RETURN TO POTATO RESEARCH

by

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Returns to Potato Research Accounting for Regional Spillover

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Abstract

Returns to investment in potato research during the 1967-1991 period were estimated for the United States and six sub-regions. The study combines time series and cross-sectional data to estimate the supply response for potatoes. State-level production was used as the dependent variable. Production of potatoes is assumed to be a function of relative expected prices of potatoes and wheat. Two research variables were also included as exogenous variables: research within the states and research within the region, but outside the states. Using these two research variables can help identify spillover of research results, which can be thought of as technological transfers.

Marginal products for research expenditures for the six sub-regions were estimated. The Northwest and the Southwest have the highest marginal productivity and the Northeast has the lowest marginal productivity. The "average" marginal product was $7.57 indicating total return from $1 invested. Evaluation of rates of return indicate that investments in research for potatoes yield a high rate of return for the originating region. Over 30 percent of the returns accrue to the state conducting the research, with substantial spillover effects to other states.

RETURNS TO POTATO RESEARCH: ACCOUNTING FOR STATE AND REGIONAL EFFECTS

INTRODUCTION

Potatoes are an important agricultural commodity with an annual farm value of about \$2.1 billion. Fall potatoes typically account for 88 percent of total production. The western region of the United States (U.S.) accounts for nearly 70 percent of fall production. The share of total output from the eastern region is 10 percent and from the central region is 20 percent. Since 1950, the western region has continued to expand its share of fall output, while the eastern region's share has dwindled. Although output in the central region rose, its share fell from 26 percent in 1950 to 20 percent in recent years (U.S. Department of Agriculture, Potato Facts, 1993).

During the 1987-91 period, an average of \$26.7 million of public funds was invested in potato research per year. About 20 percent of this investment was in genetic research and 80 percent was in non-genetic research. During this period, the central region produced 20.8 percent of the total potatoes in the U.S., processed 14.4 percent of the potatoes, and accounted for 30.7 percent of total public investments in potato research. The central region had an average research investment of 9.1 cents for each cwt. of potato production. The eastern region produced 12.7 percent of the nation's potatoes, represented about 3 percent of the processing, and accounted for 34.7 percent 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 (Table 1).

The western region produced 66.5 percent of the potatoes in the U.S., represented 82.6 percent of the total processed potatoes, and accounted for only 34.55 percent 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. In general, the distribution of public investments in potato research among regions and states is not compatible with the levels of potato production and potato processing (Table 1).

Within the western region, Idaho is the number one potato-producing state accounting for 30 percent of the total U.S. potato production, followed by Washington State with 20 percent. Idaho also ranks number one in potato processing, accounting for 46 percent of the U.S. processed potatoes, with Washington and Oregon representing 36 percent of the nation's processed potatoes. In general, the Pacific Northwest States of Idaho, Oregon, and Washington produce over 55 percent of the nation's potatoes, account for 82.6 percent of total potato processing, and represent only 24.8 percent of public investments in potato research.

Idaho had an average research investment of 1.9 cents for each cwt. of potato production, one of the lowest in the nation. Washington and Oregon had an average research investment of 3.98 cents and 4.7 cents per cwt. of potato production, respectively. Within the western region, California had the highest research investment of 7.9 cents per cwt.

The economic impact of investments in research has been evaluated for most major agricultural commodities (Araji, 1980; Norton and Davis, 1981; Ruttan, 1982). However, the economic impact of investments in potato research has not been analyzed. Given the distribution of potato production, processing and research among regions, returns to potato research should account for state and regional spill-over effects. Measurement of the spill-over effects of research results has an important policy implication concerning the allocation of research funds.

Objectives

The objective of this study is to analyze the benefit of public investments in potato research by regions accounting for spill-over effects among potato-producing regions.

RELEVANT LITERATURE

Agricultural research constitutes 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 and Ruttan, 1977). Recognizing the importance of agricultural research to improving society's well-being, federal and state governments have made a sizable investment in agricultural research. Since the late 1950's, over 50 studies have examined the economic benefit of investments in agricultural research. Most of these studies show high rates of return to public investments in agricultural research. A 1982 report by the Executive Office of the President of the U.S. shows that annual rates of return to public investments in agricultural research range between 35 and 50 percent and well above returns to other public investments.

Aggregate evaluation of the impacts of investments in agricultural research in the United States has been conducted by Griliches (1964), Latimer (1964), Evenson (1968), Lu and Cline (1977), Peterson and Fitzharris (1977), Evenson, Waggoner, and Ruttan (1979), White, Havlicek and Otto (1979), Davis (1979), White and Havlicek (1981), and Braha and Tweeten (1986). Measuring research output at an aggregate level has limitations in terms of significance 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 (Araji, 1980;

Norton and Davis, 1981; Ruttan, 1982). Araji (1988) evaluated the rates of return to investments in a state agricultural experiment station by principal function. The four principal functions performed by a state agricultural experiment station are: (1) services, (2) maintenance research, (3) applied research, and (4) basic research.

Of the major agricultural commodities produced in the U.S., potatoes are the only commodity for which the benefit of total investment in research has not been analyzed. Araji and Sparks (1976) evaluated the economic impact of investments in potato storage research conducted by the Idaho Agricultural Experiment Station and the result of which received national and international application.

Most economic analyses of the return to investments in agricultural research are on an **ex-post** basis. This started with the early work of Schultz (1971). Ruttan (1982) summarizes the various **ex-post** methodologies and gives a detailed account of agricultural research work done in many countries and many commodities. However, **ex-post** evaluation of research does not provide much information to decision-makers as to present or future areas of research that have the highest economic impacts. **Ex-ante** evaluation of research provides this type of information, although its reliability depends on the accuracy of projecting future events. Few evaluations of research have used the **ex-ante** mode. A sampling of such **ex-ante** research in the United States includes Araji, Sim, and Gardner, (1978), Griffith (1978), Lee (1981), and Shumway (1981). Klein (1985), Ulrich, Furtan, and Downey (1984), and Furtan and Ulrich (1987) used the **ex-ante** mode to evaluate research in Canada.

The spill-over effects of research results among regions or sub-regions have received little attention by economists evaluating the economic impacts of research. Latimer and Paarlburg (1965) recognized the spill-over effect of research results but were unable to empirically measure the effect of spill-over on agricultural output within the state. Since then, few studies have provided empirical measurements of the spill-over effects of research results for aggregate agriculture. The aggregate production function has been used to study the spill-over effects of research results between states or regions on an **ex-post** basis.

Evenson (1971) analyzed the spill-over effects of research for aggregate agriculture between 10 regions in the United States and estimated rates of return ranging from 30 percent to 180 percent. Evenson and Kislev (1973) estimated the productivity effects of research spill-over in wheat and maize for a cross-section of countries. They concluded that borrowed knowledge caused a strong and persistent increase in crop yield.

White and Havlicek (1981) measured the spill-over benefit of research results for aggregate agriculture for the same ten regions considered by Evenson (1971). The rate of return estimated by White and Havlicek (1981) were significantly different than those estimated by Evenson (1971) ranging from 31 percent to 62 percent.

Measuring the spill-over effects of research for aggregate agriculture has limitations in terms of allocating research funding for individual commodities. Otto (1981) used yield response functions to evaluate cross-commodity comparisons of research productivity. He developed spill-over regions for individual commodities based on research being usable for states within the same maturity region. The results of this study show that research spill-over, based on a pattern of maturity zones plus basic research shares from other states, are very significant in explaining yield for photosensitive crops like corn, sorghum, and soybeans. Research spill overs patterned on climatic and variety similarities plus basic research expenditures by other states were significant in explaining variations in wheat yield.

The spill-over effects of research results are evident not only in agriculture, but also in other industries. Jaffe (1986) estimated the return to research and development (R and D) capital was 40 percent higher than would be the case in the absence of spill over among firms in the industrial sector. Mansfield et. al. (1977) concluded that the social rate of return from industrial innovation accounting for the spill-over effects was 77 percent to 150 percent greater than the private return.

Other studies have used cost function framework to estimate the effect of spill over. Levin and Reiss (1984), using cross sections of U.S. firms, estimated that a 1 percent increase in the R and D spill over caused average costs to decline by about .05 percent. Bernstein and Nadiri (1989) estimated the effect of intra-industry spill-over for four U.S. industries. They show that a 1 percent increase in the spill over decreased average costs by .2 percent. In these studies, the R and D spill over was defined as a single aggregate. Individual industries were not treated as a separate spill-over source in the estimation of spill-over 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 spill-over source. Their results showed that there were significant differences among industries as both spill over senders and receivers. Bernstein (1989) extended this approach and applied it to nine Canadian industries. The production cost of each industry is affected separately by the R and D capital of all other industries. This allows for the sources and beneficiaries of each inter-industry R and D spill over to be traced. The finding showed that for each receiving industry, cost effects depended on the particular industrial source of the R and D spill overs. Six of the nine industries were affected by multiple spill-over sources. All nine industries were influenced by R and D spill overs, and the cost reduction ranged from .005 percent for chemical products to 1.082 percent for electrical products. The rates of return to R and D capital ranged from 24 percent for non-electrical machinery to a high of 47 percent for rubber and plastics.

The advantage of the cost function approach is that it is often more flexible in functional form and that it considers the impact of R and D spill over not only on total costs but also on the amount of labor and intermediate products demanded. The disadvantage of the cost function approach is the required use of prices and the appearance of output on the right-hand side of the equation (Griliches, 1992).

A major component of research's benefit is through the acceleration of the transfer of knowledge among countries or regions (Evenson and Kislev, 1973). The rate of spill over is greater from research of others within the same region with additional spill over, at lower rates, from neighboring regions (Huffman and Evenson, 1993). The rate of spill over of agricultural research results among regions or countries 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, 1973; Otto, 1981; Huffman and Evenson, 1993). Similarly, Griliches (1979) emphasizes the importance of technology types and industrial similarities as the basis for technology transfer between industries.

Spill over of research results between regions and sub-regions in the U.S. is facilitated greatly by the similarity of the research and extension infrastructures throughout the state agricultural experiment stations and the cooperative extension systems (Otto, 1981). Therefore, the selection of regions or sub-regions based on geoclimatic conditions and the biological and industrial (utilization) features of the commodity considered is crucial for accurate empirical measurement of the spill-over effects of research results. Given the differences in the biological features of agricultural commodities, the empirical measurements of the spill-over effects of research results for a single commodity, rather than for aggregate agriculture, seem more realistic. Funding allocation for agricultural research at the state experiment station level is generally made for individual commodities. Thus, the measurement of the spill-over effects of research results by individual commodity will provide more realistic information for funding allocation within the state agricultural experiment station, between experiment stations in a region, and for regional research.

METHODS AND PROCEDURES

For the purpose of this study, the 21 largest potato-producing states were grouped into 6 sub-regions (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 in dryland conditions. The Great Lakes 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 non-storage fresh and chipping markets with harvest in winter, spring, and summer. The Southwest sub-region 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 can be linked to the framework outlined by Houck and Ryan (1972). Within that framework, production or acreage is hypothesized to be a function of expected market conditions, government programs, and other exogenous variables. 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 usually included in the exogenous variables in order to reflect an adjustment process. 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. Lagged prices are used to represent expected prices. While other forms of price expectations are reported in the literature (Shideed and White, 1989), lagged cash prices are most frequently used to measure expectations.

Other exogenous variables include lagged production and potato research expenditures. Two research variables are used: research within the state and research within the sub-region but outside the state. Using these two research variables can help identify spill overs of research results, which can also be thought of as technological transfers. Government supply control variables are not needed in this model, because such programs do not exist for potatoes. Separate intercept terms are estimated for each state.

Econometric Model

This study combines times series and cross-sectional data. Heteroscedasticity 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 consideration of both problems (Judge et al., 1980).

The basic model used in this study has constant slope coefficients and individual intercepts for the different states. The model is specified in Equation 1.

$$(1) \quad y_{it} = \overline{\beta}_1 + u_i + \sum_{k=2}^{K} \beta_k x_{kit} + e_{it}$$

where:

y = potato production

x = exogenous variables

$i = 1, 2, ..., N$ states

$t = 1, 2, ..., T$ year

k_1 = relation expected prices of potatoes

k_2 = relation expected prices of wheat

The mean intercept is $\overline{\beta}_1$, and the intercept for each state is $\beta_i = \overline{\beta}_1 + u_i$. The u_i is the difference between the mean intercept and the individual state's intercept.

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

$$(2) \quad e_{it} = \rho_i e_{i,t-1} + v_{it}, \ i = 1, 2, ... N$$

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, as shown in Equations 3 and 4.

$$(3) \quad y_{it}' = y_{it} - \overline{y}_{i\cdot}$$

$$(4) \quad x_{kit}' = x_{kit} - \overline{x}_{ki\cdot}$$

for i = 1, 2, ..., N; t = 1, 2, ..., T; and k = 1, 2, ..., K. The dot (.) indicates which subscript has been summed over to calculate the mean. With the transformed variables, the regression model utilizes 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 estimated as shown in Equation 5.

$$(5) \quad \beta_i = y_{i.} - \sum_{k=1}^{K} \hat{\beta}_k \, \overline{x}_{ki}$$

The second step in estimation is to correct for heteroscedasticity. A least squares model is estimated by regression y' on x'. 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:

$$(6) \quad y_{it}{}^{*} = y_{it}'/\hat{\sigma}_i$$

$$(7) \qquad x_{kit}^* = x_{kit}'/\hat{\sigma}_i$$

for i = 1, 2, ..., N; t = 1, 2, ..., T; and k = 1, 2, ... K. The generalized least squares estimator can be obtained by applying least squares to the transformed variables y* and x*.

The third step in estimation corrects for autocorrelation. The residuals (e*) from the least squares regression of y* on x* are used to estimate autocorrelation coefficients (ρ_i) for each cross-section or state, as shown in Equation 8.

$$(8) \qquad \hat{\rho}_i = \sum_{t=2}^{T} \hat{e}_{it}^* \hat{e}_{i,t-1}^* \sum_{5=2}^{T} e_{i,t-1}^{*2}$$

The dependent and exogenous variables are transformed as follows:

$$(9) \qquad y_{it}^{**} = y_{it}^* - \rho_i y_{i,t-1}^*$$

$$(10) \qquad x_{kit}^{**} = x_{kit}^* - \rho_i x_{kit}^*$$

for i = 1, 2, ..., N; t = 2, 3, ..., T; and k = 1, 2, ... K. The first observation for each i and k variable is

$$(11) \qquad y_{i1}^{**} = \sqrt{1-\rho_i^2}\; y_{i1}^*$$

$$(12) \qquad x_{ki1}^{**} = \sqrt{1-\rho_i^2}\; x_{ki1}^*$$

Least squares regression of y** on x** 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 subsequent years. Hence current production is a function of past values of research expenditures. However, past values of 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 involve multicollinearity, and therefore the research effects of each period could not be measured precisely. An alternative estimation procedure that is commonly used to estimate such distributed lag models and avoid the inherent problems of multicollinearity was developed by Almon (1965). The procedure is called the Almon polynomial lag.

In this study, a quadratic polynomial lag 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:

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

for i = 1, 2, ..., N and t = 1, 2, ..., T where R is research expenditures and L is lag length. The optimal lag length is determined by maximizing R^2.

Goodness of Fit

The measure of goodness of fit used in this study is based on the correlation between y_t^{**} and the best predictor of y_t^{**} (Judge et al., 1980). With a first-order autoregressive process, the best linear unbiased one-step-ahead predictor of y_t^{**} is estimated by Equation 14.

$$(14) \quad y_t = x_t^{**}\hat{\beta} + \hat{\rho} e_{t-1}$$

The squared correlation between y_t^{**} and y_t^{**} is the R^2 used to measure goodness of fit.

Data

The data used in this study covered the period 1967-90. Although much of the data was available for a longer period of time, the research variables first became available in 1967, thus limiting the period of analysis. Potato production and prices by state are summarized in *U.S. Potato Statistics* (Lucier, Budge, Plummer, and Spurgeon, 1991). 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, Crop Reporting Board) and for 1974-90 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.

The research variables were an unpublished series from USDA, Cooperative State Research Service (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.

ANALYSIS OF THE REGRESSION RESULTS

A supply equation for potatoes was estimated for each of the 21 states, which include the northern-most 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.

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 6 to 10 for both state and regional research. The optimal number of lags was 8 years for state research and 6 years for regional research.

The regression results are reported in Tables 3 and 4. The R^2 for the model is 0.82, which indicates that the model explains 82 percent of the variation in the data. Table 3 reports the coefficients other than intercepts. Table 4 reports each state's initial standard deviation, which was used to correct for heteroscedasticity, its autocorrelation coefficient, and its intercept from the final regression model.

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, which is almost unitary. Hence in the long run, each one percent increase in the price of potatoes causes the supply of potatoes to increase one percent. The short-run, cross-price elasticity for potato production with respect to wheat price is -.16 (Table 3). The long-run, cross-price elasticity is -.55, being calculated as (-0.15889/(1 - 0.71032)) similarly to the formulation above.

The annual research impacts are shown in the bottom of Table 3. However, consideration has to be given to the adjustment coefficient on lagged production. Let γ_t be the research impacts from the current period (0) through the last period (R) with t = 0, 1, ..., R. Furthermore, let the coefficient on lagged production be designated by c. Then the impact of research on current production is:

$$(15) \quad \Delta q_0 = \gamma_0.$$

In the second year, the research impact on production is:

$$(16)\quad \Delta q_1 = \gamma_1 + c\gamma_0.$$

More generally, the annual impacts in year m can be represented as:

$$(17)\quad \Delta q_m = \sum_{j=0}^{m} c^j \gamma_{m-j}$$

These annual impacts are calculated over a very long period, which is characterized as infinity. These annual impacts are used to measure 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 are elasticities. However, these elasticities can be converted to marginal products by the following equation:

$$(18)\quad \mathrm{TMPR}_1 = \sum_{w=0}^{\infty} \mathrm{MPR}_{i(t-w)} = \sum_{w=0}^{\infty} \beta_{(t-w)}(\overline{V}_i / \overline{R}_i)$$

where

TMPR_i is the marginal product of research expenditures for region i aggregated over the lifetime of the investment,

$\mathrm{MPR}_{i(t\text{-}w)}$ is the marginal product of research expenditures in region i and year (t-w),

$\overline{V}_i$ is the mean value of potatoes in region i for 1977-90, and

$\overline{R}_i$ is mean research expenditures in region i for 1977-90.

The marginal products for research expenditures for the six sub-regions are presented in Table 5. These estimates reflect research's contribution to regional potato production. The Northwest and Southwest sub-regions have the highest marginal productivity 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 sub-regions. In contrast, the Northeast and Southeast have the lowest marginal productivity of \$2.58 and \$3.12, respectively, reflecting the high level of research investment and the low level of production. The Southwest and Northwest sub-regions also have the lowest research to value ratio of .54 percent, while the Northeast sub-region has the highest research to value ratio of 2.12 percent. The Central and Great Lakes sub-regions have marginal productivity of \$6.80 and \$4.54, respectively. The "average" marginal product, which was estimated using national averages for 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 shown in Equation 19.

$$(19) \quad \sum_{w=0}^{\infty} MPR_{i(t-w)} / (1+r_i)^{w} - 1 = 0$$

This procedure explicitly accounts for the lag structure. The rate of return for research investments are reported in Table 5. The national rate of return to investments in potato research, accounting for the spill-over 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 sub-region.

Evaluation of the rates of return reported in Table 5 indicates that investments in potato research provide very high returns, especially when the spill-over effect is accounted for. The returns from these types of investments compare favorably with alternative public investments in the sub-regions considered in this study. The total rate of return to investments in potato research in the U.S., accounting for the spill-over effects, is estimated at 79.02 percent. The internal rate of return, not accounting for the spill-over effects, to the 21 states conducting potato research averaged 31.36 percent. In other words, of the 79.02 percent total rate of return attributed to investments in potato research, about 40 percent accrue to states conducting the research and 60 percent was accounted for by the spill-over effect (Table 5). The return to states conducting potato research (31.36 percent) appears quite favorable, while substantial effects spill over to other states.

Evaluation of rates of return by sub-region indicates that investments in potato research yield different rates of return for the originating sub-regions. The Southeast sub-region had the highest internal rate of return to investment of 78.39 percent, followed by the Northeast and Great Lakes sub-regions of 39.2 percent. The ratio of internal rate of return to total rate of return was 171 for the Southeast sub-region, 94.0 for the Northeast sub-region, and 68.49 for the Great Lakes sub-region. This implies that the Southeast sub-region is a net beneficiary of spill over of potato research results from other sub-regions. The Northeast and the Great Lakes sub-regions had little net effect on total rate of return through spill over compared to the Southwest and the Northwest sub-regions.

The Southwest and the Northwest sub-regions had the highest total rates of return to investments in potato research of 153.71 percent and 126.20 percent, respectively. These two sub-regions have the highest spill over of research results to other sub-regions. The internal rate of return to investments in potato research in the Southwest sub-region is 19.60 percent and the ratio of internal to total rate of return is 12.75, the lowest compared to the other sub-regions. The internal rate of return to investment in potato research in the Northwest sub-region is 26.13 and the ratio of internal to total rate of return of 20.70, a close second to the Southwest sub-region.

SUMMARY AND CONCLUSION

The benefits of investments in research have been evaluated for aggregate agriculture and for most major agricultural commodities. Potatoes are a major agricultural commodity with an annual production value of about $2.1 billion. Annual public investments in potato research during the 1987-91 period averaged over $26.7 million. However, the economic benefits of investments in potato research have not been analyzed.

The distribution of public investments in potato research among potato-producing regions and states is not compatible with the levels of potato production and potato processing. The Central region produces 20.83 percent of the total potatoes in the U.S., processes 14.39 percent of the potatoes, and accounts for 30.34 percent of total public investments in potato research. This region has an average research investment of 9.1 cents for each cwt. of potato production. The Eastern region produces 12.67 percent of the nation's potatoes, has about 3 percent of the processing, and accounts for 34.71 percent of public investments in potato research. The Eastern region invests 16.86 cents in research for every cwt. of potatoes it produces. The Western region produces 66.5 percent of the potatoes in the U.S., represents 82.6 percent of the nation's processed potatoes, and accounts for only 34.55 percent public investments in potato research. This region has the lowest research investment per cwt. of potato production of 3.2 cents.

The spill-over effect of research results among regions or sub-regions has received little attention by economists evaluating the economic impacts of investments in research. Given the distribution of potato production and investments in potato research among potato-producing regions, analysis of the economic benefits in potato research should account for state and regional spill-over effects.

The rate of spill over of research results among regions or sub-regions is based upon 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 6 sub-regions. Consideration in the grouping process included geography, climate, production methods, and type of potato produced. The economic benefits to public investment in potato research is analyzed by accounting for the spill over of research results between the sub-regions.

The supply response model for potatoes developed for the purpose of this study uses state-level production as the dependent variable. Production of potatoes is hypothesized to be a function of relative expected prices of potatoes and a competing product (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. Lagged prices are used to represent expected prices. Other exogenous variables include lagged production and two potato research variables: (1) research expenditures within the state, and (2) research expenditures within the sub-region but outside the state.

The econometric study combines time series and cross-sectional data. The problem of heteroscedasticity associated with cross-sectional data and problem of autocorrelation associated with time series data were considered and corrected. The effect of research on production is assumed to be distributed over time. In other words, current production in a function of past values of research expenditures. A quadratic polynomial lag is used with zero end-point restrictions.

A supply equation for potatoes was estimated for the 21 potato-producing states. The analysis covered the 1967-1990 period. The optimal number of lags for state research and regional research, which exclude the state's own research, were determined by maximizing R^2. The optimal number of lags was 8 years for state research and 6 years for regional research. The R^2 for the model is 0.82, which indicates that the model explains 82 percent of the variation in the data.

The results of the study show that the short-run price elasticity of supply for potatoes is 0.28. The long-run price elasticity of supply for potatoes is calculated at 0.98. The short-run cross-price elasticity for potato production with respect to wheat price is -.16. The long-run cross-price elasticity is calculated at -.55.

The marginal product and rate of return for potato research were calculated for the six sub-regions. The Southwest and the Northwest sub-regions have the highest marginal productivity of $20.21 and $15.23, respectively. In contrast, the Northeast and the Southeast sub-regions have the lowest marginal productivity of $2.58 and $3.12, respectively. The Central and Great Lakes sub-regions have marginal productivity 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 rate of return to investment in potato research, accounting for the spill-over effects, is 79 percent. However, the national rate of return to investment in potato research, not accounting for spill over between the sub-regions, is 31.36 percent. This implies that more than 60 percent of the rate of return to investment in potato research is accounted for by the spill over of research results between sub-regions. Analyses of rates of return by sub-regions indicate that investments in research for potatoes yield different rates of return for the originating sub-regions. Public investments in potato research in the Southwest and Northwest sub-regions have the highest total rate of return (accounting for spill-over effects) of 153.71 percent and 126.20 percent, respectively. These two sub-regions have the lowest internal rate of return of 19.60 percent and 26.13 percent, respectively. In contrast, the Southeast sub-region has the highest internal rate of return of 78.39 percent. The ratio of internal rate of return to total rate of return is 171. This implies that this sub-region received significantly more research results from the other sub-regions than it sends. The Northeast had an internal rate of return of 39.20 percent and internal to total ratio of 95 which implies very little spill over of research results from this sub-region to the others.

CONCLUSIONS

The results of this study indicate significant differences in the production-research investment ratios among the major potato-producing states and regions. The Southwest and Northwest sub-regions have significantly lower ratios than the other sub-regions. This reflected in significantly high research productivity in these two sub-regions. The marginal product of $1 invested in research in the Southwest sub-region is $20.21 and in the Northwest sub-region is $15.23 compared to the average of the 21 largest potato-producing states of $7.57. The research productivity in these two sub-regions is 3 to 7 fold higher than the other sub-regions. The rate of return to investments in potato research, accounting for spill over, in these two sub-regions is 153.71 percent for the Southwest and 126.20 percent for the Northwest, significantly higher than the national average and the rates of return in the other sub-region. The spill over of research results from these two sub-regions was also significantly higher than from the other sub-regions. These results seem to suggest that the social benefit from public investments in potato research will significantly increase by increasing investments in potato research in those two sub-regions where the marginal productivity of $1 invested is significantly higher than other sub-regions and where the spill over of research results from the sub-regions is also very high.

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

Region	Production[1] 1987-91 Ave. (000 cwt.)	Investment in Research (1987-91 Ave)[2]			Res/Prod Ratio (cents/cwt)
		Genetic ($)	Non-Genetic ($)	Total ($)	
1. Western	**255,635**	**1,807,210**	**6,367,265**	**8,174,475**	**3.20**
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	.70
Nevada	2,538	0	585	585	.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
2. Central	**80,088**	**1,343,376**	**5,929,016**	**7,272,392**	**9.10**
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
3. Eastern	**48,717**	**1,486,721**	**6,725,312**	**8,212,033**	**16.86**
Delaware	1,559	0	12,408	12,408	.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
Total	**384,440**	**4,637,307**	**19,021,593**	**23,658,900**	**6.15**

[1] Source: U.S. Department of Agriculture, Economic Research Service. *Potato Facts.* Spring/Summer 1993. Washington, D.C.

[2] Source: U.S. Department of Agriculture, CSRS. *Inventory of Agricultural Research.* Washington, D.C. (Unpublished Series).

Table : State-Federal Annual Funding for Potato Research by Sub-regions, 1987-1991 Average

	Genetic Research			Non-Genetic Research			Total		
Sub-Region	State	Federal	State/ Fed Ratio	State	Federal	State/ Fed Ratio	State	Federal	State/ Fed Ratio
1. Central	**503,055**	**147,617**	**3.410**	**1,230,574**	**1,375,670**	**.894**	**1,733,629**	**1,523,287**	**1.138**
MN	300,023	46,027	6.518	699,779	998,437	.700	999,802	1,044,464	.957
ND	189,871	99,712	1.904	462,811	349,764	1.320	652,682	449,476	1.450
NE	13,161	1,878	7.000	37,062	18,935	1.957	50,223	20,813	2.410
SD	0	0	0.000	30,922	8,534	3.620	30,922	8,534	3.600
2. Great Lakes	**254,784**	**349,573**	**.730**	**1,327,843**	**1,508,441**	**.880**	**1,582,627**	**1,858,014**	**.850**
MI	51,652	16,706	3.090	377,289	419,849	.900	428,941	436,555	.980
OH	0	0	0.000	216,567	149,817	1.440	216,567	149,817	1.440
WI	203,132	332,867	.610	733,987	938,775	.780	937,119	1,271,642	.730
3. Northeast	**858,927**	**316,614**	**2.71**	**2,054,597**	**2,547,934**	**.810**	**2,913,524**	**2,864,548**	**1.020**
ME	103,078	29,050	3.540	992,677	894,767	1.050	1,095,755	923,817	1.186
NY	530,836	203,265	2.610	962,754	696,643	1.380	1,493,590	899,908	1.660
PA	225,013	84,299	2.660	99,166	956,524	.100	324,179	1,040,823	.310
4. Northwest	**265,124**	**1,126,211**	**.235**	**2,545,104**	**1,980,647**	**1.280**	**2,810,228**	**3,106,858**	**.900**
ID	35,664	282,613	.126	978,494	796,664	1.230	1,014,158	1,079,277	.930
MT	0	0	0.000	37,908	435	87.140	37,908	435	87.140
OR	168,010	6,516	25.78	632,427	287,824	2.190	800,437	294,340	2.720
WA	61,540	837,082	.070	896,275	895,724	1.000	957,815	1,732,806	.550
5. Southeast	**16,014**	**11,317**	**1.420**	**518,876**	**578,164**	**.900**	**534,890**	**589,481**	**.910**
FL	0	0	0.000	359,505	23,201	15.49	359,505	23,201	15.490
NC	110,014	11,317	9.720	159,371	554,963	.280	159,371	554,963	.280
6. Southwest	**403,643**	**23,328**	**17.300**	**942,741**	**940,487**	**1.000**	**1,346,384**	**963,815**	**1.400**
AZ	0	0	0.000	11,560	2,237	5.160	11,560	2,237	5.160
CA	118,491	11,875	9.980	448,999	829,205	.540	567,490	841,080	.670
CO	137,805	1,854	74.330	224,092	63,353	3.540	361,897	65,207	5.550
NM	0	0	0.000	0	24,975		0	24,975	
TX	147,347	9,599	15.35	258,090	20,717	12.450	405,437	30,316	13.370

Table 2: Major Potato-producing regions

Sub-Region	Production 1987-91 Ave. (000 cwt.)	Investment in Research ($)	Res./Prod. Ratio (Cents/cwt)	Primary Type of Potato	Production Method
1. Central	**41,874**	**3,578,906**	**8.54**	**chipping**	**dry**
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
2. Great Lakes	**35,024**	**3,440,619**	**9.82**	**fresh & chipping**	**irrigated**
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
3. Northeast	**32,974**	**5,858,069**	**17.76**	fresh & chipping	dry
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
4. Northwest	**202,317**	**5,917,474**	**2.92**	**frozen, fresh, & seed**	**irrigated**
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
5. Southeast	**11,138**	**1,218,798**	**10.94**	**non-storage fresh & chipping**	**dry & irrigated**
FL	8,267	382,706	4.60	non-storage fresh & chipping	dry & irrigated
NC	2,871	836,092	29.10	non-storage fresh & chipping	dry & irrigated
6. Southwest	**49,127**	**2,251,103**	**4.5**	**fresh**	**irrigated**
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	.70	fresh	irrigated
TX	3,284	373,502	11.37	fresh	irrigated

Table 3. Estimated Supply Equation for Potatoes

Variable	Coefficient	Standard Deviation	T-Statistic
Potato Price (t-1)	0.28331	0.03050	9.28799*
Wheat Price (t-1)	-0.15899	0.03074	-5.17244*
Quantity (t-1)	0.71032	0.04171	17.03024*

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-Squared	0.82279	

* Statistically significant at the .01 level.

Table 4. State-Specific Coefficients

State	Standard Deviation	Autocorrelation Coefficient	Constant
AZ	0.1745	-0.2419	6.3576
CA	0.1439	-0.2664	12.8937
CO	0.1145	0.1063	15.0899
FL	0.1978	-0.2519	9.6484
ID	0.0553	-0.3299	24.0847
ME	0.1183	-0.2682	14.8307
MI	0.1305	0.3009	11.8952
MN	0.1055	0.0141	13.9045
MT	0.0839	-0.0924	6.9655
NC	0.1296	-0.4044	7.6368
ND	0.1410	0.1422	15.2426
NE	0.1279	-0.1351	7.8938
NM	0.3103	-0.0308	7.7496
NY	0.1145	0.5606	10.5038
OH	0.1464	-0.0861	7.3280
OR	0.0846	-0.4006	16.2282
PA	0.1386	-0.2227	8.9361
SD	0.3323	-0.0772	8.5746
TX	0.1387	-0.0335	7.2869
WA	0.0442	0.0750	21.9334
WI	0.1098	-0.1774	14.4774

Table 5. Returns to Research

			Rate of Return		
Sub-region	Research to Value Ratio	Marginal Product of Research	Internal	Total	Ratio of Int/Total
	(Percent)	(Dollars)	(Percent)	(Percent)	(Percent)
Central	1.21	6.80	26.13	73.73	35.44
Great Lakes	1.20	4.54	39.20	57.23	68.49
Northeast	2.12	2.58	39.20	41.26	95.00
Northwest	0.54	15.23	26.13	126.20	20.70
Southeast	0.88	3.12	78.39	45.84	171.00
Southwest	0.54	20.21	19.60	153.71	12.75
Nation	0.90	7.57	31.36	79.02	39.68