ESTIMATING RETURNS TO AGRICULTURAL RESEARCH, EXTENSION, AND TEACHING AT THE STATE LEVEL

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Abstract

The majority of decisions concerning investment and allocation of public funds for agricultural research, extension, and teaching (RET) are made at the state-level, while most of the quantitative RET evaluations are made on a national basis. This paper illustrates an approach for conducting a disaggregated state-level evaluation of agricultural research, extension, and teaching. Ridge regression is employed to handle multicollinearity problems.

Key words: research, extension, teaching, evaluation, multicollinearity, ridge regression

The majority of decisions concerning investment and allocation of public funds for agricultural research, extension, and teaching (RET) are made at the state level while most of the quantitative RET evaluations are made on a national or regional basis (Norton and Davis). Also, most RET studies estimate returns to research and extension combined while ignoring teaching or focus on teaching impacts to the exclusion of research and extension.

The purpose of this paper is to illustrate an approach for conducting a state level RET evaluation with research, extension, and teaching disaggregated. The illustration is based upon a case study for Virginia. However, the objective of this paper is not to explain and interpret specific empirical results for Virginia, but to suggest an approach which may be useful in other states as well.

PRODUCTION FUNCTION APPROACHES

The most widely used procedure for measuring returns to agricultural research, extension, and teaching was pioneered by Griliches' estimates of the U.S. aggregate agricultural production function in 1964. The underlying hypothesis is that agricultural production is directly related to both conventional inputs such as land, labor, and capital, and to non-conventional inputs which, for lack of a better alternative, are measured as expenditures of land-grant universities on agricultural research, education, and extension. Studies conducted by Griliches, Evenson (1967, 1978), Bredahl and Peterson, Davis, White and Havlicek, and Cline and Lu for different time periods and using different specifications and models have adopted this basic approach.

These studies typically have employed the Cobb-Douglas production function utilizing cross-sectional and/or time series data. Since the marginal products of a Cobb-Douglas function equal the coefficients times their corresponding average products, one method for determining the marginal productivity of conventional and non-conventional inputs at the state level is to use the coefficients from one of these national studies and the average products for the particular state (Bredahl and Peterson). The marginal products so derived can then be used to calculate rates of return to research and extension in individual states (Babb and Pratt; Norton and Forkkio). The major difficulty with this approach is the underlying assumption that researchers in each state are equally productive.

An alternative approach is to estimate a state level time series production function with RET included as independent variables. Production function estimation involves much data collection and often encounters serious econometric difficulties, particularly multicollinearity. However, various procedures such as ridge regression, principal components regression, and mixed estimation are available for mitigating the effects of multicollinearity. One advantage with a state level approach is that the analyst can use his/her more complete knowledge of the state, data sources, and weather conditions to specify more appropriate measures than if working with data for all states or a region. For example, more detailed adjustments for price

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changes, expenditures for nonproduction purposes, land qualities, input categories, and livestock inventories can be made. Furthermore, changes in university accounting systems and organization greatly influence the research and extension data that are reported to the USDA for subsequent publication. Failure to correct for them may bias the results.

Production function analysis is not the only econometric approach available for state-level RET evaluation. Duality theory can be employed and profit, output supply, and input demand functions estimated including RET variables as fixed factors (Evenson, 1981, Huffman and Evenson). Output and input prices would also appear as arguments in these functions. However, unless output price expectations are carefully modeled, one may encounter a simultaneity problem more severe than that found with an aggregate production function. This is because current state-level output price depends in part on current state-level output quantity and the latter is the dependent variable in the supply function.[1] The dual approach with price modeled as a rational expected price in a manner similar to that suggested by Shonkwiler and Emerson is a possible alternative. However, it was decided that the production function approach with a biased estimation procedure to handle multicollinearity was a more cost effective alternative for this study. Returns to research and extension were also calculated employing national coefficients and state average products for comparison.

Estimation of a State-Level Production Function

Results from estimating a time series Cobb-Douglas production function model with public RET expenditures using ordinary least squares with annual data from 1949 to 1979 for Virginia are initially presented, Table 1. Details on construction of variables and data sources are found in the Appendix. All variables are on a per farm basis except rainfall and research[2]. Although the R^2 is very high, the OLS estimates are suspect in several respects. First, they differ substantially from the factor shares which they should approximately equal assuming the agricultural industry consists of profit maximizing competitive

TABLE 1. PRODUCTION FUNCTION ESTIMATES, FACTOR SHARES, AND VARIANCE INFLATION FACTORS, VIRGINIA, 1949-79

		OLS model		RR model (k = .02)		Variance inflation factors for OLS model
Variable	Factor share	coef.	S.E.	coef.	S.E.	
Intercept	—	−1.834	(4.001)	−2.693^{c}	(0.811)	—
Expenses	.53	0.916^{a}	(0.214)	0.285^{c}	(0.051)	1,191.0
Capital	.10	0.038	(0.193)	0.100^{c}	(0.047)	198.0
Labor	.19	0.381^{a}	(0.153)	0.108^{c}	(0.081)	23.0
Land	.18	0.011	(0.537)	0.360^{c}	(0.113)	230.0
Rainfall	—	0.022^{a}	(0.007)	0.021^{c}	(0.007)	1.4
Research^{b}	—	−0.3598^{a}	(0.168)	0.0637	(0.052)	112.0
Extension^{b}	—	0.4315	(0.559)	0.0627^{c}	(0.029)	2,189.0
Education^{b}	—	−0.2721	(0.716)	0.0979^{c}	(0.038)	2,082.0
R^2		0.991		0.986		
D.W.		2.67^{d}				

[a] Significant at the .05 level.

[b] Lagged effects of research, extension, and education were estimated using the Almon lag procedure. Only the calculated sums of the corresponding coefficients for these variables are shown to save space.

[c] Coefficient is at least twice the approximate standard error.

[d] This Durbin Watson value is inconclusive but a nonparametric, runs test indicated there was no serial correlation problem.

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[1] Simultaneity also can be a problem in a production function due to joint determination in each period of the level of inputs and the quantity of output.

[2] Variables other than research and rainfall are included on a per farm basis since the farm is the decisionmaking unit. There is a question, however, whether it is more appropriate to include research expenditures on a per farm or a per state basis. Bredahl and Peterson argue that research per farm would be correct if the number of farms was related to the number of problems on which scientists conduct research. Research per state would be correct if the research results used by one farm did not diminish those available to other farms (i.e. research is a public good). They show that the latter is statistically closer to reality and therefore the present study is conducted on a per state basis. There is the potential that per state research in combination with per farm output may bias upward research coefficients and that all variables should be on a per state basis. This potential source of bias is acknowledged although bias should arise only if the land per farm, capital per farm, and other included per farm inputs do not fully capture the effects on output per farm of changing farm size over time. This study used the per farm specification for non-research variables because of the difficulty of interpreting economic magnitudes such as returns to scale when production function variables are specified on political boundaries rather than decisionmaking units and also because of the numerous precedents in the research evaluation literature by Bredahl and Peterson, Davis, Griliches, and Evenson (1967). Extension and education, unlike research, were not included on a per farm basis because the use of extension or education by one farm generally reduces the amount available for another. A farm was defined as a place with 10 or more acres that had annual sales of agricultural products of $50 or more and a place of less than 10 acres that had annual sales of $250 or more.

firms in equalibrium (Shumway, Talpaz, and Beattie). Second, the sum of the coefficients for conventional inputs is 1.35 indicating increasing returns to scale[3]. Third, despite the high overall explanatory power of the model, only 4 of the 8 coefficients are significant at the .05 level.

A likely explanation of the differences and inconsistencies is multicollinearity. When regressor variables are highly correlated, the variances of their estimated coefficients are inflated and unstable (Weisberg, p. 175). The large variance inflation factors in Table 1 indicate severe multicollinearity. The variance inflation factors (VIF), corresponding to the diagonal elements of the correlation matrix, equal $1/(1-R_j^2)$ where R_j^2 is the coefficient of determination found by regressing the j^{th} independent variable on the remaining independent variables. In the ideal (orthogonal) situation the VIF's equal 1, i.e. $R^2_j = 0$. VIF's greater than 10 usually indicate collinearity problems. For the OLS model in Table 1, the variance inflation factor for extension indicates that the variance of the regression coefficient of extension is inflated by a factor of 2,189! Furthermore, eigenvalues ranked from largest to smallest and their associated condition indices and variance proportions are presented in Table 2. Condition indices larger than 30 and associated with variance proportions greater than .5 for individual variables generally indicate a multicollinearity problem (Bellsey, Kuh, and Welsch). Extension and teaching have variance proportions of .9656 and .9839 associated with a condition index of 3,621! Presence of multicollinearity prompted use of ridge regression (RR), a biased estimation procedure.[4]

Ridge Regression

Ridge Regression (RR) was developed by Hoerl and Kennard as an alternative to OLS to be used when collinearity is severe. RR is a more general form of least squares than OLS in the sense that the RR estimator β^* is found as a solution to the normal equations where the diagonal elements of (X'X) are perturbed. The RR estimator is defined as $\beta^* = (X'X+kI)^{-1} X'Y$ where k is a small positive number. For $k > 0$, β^* is a biased estimator for β. The RR estimator constitutes a "shrinkage" of the OLS estimator; that is, as k gets larger, β^* shrinks toward zero. This property is appealing since the absolute magnitudes of the estimated coefficients are often too large when collinearity is severe. The appeal of RR lies in the tradeoff between variance and bias of the estimated coefficients. When collinearity is severe, a small increase in k typically results in a reduction in variance at the expense of a small increase in bias resulting in more accurate estimates (Gunst and Mason, p. 341). The art of using RR effectively is choosing a k value for which estimates are stable and bias is small.

The estimated coefficients for the RR model are shown in Table 1. A number of criteria were employed in selecting the k value of .02. Convergence and stabilization were indicated by a ridge trace, Figure 1, and the RR estimate for $k = .02$ was most consistent with *a priori* expectations based on factor shares, sum of coefficients, and coefficient signs. The estimated mean square error was reduced from 7.899 for the OLS estimator to .243 for the RR estimator with $k = .02$. MSE continued to decline to $k = .20$, but it was felt that the potential added bias did not justify selecting a higher k. Furthermore, the CP and PRESS statistics were minimized at $K < .02$ and the first k for which all

TABLE 2. MULTICOLLINEARITY DIAGNOSTICS FOR THE OLS ESTIMATED AGRICULTURAL PRODUCTION FUNCTION FOR VIRGINIA, 1949-1979 (CONDITION INDICES AND VARIANCE PROPORTIONS)

		Condition	Proportion								
Ranking	Eigenvalue	index	Intercept	Expenses	Capital	Labor	Land	Rain	Research	Extension	Teaching
1	7.727	1.00	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
2	0.931	2.88	0.000	0.000	0.000	0.000	0.000	0.685	0.000	0.000	0.000
3	0.304	5.04	0.000	0.000	0.000	0.014	0.000	0.017	0.002	0.000	0.000
4	0.037	14.41	0.000	0.000	0.000	0.091	0.000	0.001	0.013	0.000	0.000
5	1.069 E-04	268.81	0.002	0.026	0.029	0.589	0.071	0.036	0.463	0.001	0.000
6	4.998 E-05	393.20	0.000	0.368	0.003	0.029	0.003	0.017	0.034	0.011	0.002
7	2.843 E-05	521.32	0.001	0.266	0.619	0.000	0.008	0.101	0.017	0.006	0.001
8	2.443 E-06	1778.00	0.995	0.266	0.000	0.164	0.741	0.052	0.120	0.017	0.013
9	5.893 E-06	3621.00	0.002	0.124	0.349	0.114	0.177	0.089	0.351	0.966	0.984

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[3] Because of large variance of the estimates, hypothesis tests could not confirm that all the coefficients were significantly different from their factor shares or that the sum of coefficients was significantly different from 1.

[4] Principal Components Regression (PCR) was also applied. There were similarities between the PCR and RR results but PCR gave larger coefficients for the non-conventional variables and the sum of the conventional coefficients was only .6 implying unreasonably low returns to scale. Therefore, only the RR results are presented in this paper. This is not to suggest that RR estimates will always be preferred to PCR estimates but that, in this particular study, RR appeared to yield the more satisfactory results in terms of coefficient stability and *a priori* expectations. Another alternative for handling multicollinearity frequently used by economists is to drop variables. We prefer techniques such as RR and PCR because they allow one to preserve the theoretical model structure.

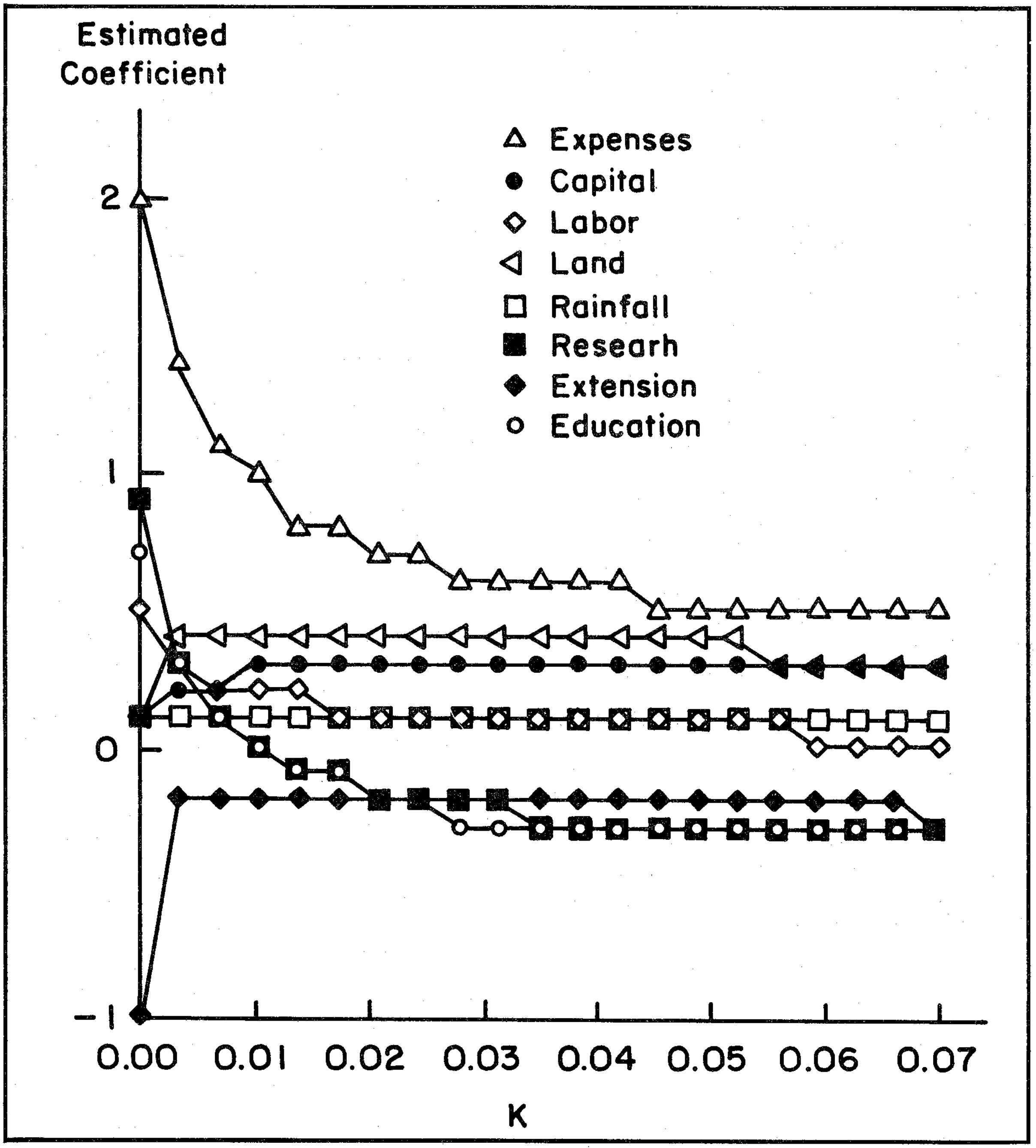

Figure 1. Ridge trace for RET model.

VIF's were below 10 was k = .02.[5] Results of this analysis support the conclusions of Brown and Beattie that for functions such as production functions for which most of the coefficients have the same expected sign and magnitude, stabilization occurs at a relatively small k value.

Six of the eight RR coefficients in Table 1 are at least twice their approximate standard errors and all have the hypothesized sign.[6] The RR estimates appear to be more plausible than the OLS estimates because (1) they are closer to the factor shares, (2) greater statistical signifi-

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[5] The CP statistic provides an alternative measure of total error based on MSE, and the PRESS Statistic is the predicted residual sum of squares (Montgomery and Peck, pp. 252-255).

[6] Since k is selected by the researcher after experimenting with the data rather than being specified in advance, it is a random variable. Hence, the RR standard errors are underestimated because they are calculated under the assumption that the variance of k is zero. However, many researchers use the RR approximated standard errors as a rough guideline for determining variable significance. For instance, it may be reasonable to consider a variable to be significant if it is two or three times as large as its approximate standard error yielded by ridge regression.

cance is obtained, (3) the sum of the conventional coefficients is closer to one, and (4) the approximate standard errors of the coefficients are smaller.

Spillovers and Private RET

The possibility of spillovers from other states and the omission of private research, extension, and teaching prompts two caveats. Land-Grant Universities in other states conduct agricultural research, extension, and teaching programs which spill over and benefit Virginia farmers and Virginia RET benefits other states. The importance of spillover effects and procedures for capturing them are described by White and Havlicek, Otto, and Evenson (1978).

Spillovers are difficult to measure in an aggregate agricultural production function because their extent and direction differ from commodity to commodity. A research spill-in variable based on federal formula funds expended in other states was tested, but its coefficient was not significant and therefore it was omitted from the analysis. Furthermore, to the extent that the omitted private (actually non-land grant) RET is positively correlated with public RET and is not captured in the prices of the conventional inputs, its omission inflates the coefficients on the included non-conventional inputs. Research, extension, and education expenditures by private firms, however, are very poorly documented, and would be very difficult to estimate. One would expect most of the benefits of private research and extension to be captured in the prices of the inputs. General education, however, may be positively correlated with the teaching variable, thereby biasing the teaching coefficient upwards.

Because of the omission of non-college of agriculture data, some authors (e.g. Griliches) attribute only a portion (typically one-half) of the returns to public funds and the remainder to private funds. The strategy in this study was to specify the variables for which data are available and to use the resulting coefficients so estimated without dividing them by two or three.

Whether estimated returns are biased upward or downward is not known. The presumption may be that they are overestimated because of the spill-ins and the omission of non-college of agriculture RET expenditures. However, the output effects that spill out to other states and sectors and, therefore, are not captured in Virginia farm output, result in a downward bias.

RETURNS ON INVESTMENT

The marginal product of research (MPR) was calculated from the RR results in Table 1 by using the following formula:

$$MPR = \sum_{j=0}^{M} a_{t-j}\ \bar{n}\ (\bar{Y}/\bar{R})$$

where MPR is the marginal product of research, a_{t-j} is the partial elasticity of production lagged j years, $\bar{n}$ is the arithmetic average number of farms, $\bar{Y}$ is the geometric mean of agricultural output, $\bar{R}$ is the geometric mean of agricultural research, and $j = 0, 1, 2 \ldots m$. Analogous formulae were used for extension and teaching.

The marginal products, i.e. the total (multi-year) return per additional dollar invested, were $12.00 for teaching, $8.94 for research, and $5.03 for extension. One must be careful in interpreting these marginal products since they accrue over several years. For example, it would be misleading to suggest that the $12 marginal product implies teaching returns of 1200 percent. Rates of return are (or at least should be) expressed on an annualized basis to permit comparisons. An additional advantage of presenting annual rates of return is that they do not depend upon which base year is utilized.

To convert to an annual basis, a second order polynomial distribution was estimated for research, extension, and education with benefits spread over 12 years for research, 9 years for extension, and 16 years for teaching. The length of lag was prespecified based upon the findings of other researchers. John Evenson (1967) found a 12-15-year research lag, Cline and Lu a 13-year lag, and White and Havlicek an 11-year lag for research and extension combined. Extension would logically have a shorter lag than research. Education would likely have a longer total lag because some of the benefits involve problem solving knowledge which depreciates very slowly.

These marginal products and benefit distribution patterns were used to convert the returns to an annualized internal rate of return. For example, the internal rate of return (r_R) was calculated for research using the $8.94 marginal product by obtaining the solution to the following equation:

$$\Sigma\ (MPR_{t-j}/(1 + r_R)^j) - 1 = 0$$

The returns to extension and teaching were similarly calculated. The internal rates of return so calculated for Virginia were 58 percent for research, 52 percent for education, and 48 percent for extension.

A COMPARISON USING NATIONAL COEFFICIENTS

As already noted, an alternative method for determining the marginal productivity of conventional and nonconventional inputs at the state level is to use coefficients from a national study and average products for a particular state. Davis, employing a cross-sectional Cobb-Douglas production function for the U.S. using 1974 data, obtained a regression coefficient of .036 for agricultural research expenditures lagged 6 years. The average value product for agricultural research in Virginia (value of agricultural output/research expenditures) was $140. Multiplying $140 by .036 yields a $5.04 marginal product of research. In order to incorporate the multi-year flow of benefits, an inverted "V" distribution was used to allocate the $5.04 marginal product over a 12-year period (6-year mean lag) resulting in an internal rate of return of 33 percent.

A rate of return also was calculated using White and Havlicek's *combined* research and extension coefficient of .0774 for their 1949-1972 time series study. Utilizing the time distribution of the partial research coefficients provided by them and the average products in Virginia, the calculated marginal product of research and extension for Virginia was $3.95 and the internal rate of return was 27 percent.

These internal rates of return of 33 percent and 27 percent for Virginia estimated from national coefficients are slightly more than half those obtained with the RR model using time series data for Virginia. The national coefficient approach can be used when administrators request information on short notice. Its underlying assumption, however, that research, extension, and teaching expenditures are equally productive in all states, creates some skepticism of the results. Also, few of the national studies were able to disaggregate research, extension, and teaching.

CONCLUSION

Estimates of rates of return on public investments in agricultural research, extension, and teaching are requested by university administrators, budget analysts, elected officials, and agricultural leaders. Most such estimates have been made at the national level and emphasized research despite the fact that most public investment and allocation decisions are decentralized to the state-level. State level estimates for agricultural research, extension, and teaching are simply not available.

Alternative approaches are available for analyzing returns to investments in agricultural research, extension, and education for a particular state. These approaches differ in terms of their validity as well as complexity and cost. The experience of this study is too limited a basis to warrant the use of production functions and ridge regression for every analysis for which RET coefficients are to be estimated at the state-level. However, since RET studies in other states are likely to be beset with some degree of multicollinearity, consideration of biased estimation techniques as methods for obtaining more stable, and hence more accurate results is encouraged if production function analysis is used.

Agricultural research, extension, and teaching involves the allocation of millions of dollars of public funds in what all available evidence suggests is a very high return investment. Others are encouraged to conduct disaggregated detailed state level analyses as well to provide information at the level where most of the funding and allocation decisions are made.

APPENDIX

Output—Output equals cash receipts from farm marketings plus total non-money income minus rental value of farm dwellings plus net change in farm inventory (Virginia Crop Reporting Service). Each component is deflated by the index (1967 = 100) of prices received by farmers on all farm products (U.S. Council of Economic Advisors).

Operating Expenses—Operating expenses equal the sum of expenses for feed, livestock, fertilizer, seed, repairs, and miscellaneous items (Virginia Crop Reporting Service). Feed expenses are deflated by the index (1967 = 100) of prices paid for feed, livestock expenses by the index (1967 = 100) of prices paid for livestock, seed expenses by the index (1967 = 100) of prices paid for seed; and miscellaneous expenses, repairs, and operation of capital items by the index (1967 = 100) of prices paid for aggregate production (U.S. Department of Agriculture a).

Capital—The capital services variable was constructed by summing the service flow from buildings, machinery, livestock inventory, crops stored on and off farms, and working capital.

The service flow from buildings is the value of farm structures excluding dwellings (U.S. Department of Agriculture e) deflated by the index (1967 = 100) of building and fencing materials (U..S Department of Agriculture a) and multiplied by the mortgage interest rate (Melichar and Waldheger).

The service flow from machinery is the value of machinery in Virginia multiplied by the U.S. ratio of production assets to farm assets (U.S. Department of Agriculture b). This value is deflated by the U.S. index of prices paid by farmers for tractors and self-propelled machinery (U.S. Department of Agriculture a) and then multiplied by the U.S. non-real estate debt average interest rate used by banks (Melichar and Waldheger). Depreciation for both buildings and machinery was a combined figure taken from the Virginia Crop Reporting Service and deflated by a 1967 = 100 index of prices paid by farmers.

Service flows from livestock and poultry equal the livestock and poultry inventory deflated by the Virginia index (1967 = 100) of meat animals (Virginia Crop Reporting Service) and multiplied by the non-mortgage interest rate.

The remainder of the capital variable equals one-third the value of crops stored on and off farms to reflect their average value plus working capital, deflated by the Virginia index of feed grains and hay (Virginia Crop Reporting Service) and then multiplied by the non-mortgage interest rate (Melichar and Waldheger). Capital stock levels were deflated before using the market interest rate appropriate for each type of capital.

Labor—Labor is defined as man years; i.e., total hours of labor worked per year by operators, hired workers, and family divided by 2000. Total hours worked was calculated by multiplying the average number of hours worked per week for each type of worker (U.S. Department of Agriculture d) by the number of workers of that type (Virginia Crop Reporting Service), and then multiplied by 52 weeks.

Land—The weighted land variable is Census of Agricultural data of harvested cropland + (pastured cropland x .5) + (total woodland x .075) + (land in farms − total cropland − total woodland) x .25). Non-census years were derived by interpolation.

Weather—The rainfall variable represents July precipitation for Virginia minus the mean precipitation for Virginia for the years 1932-1979 (U.S. Department of Agriculture. g).

Research—Research expenditures for the years 1938-1966 were obtained from (U.S. Department of Agriculture. f), and for later years were provided by Vernon Boggs (Virginia Polytechnic Institute and State University. b). Funds for the College of Agriculture at Virginia Tech exclude research expenditures for Home Economics and Veterinary Science. Research expenditures for each year are deflated by the index of government purchases of goods and services (U.S. Council of Economic Advisors) and the AAUP index of professor's salaries (Havlicek and Otto). The index of government purchases is weighted by .3 and the salary index by .7. A 12-year Almon polynomial lag is used for research.

Extension—Extension expenditure for 1942-1977 were obtained from (U.S. Department of Agriculture. c). Data for 1978 and 1979 were obtained from Robert Swain (Virginia Polytechnic Institute and State University. c). These numbers were adjusted to remove non-agricultural extension. The deflator is the same as that used for research expenditures. An 8-year Almon polynomial lag is used for extension which impacts on output with a shorter lag than research.

Education—The education variable is composed of expenditures on vocational education plus teaching expenditures for the College of Agriculture at Virginia Tech. Vocational Education expenditures for 1934-1962 were obtained from Latimer and for later years from U.S. Department of Commerce. Teaching expenditures for the College of Agriculture were obtained from Annual Financial Reports, Virginia Polytechnic Institute and State University. Deflators are the same as for research and extension. A 15-year Almon polynomial lag is used for the education variable because education depreciates slowly.

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