research results.

The rate of return to investments in potato research in the U.S. is estimated at 79%. Of this, 31% accrues to states conducting the research and 69% is accounted for by the spillover effects.

Key words: regional spillovers, research evaluation

Introduction

Agricultural research is an investment aimed at improving the well-being of farmers and consumers by reducing costs, increasing output, improving product quality, or introducing new products (Arndt, Dalrymple, and Ruttan). Recognizing the importance of this investment, federal and state governments have made a sizable investment in agricultural research. Since the late 1950s, over sixty studies have examined the economic benefits of investments in agricultural research.

Aggregate evaluations of the impacts of investments in agricultural research in the United States have been conducted by Griliches (1964); Latimer; Evenson (1968); Lu and Cline; Peterson and Fitzharris; Evenson, Waggoner, and Ruttan; White, Havlicek and Otto; Davis; White and Havlicek; and Braha and Tweeten. Measuring research output at an aggregate level has limitations in terms of relevance to decision making at the micro level. Evenson (1967) argues that a more useful approach is to measure research productivity for a particular commodity or a particular agricultural experiment station.

Several studies have analyzed the impacts of investments in research for a wide range of agricultural commodities in several countries (Araji 1980; Norton and Davis; Ruttan). Araji (1988) evaluated the rates of return to investments in the Idaho agricultural experiment station. Norton and Paczkowski estimated the rate of return to agricultural research and education in Virginia. Most of these studies show rates of return of over 25%. However, these studies have generally ignored the spillover effects of research results among states, regions, or countries.

Research generates new knowledge which may be disseminated far beyond where the research is conducted. The spillover effects of research results among states or regions have received little attention by economists evaluating the economic impacts of agricultural research. Latimer and Paarlberg recognized the spillover effect of research results but were unable to empirically measure the effect of spillovers across states. Subsequently, a few

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studies have provided empirical estimates of the spillover effects of research for aggregate agriculture (Huffman and Evenson).

A major source of research benefits is the acceleration of the transfer of knowledge among countries or regions (Evenson and Kislev). The highest rate of research spillover occurs within the same region, and lower spillover rates are evident in neighboring regions (Huffman and Evenson). The spillover rate for agricultural research results is based upon the similarities of the geoclimatic conditions, the biological features of the individual commodities, and the research and extension infrastructure (Evenson and Kislev; Otto; Huffman and Everson). Similarly, Griliches (1979) emphasizes the importance of technological types and industrial similarities as the basis for technological transfer between industries.

Selecting regions based upon geoclimatic conditions and the biological and industrial (utilization) features of the commodity considered is crucial for accurate empirical measurement of the spillover effects of research results. Given the differences in the biological features of agricultural commodities, it is appropriate to empirically measure the spillover effects of research results for a single commodity. Funding allocations for agricultural research at the state experiment station level are generally made, at least in part, to individual commodities. Thus, the measurement of the spillover effects of research results for individual commodities has some potential for generating information that can be used in planning future research. This study accounts for spillovers in analyzing the returns to research for a single commodity—potato.

The economic impacts of investments in research have been evaluated for most major agricultural commodities in the United States, except for potatoes. Potatoes are an important U.S. agricultural commodity with an annual farm value of about $2.1 billion and a processed value of over $4 billion. During the 1987–91 period, an annual average of $26.7 million of U.S. public funds was invested in potato research (USDA/CSRS). About 20% of this investment was in genetic research. During this period, the central region produced 20.8% of the nation's potatoes, processed 14.4% of the potatoes, and accounted for 30.7% of total public investments in potato research (USDA/ERS; USDA/CSRS). The central region had an average research investment of 9.1 cents for each cwt of potato production. The eastern region produced 12.7% of the nation's potatoes, processed about 3% of all potatoes being processed, and accounted for 34.7% of public investments in potato research. The eastern region had an average research investment of 16.86 cents for each cwt of potatoes it produced. The western region produced 66.5% of the potatoes in the U.S., processed 82.6% of the total processed potatoes, and accounted for only 34.55% of public investments in potato research. The western region had an average research investment of only 3.2 cents for each cwt of potato production, the lowest of the three regions (table 1).

The wide differences in public research expenditures for potato research across major regions can be attributed to several factors. Potato production has shifted among regions, while research allocations have not adequately adjusted. Regions with more heterogeneity in production and geoclimatic conditions require more research than other regions. Interest group pressure of potato growers places differential demands on research programs across regions.

Estimating the returns to potato research must account for the internal benefits to each state conducting the research and the spillover effects to other states. The spillover effects of research results have policy implications concerning the allocation of public research funds among states and regions.

Table 1. Potato Production and Public Investments in Research by Regions

Region	Production[a] 1987–91 Avg. (1,000 cwt)	Investment in Research (1987–91 Avg) Genetic[b] ($)	Nongenetic[b] ($)	Total[b] ($)	Res/Prod Ratio (¢/cwt)
Western					
Arizona	1,597	0	27,637	27,637	1.70
California	17,616	119,683	1,278,204	1,397,887	7.90
Colorado	23,143	139,659	287,444	427,103	1.80
Idaho	109,208	318,276	1,775,171	2,093,447	1.90
Montana	2,465	0	38,632	38,632	1.50
New Mexico	3,487	0	24,974	24,974	0.70
Nevada	2,538	0	585	585	0.02
Oregon	23,117	174,526	920,250	1,094,776	4.70
Texas	3,284	156,945	216,557	373,502	11.37
Utah	1,592	0	5,513	5,513	0.03
Washington	67,587	898,621	1,791,998	2,690,619	3.98
Subtotal	255,634	1,807,210	6,366,965	8,174,475	3.20
Central					
Illinois	849	0	27,370	27,370	3.20
Indiana	945	24,686	194,595	219,281	23.20
Iowa	256	25,352	266,184	291,537	100.14
Michigan	10,960	68,357	797,138	865,495	7.90
Minnesota	16,596	346,095	1,698,216	2,044,311	12.32
Missouri	1,140	28,227	13,361	41,588	3.70
Nebraska	3,079	30,077	55,996	86,073	2.80
North Dakota	20,270	284,583	797,574	1,082,157	5.33
Oklahoma	1,750	0	366,365	366,365	20.93
South Dakota	1,929	0	39,456	39,456	2.00
Wisconsin	22,314	535,998	1,672,761	2,208,759	9.90
Subtotal	80,088	1,343,376	5,929,016	7,272,392	9.10
Eastern					
Delaware	1,559	0	12,408	12,408	0.08
Florida	8,267	0	382,706	382,706	4.60
Maine	21,186	212,128	1,887,444	2,099,572	9.90
No. Carolina	2,871	121,331	714,334	836,092	29.10
New Jersey	986	84,114	154,902	239,016	24.24
New York	7,380	734,100	1,659,396	2,393,496	32.40
Pennsylvania	4,408	309,311	1,055,690	1,365,001	30.96
Rhode Island	275	0	214,079	214,079	77.84
Virginia	1,785	13,329	656,761	670,090	37.54
Subtotal	48,717	1,486,721	6,725,312	8,212,033	16.86
Total	384,440	4,637,307	19,021,593	23,658,900	6.15

[a] Source: USDA/ERS, 1993.

[b] Source: USDA/CSRS, September 1991.

Relevant Literature

The aggregate production function has been used to study the spillover effects of research results between states or regions on an ex post basis. Evenson, Waggoner, and Ruttan analyzed the spillover effects of research for aggregate agriculture in the U.S. and estimated rates of return ranging from 45% to 130%, with from one-third to two-thirds of the benefits accruing to the states conducting the research. Evenson and Kislev estimated the productivity effects of research spillovers in wheat and maize for a cross section of countries. They concluded that borrowed knowledge caused a strong and persistent increase in crop yields. White and Havlicek measured the spillover effects of research results for aggregate agriculture for ten regions. The rates of return estimated by White and Havlicek ranged from 31% to 62%.

Measuring the spillover effects of research for aggregate agriculture does not provide adequate information for allocating research funds among individual commodities. To overcome this problem, supply response models have been estimated for individual commodities (Zentner; Fox, Roberts, and Brinkman). Otto used yield response functions to evaluate cross-commodity comparisons of research productivity. His results show that research spillovers are significant in explaining yields for photosensitive crops like corn, sorghum, and soybeans. Research spillovers patterned on climatic and variety similarities plus basic research expenditures by other states were significant in explaining variations in wheat yield.

The spillover effects of research results are evident not only in agriculture but also in other industries. Jaffe estimated the returns to research and development (R and D) capital were 40% higher than the case would be in the absence of spillovers among firms in the industrial sector. Mansfield et al. concluded that the social rate of return from industrial innovation accounting for the spillover effects was 77% to 150% greater than the private return.

Other studies have used a cost function framework to estimate the effects of spillovers. Levin and Reiss, using cross-sectional data on U.S. firms, estimated that a 1% increase in R and D spillovers caused average costs to decline by about 0.05%. Bernstein and Nadiri (1989) estimated the effects of intraindustry spillovers for four U.S. industries. They show that a 1% increase in spillovers decreased average costs by 0.2%. In these studies, R and D spillovers were defined as a single aggregate. Individual industries were not treated as a separate spillover source when estimating spillover effects and rates of return.

Bernstein and Nadiri (1988) developed a model for five U.S. high-tech industries which allowed each industry to be a distinct spillover source. Their results showed significant differences among industries as both spillover senders and receivers. Bernstein extended this approach and applied it to nine Canadian industries. The production cost of each industry is regressed on the R and D capital of all other industries, which allows for the sources and beneficiaries of each interindustry R and D spillover to be traced.

Methods and Procedures

The study covered the 21 major potato-producing states, which include the northernmost states of the U.S. and some states in the southwest and southeast (table 2). The analysis covered the period 1977–90, with earlier years in the data set used to capture the lagged effects of research on production.

Table 2. Potato Production, Investments in Research, Type of Potato Produced, and Production Method for the Six Major Potato Producing Subregions

Subregion	Production[a] 1987–91 Avg. (1,000 cwt)	Research Investment[b] ($)	Res./Prod. Ratio (¢/cwt)	Primary Potato Type	Production Method
Central					
MN	16,596	2,044,311	12.32	chipping	dry
ND	20,270	1,082,157	5.33	chipping	dry
NE	3,079	86,073	2.80	chipping	dry
SD	1,929	366,365	2.04	chipping	dry
Total	41,874	3,578,906	8.54	chipping	dry
Great Lakes					
MI	10,960	865,495	7.90	fresh & chipping	irrigated
OH	1,750	366,365	20.93	fresh & chipping	irrigated
WI	22,314	2,208,759	9.90	fresh & chipping	irrigated
Total	35,024	3,440,619	9.82	fresh & chipping	irrigated
Northeast					
ME	21,186	2,099,572	9.90	fresh & chipping	dry
NY	7,380	2,393,496	32.40	fresh & chipping	dry
PA	4,408	1,365,001	30.96	fresh & chipping	dry
Total	32,974	5,858,069	17.76	fresh & chipping	dry
Northwest					
ID	109,208	2,093,447	1.90	frozen, fresh, & seed	irrigated
MT	2,465	38,632	1.50	frozen, fresh, & seed	irrigated
OR	23,117	1,094,776	4.70	frozen, fresh, & seed	irrigated
WA	67,527	2,690,619	3.98	frozen, fresh, & seed	irrigated
Total	202,317	5,917,474	2.92	frozen, fresh, & seed	irrigated
Southeast					
FL	8,267	382,706	4.60	nonstorage fresh & chipping	dry & irrigated
NC	2,871	836,092	29.10	nonstorage fresh & chipping	dry & irrigated
Total	11,138	1,218,798	10.94	nonstorage fresh & chipping	dry & irrigated
Southwest					
AZ	1,597	27,637	1.70	fresh	irrigated
CA	17,616	1,397,887	7.90	fresh	irrigated
CO	23,143	427,103	1.80	fresh	irrigated
NM	3,487	24,974	0.70	fresh	irrigated
TX	3,284	373,502	11.37	fresh	irrigated
Total	49,127	2,251,103	4.50	fresh	irrigated

[a] Source: USDA/ERS, 1993.

[b] Source: USDA/CSRS, September 1991.

For the purpose of this study, the 21 largest potato-producing states were grouped into six subregions (table 2). Although no two potato states are exactly alike, considerations in the grouping process included geography, climate, production methods, and type of potato produced. Growers in the central region produce much of the nation's fall-crop chipping potatoes under dryland conditions. The Great Lake states produce fresh and chipping potatoes, mostly under irrigation. Northeastern growers produce fresh and chipping potatoes mostly without irrigation. Potatoes in the northwest are grown under irrigation primarily for frozen and fresh markets. Potatoes in the southeast are grown for nonstorage fresh and chipping markets with harvest in winter, spring, and summer. The southwest subregion primarily produces fresh market potatoes under irrigation with harvest in all four seasons.

Supply Response Model

In this study, the ex post approach is used to analyze the economic impact of investment in potato research. Modern supply response analysis is illustrated in the framework outlined by Houck and Ryan. Their basic framework can be used to explain either production or acreage. Expected market conditions include the expected prices of the commodity under consideration and competing commodities. These expected prices are deflated by cost of production. The dependent variable lagged one period is often included as an exogenous variable in order to reflect a partial adjustment process (Nerlove). Otherwise, a supply response model without a lagged dependent variable indicates that all adjustments in the dependent variable in response to a change in the exogenous variable are completed within one period.

The potato supply response model developed for this study uses state-level production as the dependent variable. Production of potatoes is assumed to be a function of relative expected prices of potatoes and wheat. Relative prices are constructed by deflating average potato and wheat prices in each state by the average wage rate, reflecting an important factor of production—labor. With relative prices, the supply equation is homogeneous of degree zero in all prices. Prices lagged one period are used to represent expected prices as there are no direct measures of expected price or even a futures price for potatoes.

Other exogenous variables include lagged production and potato research expenditures. Two research expenditure variables are used, research within the state and research within the subregion but outside the state. Research expenditures outside the state identify spillovers of research results, which can also be thought of as technological transfers. The greatest spillovers were expected to occur within subregions, because of the similarities in production and geoclimatic conditions. Separate intercept terms are estimated for each state.

Econometric Model

This study combines time-series and cross-sectional data. Heteroskedasticity is often a problem with cross-sectional data, and autocorrelation is often a problem with time-series data. Combining the two types of data requires considering both problems (Judge et al.).

The basic model used here has constant slope coefficients and individual intercepts for the different states.

$$y_{it} = \overline{\beta}_0 + u_i + \sum_{k=1}^{K} \beta_k x_{kit} + e_{it}, \qquad i = 1, \dots, N \quad (1)$$

$$t = 1, \dots, T,$$

where y_{it} is potato production, X_{1it} is ratio of expected potato price to wage rate, X_{2it} is ratio of expected wheat price to wage rate, X_{3it} is lagged potato production, X_{4it} is distributed lag of internal research expenditures, and X_{5it} is distributed lag of regional research expenditures. The research variables are linear combinations of annual research expenditures using a polynomial distributed lag procedure described below. The mean intercept is $\overline{\beta}_0$, and the intercept for each state is $\beta_1 = \overline{\beta}_0 + u_i$. The u_is are the difference between the mean intercept and the individual state's intercept.

The disturbance vector for each state is $(e_{i1}, e_{i2}, \dots, e_{iT})'$. The basic assumptions for each disturbance vector are $E(e_i) = 0$ and $E(e_i^2) = \sigma_i^2$, indicating heteroskedasticity. In addition, the disturbance vector for each state is assumed to follow a first-order autoregressive process:

$$e_{it} = \rho_i e_{i,t-1} + v_{it}, \quad i = 1, \dots, N, \tag{2}$$

where ρ_i is an autocorrelation coefficient and v_{it} is a stochastic error term with mean zero and variance σ_Y^2.

Estimation Procedure

The first step in estimation is to transform the dependent variable y_{it} and the exogenous variables x_{kit} by subtracting the cross-sectional means:

$$y'_{it} = y_{it} - \overline{y}_i \quad \text{and} \quad \begin{array}{l} i = 1, \dots, N \\ t = 1, \dots, T \end{array} \tag{3}$$

$$x'_{kit} = x_{kit} - \overline{x}_{kit}, \qquad k = 1, \dots, K, \tag{4}$$

where $\overline{y}_i$ and $\overline{x}_{ki}$, are averaged over t. With the transformed variables, the regression model uses the variation of the variables within each state. This transformation simplifies the estimation procedure by eliminating the need to include separate dummy variables for each state. Thus the size of the matrix to be inverted is reduced considerably. The individual intercepts for each state can be recovered as:

$$\beta_i = y_i - \sum_{k=1}^{K} \hat{\beta}_k \, \overline{x}_{ki}. \tag{5}$$

The second step is to correct for heteroskedasticity. A least squares model is estimated by regressing y'_{it} on x'_{kit}. The residuals from that model are used to estimate the variance σ_i^2 for each cross section or state. While the diagonal elements of the covariance matrix, Φ, are $E(e_i^2) = \sigma_i^2$, the off-diagonal elements are assumed to be zero, $E(e_r e_s) = 0$ for $r \neq s$. With an estimate of each cross-sectional variance (σ_i^2), the dependent and exogenous variables are transformed as follows:

$$y^*_{it} = y'_{it} / \hat{\sigma}_i, \quad \text{and} \quad \begin{array}{l} i = 1, \dots, N \\ t = 1, \dots, T \end{array} \tag{6}$$

$$(7) \qquad x^*_{kit} = x'_{kit} / \hat{\sigma}_1, \qquad k = 1, \ldots, K.$$

The generalized least squares estimator can be obtained by applying least squares to the transformed variables y^*_{it} and x^*_{kit}.

The third step in estimation corrects for autocorrelation.The residuals (e^*_{it}) from the least squares regression of y^*_{it} on x^*_{kit} are used to estimate autocorrelation coefficients (ρ_i) for each cross section or state:

$$(8) \qquad \hat{\rho}_i = \sum_{t=2}^{T} \hat{e}^*_{it}\hat{e}^*_{i,t-1} / \sum_{t=2}^{T} \hat{e}^{*2}_{i,t-1}.$$

The dependent and exogenous variables are transformed as follows:

$$(9) \qquad y^{**}_{it} = y^*_{it} - \rho_i y^*_{i,t-1}, \quad \text{and} \quad \begin{array}{l} i = 2, \ldots, N \\ t = 2, \ldots, T \end{array}$$

$$(10) \qquad x^{**}_{kit} = x^*_{kit} - \rho_i x^*_{kit}, \qquad k = 1, \ldots, K.$$

The first observation for each *i* and *k* variable is

$$(11) \qquad y^{**}_{i1} = \sqrt{1 - \rho_i^2}\, y^*_{i1}, \quad \text{and}$$

$$(12) \qquad x^{**}_{ki1} = \sqrt{1 - \rho_1^2}\, x^*_{ki1}.$$

Least squares regression of y^{**}_{it} on x^{**}_{kit} yields the desired generalized least squares estimates of the supply response equation.

Polynomial Lag

The effect of research on production is assumed to be spread out or distributed over time. In other words, research expenditures in one period may affect production in many subsequent years. Hence, current production is a function of past research expenditures. However, past research expenditures tend to be highly correlated due to the incremental process of governmental budgetary decisions. Regressing current production directly on past values of research expenditures would result in multicollinearity, and therefore, the research effects of each period could not be measured precisely. An alternative procedure is to estimate distributed lag models and avoid the inherent problems of multicollinearity. An example is the distributed lag model developed by Almon, called the Almon polynomial lag structure.

In this study, a quadratic polynomial lag structure is used with zero end-point restrictions. These restrictions result from the assumptions that research has no contemporaneous impact on production, and that after a sufficiently long period, research has no significant impact on production. The quadratic form implies that the research impact is small at first but increases over time to a maximum. After reaching the maximum, the research effect declines over time until it becomes essentially zero. The conglomerate research variable to be used in the regression model is calculated as follows:

$$(13) \qquad x_{it} = \sum_{j=0}^{L} (jL - j^2) R_{i,t-j}, \quad i = 1, 2, \ldots, N$$

$$t = 1, 2, \ldots, T,$$

where the $R_{i,t-j}$ are research expenditures in state i at time t–j, and L is lag length. The regression coefficient on the conglomerate research variable, b_R, can be used to find individual effects b_{Ri} as follows:

$$(14) \qquad b_{Ri} = b_R \, (iL - i^2) \Big/ \left[\sum_{j=0}^{L} (jL - j^2) \right].$$

The optimal number of lags for state research and regional research, which excludes the state's own research, was determined by maximizing R^2. The number of potential lags was iterated from six to ten for both state and regional research. The optimal number of lags was eight years for state research and six years for regional research. The number of lags considered was limited by the availability of data, but the optimal lags were fewer than the maximum number considered.

Goodness of Fit

The measure of goodness of fit used in this study is based on the correlation between y_{it}^{**} and the best predictor of y_{it}^{**} (Judge et al.). With a first-order autoregressive process, the best linear unbiased one-step-ahead predictor of y_{it}^{**} is estimated by

$$(15) \qquad \hat{y}_{it}^{**} = x_{it}^{**} \hat{\beta} + \hat{\rho} e_{i,t-1}.$$

The squared correlation between y_{it}^{**} and $\hat{y}_{it}^{**}$ is the $\hat{R}^2$ used to measure goodness of fit.

Data

The data used in this study covered the period 1967–90. All variables were analyzed in logarithmic form. Potato production and prices by state are summarized in *U.S. Potato Statistics* (Lucier et al.). Wheat prices, as well as potato prices, are reported in the annual summaries of *Agricultural Prices* (USDA/NASS). Farm wage rates for 1967–74 are reported in *Farm Labor* (USDA/SRS) and for 1975–90 are reported in *Farm Employment and Wage Rates* (USDA/NASS). The farm wage data were reported on a state basis prior to 1985. In 1985 and subsequent years, farm wage rates are regional averages.

Annual research expenditures for potatoes were an unpublished series from USDA/CSRS. The unpublished series provided more detailed data than is reported in the annual report Inventory of Agricultural Research (USDA/CSRS). However, the same information system generated the potato research variables as the annual report on research.

Table 3. Estimated Supply Equation for Potatoes

Variable	Coefficient	Standard Deviation	Student's t-Statistic
Potato price (t–1)	0.28331[a]	0.03050	9.28799
Wheat price (t–1)	– 0.15899[a]	0.03074	– 5.17244
Quantity (t–1)	0.71032[a]	0.04171	17.03024
Polynomial lags:			
Period	State Research	Regional Research	
(t)	0.00000	0.00000	
(t–1)	0.00052	0.00113	
(t–2)	0.00089	0.00181	
(t–3)	0.00111	0.00204	
(t–4)	0.00118	0.00181	
(t–5)	0.00111	0.00113	
(t–6)	0.00089	0.00000	
(t–7)	0.00052	0.00000	
(t–8)	0.00000	0.00000	
Sum	0.00622	0.00793	
R^2	0.82279		

[a] Statistically significant at the 0.01 level.

Analysis of the Regression Results

The regression results are reported in table 3. The R^2 for the model is 0.82, which indicates that the model explains 82% of the variation in the data. Table 3 reports the coefficients other than state-specific intercepts. The two price variables and the lagged production variable are statistically significant. Using an F-statistic, the research variables are jointly significant at the 0.05 level.

From table 3, the short-run price elasticity of supply for potatoes is 0.28, which is inelastic. The long-run price elasticity of potatoes can be calculated by dividing the coefficient on potato price by one minus the coefficient on lagged production (0.28331/(1 – 0.71032)). This calculation yields a long-run price elasticity of supply for potatoes of 0.98. Hence in the long run, each 1% increase in the price of potatoes causes the supply of potatoes to increase almost 1%. The short-run, cross-price elasticity of potato production with respect to wheat price is –0.16 (table 3). The long-run, cross-price elasticity is –0 .55, being calculated as (– 0.15899/(1 – 0.71032)).

The annual research impacts (b_{Ri}) are shown in the bottom of table 3. However, consideration has to be given to the adjustment coefficient on lagged production (β_3). These annual impacts are used in computing the marginal products and internal rates of return which are reported in the next section.

Marginal Product and Rate of Return

Marginal Product

The marginal product and rate of return for agricultural research investment can be calculated from the regression results. The regression coefficients on the research expenditure variables can be converted to marginal products by the following equation:

$$MPR_{im} = \sum_{j=0}^{Lm} \beta_3^{m-j} b_{Rj} \overline{V}_i / \overline{R}_i, \tag{16}$$

where MPR_{im} is the single-year marginal product of research expenditures in region i and year m, V_i is the geometric mean value of potatoes in region i for 1977–90, $\overline{R}_i$ is the geometric mean research expenditures in region i for 1977–90, β_3 is the lagged production coefficient, b_{Rj} is the year-specific impact of research, and Lm is the minimum of L (lag length) and m (year of interest).

The marginal products for research expenditures for the six subregions are presented in table 4. These estimates reflect research's contribution to regional potato production. The northwest and southwest subregions have the highest marginal products of \$15.23 and \$20.21, respectively. This reflects the relatively low levels of research investment and relatively high levels of production in these two subregions. In contrast, the northeast and southeast have the lowest marginal products of \$2.58 and \$3.12, respectively, reflecting the high level of research investment and the low level of production. The southwest and northwest subregions also have the lowest research to value ratio of 0.54%, while the northeast subregion has the highest research to value ratio of 2.12%. The central and Great Lakes subregions have marginal products of \$6.80 and \$4.54, respectively. The "average" marginal product, which was estimated using national geometric averages for value of output and research expenditures, was \$7.57, indicating the total returns from \$1 invested in potato research.

Rate of Return

Since the returns are not forthcoming immediately, it is important to determine the rate of return associated with research investments. The rate of return (r_i) for each region i can be calculated as:

$$\sum_{m=1}^{\infty} MPR_{im} / (1 + r_i)^m - 1 = 0. \tag{17}$$

Since the analysis is based on constant prices, this estimate is a real rate of return.

This procedure explicitly accounts for the research lags. The rate of return for research investments are reported in table 4. The national real rate of return on investment in potato research, accounting for the spillover effects, is 79%. There is a direct relationship between marginal products and rate of return on investment, since the same lag structure is assumed to exist in every subregion.

The rates of return reported in table 4 indicate that investments in potato research provide very high returns, especially when the spillover effect is included. The returns from

Table 4. Returns to Investments in Potato Research by Subregions

Subregion	Research to Value Ratio (%)	Marginal Product of Research ($)	Internal Share of Benefits (%)	Rate of Return (%)
Central	1.21	6.80	26.13	73.73
Great Lakes	1.20	4.54	39.20	57.23
Northeast	2.12	2.58	39.20	41.26
Northwest	0.54	15.23	26.13	126.20
Southeast	0.88	3.12	78.39	45.84
Southwest	0.54	20.21	19.60	153.71
Nation	0.90	7.57	31.36	79.02

investments in potato research compare favorably with alternative public investments in the subregions considered in this study. Of the 79% total rate of return attributed to investments in potato research, 31% accrue to states conducting the research and 69% is accounted for by the spillover effect (table 4). The return to states conducting potato research appears quite favorable, with substantial spillover effects to other states.

The southwest and the northwest subregions had the highest rates of return to investments in potato research of 153.71% and 126.20%, respectively. The central and Great Lakes subregions had rates of return of 73.73% and 57.23%, respectively. The southeast and northeast had rates of return of 45.84% and 41.26%, respectively. The southwest, northwest, and central subregions have the highest spillover rates of research results. The southeast subregion had little spillover of research results (22%). In general, even the lowest rates of return were very favorable in terms of general social investments.

Summary and Conclusions

The distribution of public investments in potato research among potato-producing regions in the United States is not compatible with the levels of potato production and potato processing. Large public investments in potato research continue to be allocated for those states with declining production and processing. Research investments in potatoes range from 16.8 cents per cwt in the eastern region to only 3.2 cents per cwt in the western region.

Measuring the economic benefits from potato research should account for spillover effects. The rate of spillovers of research results is influenced by the similarities of the geoclimatic conditions and the biological features of the individual commodities. In this study, the 21 largest potato-producing states were grouped into six subregions based upon similarities in geography, climate, production methods, and type of potato produced.

The supply response model for potatoes developed for this study uses state-level production as the dependent variable. Production of potatoes is explained by relative expected prices of potatoes and competing products, lagged production, and two potato research variables: (*a*) research expenditures within the state and (*b*) research expenditures within the subregion but outside the state.

The marginal product and rate of return for potato research were calculated for the six subregions. The southwest and the northwest subregions have the highest marginal products of \$20.21 and \$15.23, respectively. In contrast, the northeast and the southeast subregions have the lowest marginal products of \$2.58 and \$3.12, respectively. The central and Great Lakes subregions have marginal products of \$6.80 and \$4.54, respectively. Average marginal product for potato research for the 21 potato-producing states is \$7.57, indicating the total return from a \$1 investment in potato research.

The national real rate of return to investment in potato research, accounting for the spillover effects, is 79%. However, the average share of the benefits which accrue to the originating state is only 31.36%. This implies that about 69% of the benefits from investment in potato research spillover to other states. Public investments in potato research in the southwest and northwest subregions have the highest total rate of return of 153.71% and 126.20%, respectively.

The results of this study indicate that research productivity in the southwest and the northwest subregions is three to seven fold higher than the other subregions. The spillover of research results from these two subregions was also significantly higher than from the other subregions. These results suggest that the benefits of potato research would be higher if more of it occurred in the western region.

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