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Research Contributions from the Soybean Checkoff Program

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Soybean producers participate in a checkoff program to support research and market development activities. Checkoff funds are used for both yield-enhancing and cost-reducing production research. Using USDA cost-of-production data and a regional modeling framework with greater model pretest support than several alternatives, national marginal returns to producers are estimated to be higher for checkoff-supported research than for publicly supported soybean research. They are also higher for checkoff cost-reducing research than for checkoff yield-enhancing research.

Key words: checkoff, economic modeling, research returns, soybeans

Introduction

Since the early 1950s, many U.S. soybean producers have cooperatively invested in soybean production research. Since 1991, that has been accomplished through a mandatory, industry-wide checkoff program to support research and market promotion of soybeans.[1] In 1994, private investments in U.S. soybean research funded by the producer-controlled organization were nearly 10% as great as publicly supported soybean research. With so much concern about resource accountability, the existence of this program concurrent with public research programs provides a natural laboratory for evaluating alternative mechanisms for managing research funding.

From a political economy perspective, a natural concern is which research portfolio yields the higher return per dollar invested. In particular, would society benefit more by having all (or at least relatively more) of the total research funding managed by the public organization or by the producers' organization?[2] From the soybean producers'

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[1] A mandatory industrywide checkoff program was authorized in the 1990 farm bill and implemented following a referendum by soybean producers. However, state-level checkoff programs had existed in several states for nearly four decades. Checkoff funds were (and still are) collected by the state organizations. Even prior to the national program, a national office administered part of the funds. About half of the funds have been managed by the states and half by the national organization. The states allocate most of their funds to soybean production research, while the national program funds both soybean research and market development activities. Most of the checkoff research funds go to state experiment stations.

[2] Because decisions by one set of research portfolio managers may not be independent of those made by another, investment return information must be interpreted cautiously. It may have policy value only at the margin—that is, for small rather than large changes in portfolio management. Even if the returns in one portfolio are substantially higher than another, it may not be possible to attain the higher return on that portfolio without some continued investment in the other portfolio.

perspective, an obvious concern is whether their investments have benefitted producers more than they have cost them. Should they favor continued voluntary support of soybean research?

To help analysts address these questions, there is a substantial body of literature dating to the 1950s dealing with estimation of economic returns to investments in agricultural research. It builds on seminal work by Schultz and by Griliches. Important contributions to the theoretical and empirical literature have been made by a number of researchers (e.g., Evenson; Peterson; Huffman and Evenson 1989; Norton and Davis; Fox; Pardey and Craig; and Chavas and Cox). While empirical estimates of returns to agricultural research vary by commodity, location, and method of estimation, they have generally been quite high. Nearly all rate-of-return estimates exceed 25%, and some surpass 100%. For example, of more than 75 estimates reported by Evenson, Waggoner, and Ruttan, and by Tweeten, nine out of ten exceeded 25%. Recent work has addressed possible errors in earlier methods, including the failure to account for deadweight losses associated with tax collection to support public research (Fox), but most estimates of the return to public investment in agricultural research are still above typical rates of return on private investments.

Two of the more important methods of measuring rates of return to agricultural research are the following:

1. Estimate the impact of past research investments on farm profits by statistically estimating the relationship between profit and a set of variables that include prices, farm program provisions, and research investments.

2. Alternatively, compute changes in productivity (the ratio of outputs to inputs) for each year; statistically regress the productivity changes on farm programs, research investments, and other potentially relevant variables; then measure the value of the productivity changes caused by research investments using current output and input prices.

Because of the difficulty of accurately tracing the uncertain effects of such contributions to technology, a number of methodological issues must be addressed. There may be a long delay between the commitment of research resources and discovery of new knowledge, and sometimes an even longer delay between the discovery and widespread adoption of new (or improved) technology. Consequently, careful attention must be given to measuring the time lags between research investments and their payoffs. Because soybeans are seldom produced as a monoculture, the returns to soybean research may not be independent of returns to research on crops produced in rotation with soybeans, the most obvious of which is corn. In addition, research is an inherently uncertain productive enterprise because the discovery of new knowledge is not a repetitive production process. Thus, special care must be used to deal with its extreme randomness.

The empirical objectives of this study are to: (*a*) estimate the marginal return to U.S. publicly supported soybean and corn research and two types of privately supported research on soybeans (i.e., cost-reducing and yield-enhancing research), and (*b*) determine whether continued support of the checkoff program by soybean producers is in their collective best interest. Because empirical results are often sensitive to model specification, auxiliary specification objectives are also pursued to assure reasonable confidence in the findings of this study.

Method of Analysis

The impact of past research investments on soybean producer profits is measured in this study using the first of the two methods noted above. That is, the relationship between regional producer profits and a set of explanatory variables that include research investments is statistically estimated. The marginal regional impacts of changing research investments are examined using these estimated equations. The regional impacts are cumulated for the nation. Because of the high level of regional spillover effects frequently observed in agricultural research benefits, only national impacts are reported.

One of the important model specification issues that must be addressed prior to estimating impact on producer profits is what behavioral objective, if any, to maintain in the estimation. If the objective is known or can be presumed with reasonable confidence prior to estimation, greater estimation efficiency can be achieved. In addition, the demands placed on a limited data set can be reduced. Prior nonparametric tests of the weak axiom of profit maximization have consistently found only minor departures from this hypothesis evident in national and state-level agricultural production data (Williams and Shumway 1998a,b; Lim and Shumway). Consequently, each of seven soybean production regions (Atlantic, Corn Belt, Delta, Lake States, Plains, South, and Other) is modeled as though it is a single, price-taking, profit-maximizing firm.

The empirical objectives of the study are pursued by estimating the parameters of a restricted profit function for each region with all inputs presumed to be in continuous equilibrium. That is, in each time period each variable input is used to the point at which the value of its marginal product (VMP) equals its exogenous price, the price of each quasi-fixed input equals its VMP at the exogenous quantity level, and the marginal cost of each output level equals its exogenous expected price. Research stock variables are also included as regressors (i.e., exogenous variables).

The profit function is chosen for the estimation framework because of its convenience. Since our primary empirical concern is to estimate the collective value of research support from the soybean checkoff program to those who pay for it, we estimate the value of the research to soybean farmers. The annual value to farmers in a given region from investment in a particular class of research can be measured directly by the estimated marginal impact on farm profits. That can be determined by taking the first derivative of the regional profit function with respect to the research variable and multiplying it by the derivative of the research variable with respect to research investment. National present value of the marginal investment can then be computed by summing the discounted marginal impacts across the impact period and across the seven regions.

This procedure provides estimates of the national marginal value of research investments subject to all other exogenous variables remaining constant. In the restricted profit function, the latter are expected prices of outputs, prices of variable inputs, and quantities of quasi-fixed inputs. To the extent that the research induces changes in the aggregate quantities of outputs or variable inputs or in the prices of quasi-fixed inputs, the total value of the benefits could change and some of the research benefits could shift from soybean producers to consumers and/or primary input owners. Because soybean production is a minor part of agricultural production in most regions, the most likely impact on the exogenous variables from an increase in research expenditures would be a reduction in soybean price. In that case, some of the benefits would transfer to consumers. Some benefits could also partially transfer to any downstream (i.e., post-farmgate) firm that is able to exert market power.

Estimation

Except for selection of the price expectation formulations, the model specification tests and empirical objectives are approached by estimating systems of first-derivative equations of the regional restricted profit functions. Each regional system of normalized netput supply (i.e., positive output quantity and negative input quantity) equations is estimated independently of other regions. In addition, the inverse negative input demand equations for quasi-fixed inputs are included in the estimation of the final model and in the specification tests for research stock variables.

Iterative generalized least squares for a seemingly unrelated system of equations (as implemented in SHAZAM 7.0) is used to estimate these models for the specification tests. Iterative nonlinear generalized least squares for a seemingly unrelated system of equations is used to estimate the final models.

Each equation is assumed to have an additive error term that may be contemporaneously correlated with the error term of other equations in the estimated system. Linear homogeneity of the profit function in prices and symmetry among shared parameters is maintained in each estimated system. The condition that netput supplies slope upward in own prices is maintained in the final model.

Data

Our regional models correspond to the seven regions in the SOYMOD soybean simulation model (Williams 1985, 1995). Annual regional expenditure data for the period 1975–94 are taken from U.S. Department of Agriculture/Economic Research Service (USDA/ERS 1996a), “Cost-of-Production” statistics. They are expenditures on each of 12 inputs per planted acre of soybeans and corn in each of four regions. Because the two sets of regions do not coincide, the cost-of-production regions for both soybeans and corn are matched with our regions using the largest number of overlapping states as the criterion.

Because neither state nor regional price series are available for the input categories for the entire data period, U.S. input price indices are used. Price indices for seed, fertilizer, chemicals, fuel, hired labor, and operating capital (interest rate) are taken from USDA/National Agricultural Statistics Service (USDA/NASS 1996a), *Agricultural Prices*, and from the USDA/ERS (1996b) electronic database. Price indices for custom operations (purchased services), capital replacement, repairs, and nonland capital (durable equipment), and unpaid labor (self-employed labor) are derived from Ball. Missing data are approximated by regressing the incomplete series on variables with complete data series.

Regional planted acreage of soybeans and corn are from USDA/NASS (1996b), “Crop Production Summary.” They are used to multiply the respective production costs per acre to obtain total regional cost for each input. Regional input quantity indices are computed for each crop by dividing regional input costs by the respective price indices.

On pragmatic grounds, the 11 national input price indices are aggregated into three variable input categories (chemicals, capital, and other purchased inputs) and one quasi-fixed input category (labor) for each region by the Tornqvist index procedure.[3] Regional expenditure shares are used as weights. Regional opportunity cost per planted acre is taken from the cost-of-production data as the price for the second quasi-fixed input category (land). Aggregate quantity indices are obtained by dividing total regional cost for the category by the respective Tornqvist price index. The inputs aggregated into each category are: (*a*) chemicals—fertilizer and chemicals; (*b*) capital—capital replacement, repair, and nonland capital; (*c*) other purchased inputs—fuel, seed, operating capital, and custom operations; and (*d*) labor—hired and unpaid labor. Regional planted acreage is used for the quantity of land.

Because historical output price data are used to test alternative formulations of expected market prices, regional annual output price data are required for a longer data period. They are constructed as weighted averages of state farm prices for the period 1949–94, with the weights based on annual planted acreage of the respective crop. The state-level output price data are taken from *Agricultural Prices* (USDA/NASS 1996a) and *Agricultural Statistics* (USDA/Statistical Reporting Service 1996). Annual U.S. loan rates, target prices, acreage reduction, and flex acreage policies for the period 1975–94 are from the USDA's *Agricultural Outlook*, *Feed Situation and Outlook Yearbook*, and *Oilseed Situation and Outlook Yearbook* (USDA/ERS 1994a,b,c), and from the Food and Agricultural Policy Research Center (FAPRI).

Annual U.S. public expenditures on soybean and corn research for the period 1970–94 are from the USDA/Cooperative State Research Service's *Inventory of Agricultural Research* (annual series, 1971–95). They include research conducted by national organizations (such as the Agricultural Research Service) and by state agricultural experiment stations. U.S. data for two additional years, 1960 and 1965, are from Huffman and Evenson (1993). Data for years between 1960 and 1965, and between 1965 and 1970 are approximated by linear extrapolation.

Annual U.S. checkoff expenditures for two types of soybean research—yield-enhancing and cost-reducing—for the period 1978–94 are from Smith and Associates. Yield-enhancing research is limited to production-oriented research that has the goal of increasing soybean yields per unit of land. Cost-reducing research includes all other types of research having the goal of lowering the cost of producing soybeans and soybean products. No records for research investments from soybean checkoff funds are available before 1978. Neither are complete data available on states where the research was performed. Estimated U.S. investments for earlier years are obtained by regressing both types of research checkoff expenditures on national soybean receipts, year, and the square of receipts from 1978 to 1994.

An annual U.S. agricultural research price index for the years 1960–90 is derived from Huffman and Evenson (1993), and from Huffman for 1991–94. Research expenditures are converted to real-dollar series for use in constructing the research stock variables by dividing the respective research expenditure data by the research price index.

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[3] Inputs were aggregated because estimating a model with 11 inputs would leave few degrees of freedom and because such a detailed model was not warranted by the objectives of this study. Using national data for the U.S., Williams and Shumway (1998b) found empirical support for consistently aggregating inputs into these four categories based on nonparametric tests of homothetic separability. Land and labor are treated as quasi-fixed inputs because they tend to adjust to optimal levels more slowly than other inputs used in agricultural production.

Model Specification Tests

Several model structure and variable definition issues were addressed by means of model specification pretests. They included price expectation, functional form, production structure, and research lag structure. To not detract from the primary objectives of the study, we simply note the selected specifications from the first three tests and report details only for the last test. (Details of all tests are available on request from the authors.)

Price expectations are a combination of quasi-rational market price expectations and loan rate for soybeans, and a combination of quasi-rational market price expectations and target price for corn. The normalized quadratic is chosen for the functional form of the restricted profit function. The production structure for both commodities is nonjoint in all regions, which implies that soybean production and input usage for soybean production can be reasonably modeled in each of the regions without accounting for the effects of changes in any other commodity's expected output price. The analogous implication applies to corn production.[4]

Maintaining the above assumptions regarding model specification, the final set of specification tests focused on alternative lag structures in order to define soybean and corn research stock variables from research investments. Two systems of equations were estimated for the Corn Belt region, each of which included one output supply equation [soybeans or corn (y_1)], three input demand equations [chemicals (y_2), capital (y_3), and the numeraire input—other purchased inputs (y_4)], and two inverse quasi-fixed input demand equations [labor (w_5) and land (w_6)]:

$$\text{(1a)} \qquad y_i = \alpha_i + \sum_{j=1}^{3} \alpha_{ij} p_j + \sum_{k=5}^{6} \beta_{ik} z_k + \sum_{m=7}^{n} \delta_{im} r_m, \quad i = 1, 2, 3;$$

$$\text{(1b)} \qquad y_4 = \alpha_4 + \sum_{k=5}^{6} \beta_k z_k - 0.5 \sum_{i=1}^{3} \sum_{j=1}^{3} \alpha_{ij} p_i p_j + 0.5 \sum_{k=5}^{6} \sum_{l=5}^{6} \psi_{kl} z_k z_l + \sum_{k=5}^{6} \sum_{m=7}^{n} \delta_{km} z_k r_m;$$

and

$$\text{(1c)} \qquad -w_k = \beta_k + \sum_{j=1}^{3} \beta_{kj} p_j + \sum_{l=5}^{6} \psi_{kl} z_l + \sum_{m=7}^{n} \delta_{km} r_m, \quad k = 5, 6,$$

where w_k is the normalized price of quasi-fixed input k; r_m is the research stock variable m; and α, β, ψ, and δ are parameters to be estimated. Quantities of all inputs were negatively measured. Equation (1a) is the system of linear variable netput supplies, (1b) is

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[4] The nonjoint conclusion is an admittedly surprising result since corn and soybeans are frequently grown on the same farm, often in rotation, and using much of the same equipment. No claim is made here that the micro-production functions for soybeans and corn are actually independent. However, the regional cost-of-production data do not reflect an interdependence in their aggregate production functions. It is possible that this result is due to the methods used by USDA to compile the cost-of-production data. In the data series, inputs are fully allocated between crops even though the input quantities required to produce given amounts of corn and soybeans on the same farm may not be as great as the input quantities required to grow the same amounts of corn and soybeans on two specialized farms. Because of the unexpected nature of this test result, the sensitivity of major study conclusions to this specification will be examined.

the numeraire (normalizing) netput supply, and (1c) is the system of negative inverse quasi-fixed input demands. Linear homogeneity of the profit function in exogenous prices was maintained by normalization of prices by the price of other purchased inputs (netput 4). Symmetry of the cross-parameters α_{ij} with α_{ji}, β_{ik} with β_{ki}, and ψ_{kl} with ψ_{lk} (i.e., maintaining the hypothesis that the profit function is twice continuously differentiable) was achieved by linear restrictions. Linear and squared terms on the research variables that derive from a fully expanded profit function were omitted from (1c) to reduce collinearity among the regressors.

The research stock variables were formed as a weighted average of historical research investments measured in real dollars. They are proxies for the quantity of effective research and are included in the model as exogenous variables. These variables were formed as follows:

$$(2) \qquad r_{mt} = \sum_{r=1}^{s} \lambda_{mr} I^{*}_{m,t-r}, \quad \sum_{r=1}^{s} \lambda_{mr} = 1,$$

where $I^{*}_{mt} = I_{mt}/p_{mt}$ is the real-dollar research investment of type m in year t, I_{mt} is the nominal-dollar research investment of type m in year t, p_{mt} is the corresponding research price index, λ_{mr} is the weight on the real-dollar research investment of type m lagged r years, and s is the lag length over which research investments are expected to impact farm profits.

Seven alternative lag structures were considered in the construction of research stock variables from research investments and are depicted in figure 1, panels (a)–(g). These included:

(a) Almon Polynomial Distributed Lag—lag length of 15 years;
(b) Almon Polynomial Distributed Lag—lag length of 30 years, truncated at the 15th year;[5]
(c) Trapezoidal Lag Structure—first linearly increasing (7 years), constant (6 years), and then decreasing (17 years), truncated at the 15th year;
(d) Trapezoidal Lag Structure—first linearly increasing (5 years), constant (10 years), and then decreasing (15 years), also truncated at the 15th year;
(e) Gamma Distribution Lag Structure—infinite lag, peak at the 5th year, truncated at the 15th year;
(f) Gamma Distribution Lag Structure—infinite lag, peak at the 10th year, truncated at the 15th year; and
(g) Gamma Distribution Lag Structure—infinite lag, peak at the 15th year, truncated at the 15th year.

Tests were conducted with the model defined in equations (1a)–(1c) to determine which of the seven alternative lag structures on research investments was preferred for defining the research stock variables. Three exogenous research variables were included in the soybean models (stocks of soybean public research, yield-enhancing checkoff, and

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[5] For the polynomial distributed lag, a quadratic polynomial with two endpoint constraints was specified to form a stock of research investments in order to avoid negative lag coefficients for individual years at the beginning or end of the lag structure. The major constraint to analyzing the lag length and lag structure was the small number of observations on research investments. For that reason, we focused on lag lengths of 15 years. We also included some 30-year lag structures truncated at the 15th year.

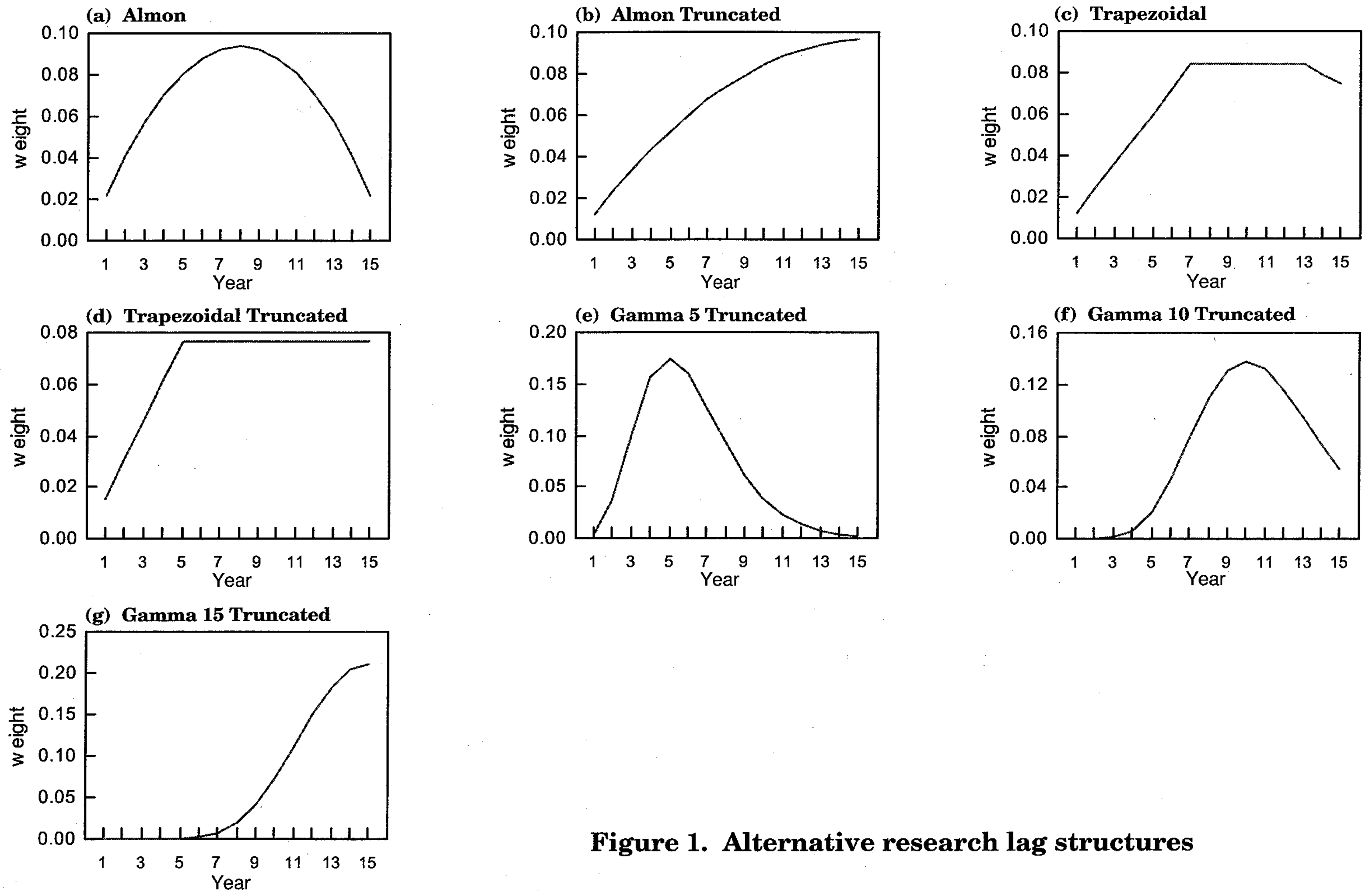

Figure 1. Alternative research lag structures

cost-reducing checkoff investments). A total of 49 alternative models were estimated to permit independence of the lag structure between public research and research supported by the checkoff program.

Lag structures were chosen based on a combination of formal statistical tests (likelihood dominance criterion) and heuristic criteria (number of significant parameters and number of expected signs on own-price netput supply response). From among 49 alternatives, the gamma distribution lag structure (e) was chosen for public soybean research, and the trapezoidal lag structure (c) was chosen for soybean checkoff cost-reducing and yield-enhancing research.

To determine preferred lag structure for the corn research stock variable, a system of equations was estimated for the corn model in the Corn Belt region with one research variable (stock of corn public research) using the same alternative lag structures on the research investments. Using the same test criteria, the same gamma lag structure (e) was chosen for corn public research as for soybean public research.

Empirical Model and Results

With the selected specifications of the research stock variables, equations (1a)–(1c) were estimated for each crop in each region (n was 9 for the soybean models and 7 for the corn models). In addition to maintaining homogeneity and symmetry in each regional commodity model, the netput supply equations were constrained to be upward sloping in own-price. This was accomplished by estimating a squared parameter on own-price. Because price-taking, profit-maximizing behavior by individual firms does not imply that an aggregate of firms exhibits the same properties, convexity of the profit function in prices was not maintained.

Although time is often included as a regressor in netput supply models, it was not included here. There are two important reasons for its exclusion. First, since research variables were included, it was not needed to serve as a proxy for disembodied technical change. Second, when time is included in equations with nonstationary and cointegrated variables, serious erroneous inferences can be obtained (Clark and Youngblood; Lambert and Shonkwiler; Ng). Although time-series tests were not conducted with these data because of the relatively few observations (20 years), tests with similar agricultural production data generally conclude that variables in these types of equations are nonstationary and cointegrated.

Durbin-Watson statistics were computed for each estimated equation to determine whether autocorrelation might be a serious problem. Evidence of significant autocorrelation was found in the soybean model estimates for the Other region, and in the corn model estimates for all regions. Soybean model parameters were reestimated for the Other region and the corn model parameters were reestimated for all regions, allowing for a unique first-order scalar autocorrelation parameter in each equation. Corn model estimates were obtained allowing for unique second-order autocorrelation parameters in the Plains, South, and Other regions.

The model parameter estimates thus obtained for the regional soybean models are reported in table 1. More than half of the parameter estimates were significant at the 5% level. The corresponding parameter estimates for the regional corn models are reported in table 2. Two-thirds of the corn model parameter estimates were significant.

Research Bias Effects

Estimates of the input bias effects of technical change from the various sources and types of research investments were computed following Huffman and Evenson (1989) as marginal relative impacts. For each crop, input bias (ρ_{im}, $i = 2, \ldots, 6$) was measured as the partial derivative of the logarithm of the input's cost share with respect to the logarithm of the research stock variable:

$$(3)\qquad \rho_{im} = r_m\left(\delta_{im}/y_i + \sum_{j=2}^{3}\delta_{jm}p_j/C\right), \quad i = 2, 3;$$

$$\rho_{4m} = r_m\left(\sum_{k=5}^{6}\delta_{km}z_k/y_4 + \sum_{j=2}^{3}\delta_{jm}p_j/C\right);$$

$$\rho_{im} = r_m\left(-\delta_{im}/w_i + \sum_{j=2}^{3}\delta_{jm}p_j/C\right), \quad i = 5, 6.$$

Because the form of the profit function was not amenable to maintaining estimation restrictions that input cost shares sum to 1.0, the input biases do not necessarily sum to zero.

Bias estimates from both soybean and corn research are reported in table 3, along with their approximate standard errors. Among the bias estimates that were statistically significant at the 10% level, magnitudes varied widely, as did directional impacts of a particular research variable across regions. For example, increases in public corn research were associated with about as many input-using as input-saving biases for every input except land. For land, the significant biases were primarily input saving.

More consistency in the bias effects was found for each type of soybean research than for public corn research. For example, biases from increases in public soybean research were almost entirely labor and land using, and capital and other purchased inputs saving. Biases from yield-enhancing checkoff research were labor and other purchased inputs using and land saving, while those from cost-reducing checkoff research were chemical, labor, and land using. For all other inputs, the number of significant input-using biases was nearly the same as the number of input-saving biases. So all types of soybean research were generally labor using, but no other consistent generalizations emerge across research types.

Marginal Value of Research Investments

The marginal value of each type of research investment in year $t - s$ was computed as the total discounted value of marginal profit (*TMPI*) with respect to a one-unit change in the research investment:

$$(4)\qquad TMPI_{m,t-s} = \sum_{r=1}^{s} MPI_{m,t-r}/(1 + d)^r,$$

where *MPI* is the annual flow of estimated marginal profit due to a one-unit change in research investment in an earlier year, *s* is the length of time over which the research is expected to contribute value, *m* is research type, and *d* is the real discount rate (0.035). Because the profit functions were estimated for individual regions using U.S.

Table 1. Parameter Estimates of Soybean Models, by Region

	ATLANTIC		CORN BELT		DELTA		LAKE STATES	
Parameter[a]	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
α1	0.0215	0.0388	-0.3176	0.2678	0.0392	0.0904	-0.0880	0.0748
α2	0.1080	0.0711	2.5411	0.4687	0.8264	0.1204	0.2486	0.0818
α3	-0.3808	0.0811	-2.4932	0.5353	-1.0431	0.1989	-0.3143	0.1182
α4	-0.2059	0.0248	-1.0529	0.3921	-0.3917	0.0730	-0.0999	0.0511
β5	-0.3319	0.2631	0.1134	0.2640	0.5373	0.4829	-0.1040	0.2659
β6	1.3551	20.3650	38.1160	16.0200	37.4360	21.5800	57.0700	12.8640
α11	-0.0040	0.0066	-0.0022	0.0355	0.0313	0.0109	-0.0036	0.0116
α12	-0.0139	0.0035	-0.0632	0.0172	-0.0270	0.0072	-0.0106	0.0029
α13	0.0049	0.0034	0.0219	0.0273	-0.0310	0.0179	-0.0036	0.0042
β15	-0.1072	0.0262	-0.0705	0.0106	-0.1304	0.0220	-0.0790	0.0143
β16	-14.6750	1.2660	-23.0930	1.3488	-15.9690	1.6791	-23.2680	0.9571
δ17	0.0003	0.0011	0.0151	0.0075	0.0011	0.0024	0.0037	0.0021
δ18	-0.0011	0.0396	-0.6352	0.2632	-0.0509	0.0871	-0.1065	0.0725
δ19	0.0104	0.1729	3.4325	1.1335	0.2728	0.3812	0.4902	0.3105
α22	0.3965	0.0492	0.3158	0.1692	0.2204	0.0729	0.0461	0.0994
α23	-0.0513	0.0251	-0.0256	0.1603	0.1803	0.0868	0.0640	0.0290
β25	0.5254	0.1283	0.0831	0.0981	0.2774	0.1152	0.1137	0.0943
β26	81.6950	12.2640	87.0630	11.8040	57.8010	10.6620	65.9100	8.5152
δ27	0.0043	0.0026	-0.0013	0.0134	-0.0120	0.0045	0.0011	0.0028
δ28	-0.0910	0.0788	-0.1204	0.4160	0.1743	0.1389	-0.0510	0.0849
δ29	0.0472	0.3025	-0.1989	1.7752	-0.8142	0.5214	0.2066	0.3737
α33	0.0120	0.0230	0.0529	0.3361	0.0014	0.1896	0.0030	0.1458
β35	-0.4561	0.1064	0.0793	0.1113	0.1623	0.1529	-0.0195	0.1598
β36	-0.3218	6.0091	-2.6280	13.0310	-3.1734	9.2320	1.0378	10.7520
δ37	0.0044	0.0021	0.0235	0.0149	0.0181	0.0039	0.0005	0.0035
δ38	-0.0753	0.0822	-0.5814	0.4654	-0.2486	0.1252	-0.0216	0.1077
δ39	0.3287	0.3648	2.7456	2.0017	0.6621	0.5085	0.0149	0.4736
ψ55	0.4348	0.2519	-0.2602	0.1258	0.1152	0.2824	0.0302	0.5251
ψ56	53.0330	31.4280	18.3500	5.4961	7.0746	22.2860	29.5180	16.6450
δ57	0.0190	0.0067	0.0040	0.0051	-0.0134	0.0084	0.0035	0.0065
δ58	-0.6364	0.2030	-0.3561	0.1102	-0.0342	0.2171	-0.3473	0.1347
δ59	1.2379	0.7804	0.7840	0.4120	-0.5497	0.8280	0.8895	0.5011
ψ66	50.1560	16.3430	16.0740	5.6198	62.0940	12.0980	-0.0813	1.1341
δ67	-0.1240	0.4919	-0.9871	0.2924	-1.1681	0.4092	-1.0213	0.3006
δ68	-8.3883	16.4700	17.1240	7.3157	10.3300	13.4060	19.2820	6.6283
δ69	9.9954	70.8730	-20.6500	30.1500	-6.7644	58.0500	-32.9060	26.8310

[a] Parameters are identified in equation system (1a)–(1c). Numbers denote the following: 1 = soybeans, 2 = chemicals, 3 = capital, 4 = other purchased inputs, 5 = labor, 6 = land, 7 = public research, 8 = yield-enhancing checkoff research, and 9 = cost-reducing checkoff research. All six of the estimated autocorrelation parameters were significant at the 5% level in the Other region.

Table 1. Extended

	OTHER		PLAINS		SOUTH	
Parameter[a]	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
α1	-7.3487	0.1519	-0.1929	0.0650	0.0314	0.0709
α2	-7.1676	0.1460	0.1001	0.0594	0.3613	0.0714
α3	-7.5251	0.1553	-0.3562	0.1183	-0.5369	0.0784
α4	12.9100	0.9622	-0.1125	0.0401	-0.1634	0.0291
β5	-5.1727	0.3793	-0.7862	0.2034	0.5264	0.3900
β6	-2.1515	0.9363	37.2460	16.3000	93.0770	17.1200
α11	0.9419	0.0073	0.0081	0.0079	0.0024	0.0209
α12	0.8466	0.0131	-0.0059	0.0022	-0.0274	0.0029
α13	0.9091	0.0158	0.0039	0.0026	-0.0168	0.0077
β15	0.2451	0.0828	-0.0538	0.0099	-0.1532	0.0302
β16	-4.0884	0.6909	-17.5210	1.3558	-15.8050	0.9548
δ17	0.0555	0.0246	0.0059	0.0018	0.0012	0.0020
δ18	0.0926	0.0397	-0.1935	0.0636	-0.0343	0.0714
δ19	0.3510	0.1767	0.9558	0.2731	0.1413	0.3034
α22	0.9305	0.0108	0.1353	0.0618	0.3842	0.0346
α23	0.8604	0.0145	0.0159	0.0254	0.1616	0.0546
β25	0.6634	0.1749	0.2893	0.0716	0.4532	0.1286
β26	8.1168	1.1175	49.8820	6.9376	50.1040	7.5892
δ27	0.0541	0.0236	0.0034	0.0021	-0.0075	0.0036
δ28	0.0881	0.0385	-0.0035	0.0541	0.1500	0.1098
δ29	0.2487	0.1717	-0.0232	0.2318	-0.8252	0.3827
α33	0.9715	0.0095	0.0023	0.1055	0.0514	0.0406
β35	0.3780	0.1440	-0.3591	0.1547	0.1640	0.1415
β36	2.7384	0.8409	-16.9340	11.3070	10.8360	5.5124
δ37	0.0576	0.0249	-0.0026	0.0037	0.0077	0.0025
δ38	0.0933	0.0398	-0.1094	0.1128	-0.0740	0.0843
δ39	0.4194	0.1760	0.3643	0.4851	0.2426	0.3271
ψ55	3.5668	0.8002	1.1750	0.2036	0.2331	0.6590
ψ56	5.1670	0.9660	-15.3220	23.5530	-1.2224	15.5600
δ57	0.0303	0.0125	0.0097	0.0060	-0.0160	0.0089
δ58	-0.2353	0.1284	-0.4091	0.1210	0.2026	0.2083
δ59	-0.1956	0.4850	0.5758	0.4321	-1.7401	0.7792
ψ66	-3.4044	0.9399	-0.6728	4.5274	0.3794	14.4620
δ67	1.6542	0.9926	-0.6201	0.3096	-1.5777	0.4008
δ68	-8.4804	1.1265	19.4860	6.2909	31.0430	11.9420
δ69	-3.5131	0.8832	-45.0220	23.5710	-154.3700	48.8150

Table 2. Parameter Estimates of Corn Models, by Region

	ATLANTIC		CORN BELT		DELTA		LAKE STATES	
Parameter[a]	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
$\alpha 1$	0.3669	0.3203	6.1615	0.8542	-0.1580	0.0675	1.0309	0.5411
$\alpha 2$	-0.2068	0.1413	2.7919	0.4429	-1.0628	0.0535	8.1452	1.3366
$\alpha 3$	-0.1301	0.1168	2.8513	0.4431	-1.9558	0.0489	-2.1034	0.2083
$\alpha 4$	-0.9055	0.1673	-4.5249	0.1661	0.0010	0.0033	-1.7165	0.1020
$\beta 5$	0.4482	0.4802	1.0763	0.0394	1.7097	0.1714	-2.4616	0.5909
$\beta 6$	-39.0470	4.8580	0.9890	1.0149	14.7420	1.1774	135.5000	11.7510
$\alpha 11$	-0.1455	0.0208	0.1037	0.0157	-0.0430	0.0036	-0.0283	0.0369
$\alpha 12$	-0.0239	0.0075	-0.3181	0.0157	-0.0013	0.0005	-0.1143	0.0103
$\alpha 13$	-0.0048	0.0077	0.1993	0.0369	-0.0043	0.0011	0.2356	0.0248
$\beta 15$	0.0547	0.0231	0.0099	0.0132	0.0047	0.0150	0.1587	0.0462
$\beta 16$	-13.4200	2.4954	-14.4910	1.0395	-26.5420	1.8512	-17.2720	7.9222
$\delta 17$	-0.0034	0.0071	0.2491	0.0241	0.0030	0.0018	-0.0060	0.0057
$\alpha 22$	-0.1923	0.0457	1.0975	0.0549	0.0425	0.0051	0.6744	0.0243
$\alpha 23$	-0.1315	0.0268	-2.2403	0.1301	-0.0020	0.0044	-0.4470	0.0191
$\beta 25$	0.0059	0.1114	-0.4279	0.0376	-0.1527	0.0983	-0.2321	0.1426
$\beta 26$	27.6740	4.0609	3.4771	0.9981	56.3990	1.7183	99.7340	8.7357
$\delta 27$	0.0033	0.0027	-0.1454	0.0111	-0.0004	0.0005	0.0145	0.0082
$\alpha 33$	0.4502	0.0450	0.8770	0.0487	0.1548	0.0086	-0.0624	0.1610
$\beta 35$	0.3238	0.1029	-0.5394	0.0450	0.7133	0.1072	0.1064	0.1830
$\beta 36$	26.9640	3.8241	0.1273	0.9913	-51.8270	1.2644	-27.5070	16.5460
$\delta 37$	0.0003	0.0024	-0.0707	0.0101	-0.0029	0.0008	0.0207	0.0024
$\psi 55$	-0.5955	0.3645	-0.3496	0.0258	-0.6939	0.6192	-0.0514	0.2307
$\psi 56$	34.7910	8.4010	-10.9750	0.7656	5.0767	1.0012	-63.5580	6.7466
$\delta 57$	0.0160	0.0103	-0.0317	0.0007	-0.0438	0.0041	0.0311	0.0104
$\psi 66$	3.0509	1.1368	1.3317	1.0008	4.8502	1.0043	-65.7570	2.2957
$\delta 67$	-0.4661	0.1687	0.4369	0.0286	0.8513	0.1033	-3.5797	0.2826

[a] Parameters are identified in equation system (1a)–(1c). Numbers denote the following: 1 = corn, 2 = chemicals, 3 = capital, 4 = other purchased inputs, 5 = labor, 6 = land, and 7 = public research. First-order autocorrelation models were estimated for the Atlantic, Corn Belt, Delta, and Lake States regions. All six estimated autocorrelation parameters were significant in each of those regions. Second-order autocorrelation models were estimated for the remaining regions. All 12 estimated autocorrelation parameters were significant in the Other and Plains regions. In the South region, the estimated first-order parameters were significant only for the chemical and labor inputs, and the estimated second-order parameters were significant only for chemicals.

research stock variables, *MPI* was derived for the U.S. by summing the estimated regional marginal profit impacts as follows:

$$(5)\qquad MPI_{m,t-r} = \partial\pi_t/\partial I_{m,t-r} = \left(\partial\pi_t/\partial r_{mt}\right)\left(\partial r_{mt}/\partial I_{m,t-r}\right)$$
$$= p_4\left[\sum_{j=1}^{7}\left(\sum_{i=1}^{3}\delta_{jim}p_i + \sum_{k=5}^{6}\delta_{jkm}z_k\right)\right]\left(\lambda_{mr}/p_{m,t-r}\right),$$

Table 2. Extended

	OTHER		PLAINS		SOUTH	
Parameter[a]	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
α1	3.2220	0.1354	-2.2092	0.4984	3.9371	2.6809
α2	0.4954	0.0918	-3.3054	0.1630	1.1634	0.5990
α3	0.4255	0.0814	-0.3994	0.3759	0.2763	0.3605
α4	-0.2306	0.0563	-0.6468	0.0463	-2.0216	0.0994
β5	-0.4051	0.0433	-1.9364	0.0169	0.6456	0.2026
β6	-8.6677	1.0299	3.6673	0.9792	-5.4365	5.0837
α11	0.0755	0.0061	-0.0780	0.0114	-0.1477	0.0262
α12	0.0136	0.0013	0.0674	0.0026	-0.0073	0.0125
α13	-0.1274	0.0067	-0.0038	0.0110	-0.0313	0.0375
β15	-0.0554	0.0103	0.0268	0.0023	0.0397	0.0832
β16	-11.0300	1.1063	-3.6864	0.9123	-34.2560	3.7994
δ17	0.0100	0.0020	0.1402	0.0246	0.0591	0.0097
α22	0.0032	0.0200	0.0483	0.0213	0.1864	0.2855
α23	0.1095	0.0101	-0.2024	0.0114	-0.1315	0.0209
β25	-0.1566	0.0270	-0.1298	0.0053	-0.4933	0.5117
β26	60.0810	2.8630	2.7087	0.9456	101.1400	23.6740
δ27	-0.0024	0.0010	-0.0521	0.0028	0.0165	0.0132
α33	0.2137	0.0225	-0.0805	0.0373	0.5127	0.0825
β35	0.1375	0.0383	-0.0674	0.0084	0.0352	0.1058
β36	-12.7380	1.1552	-0.9402	0.9804	35.6640	2.1795
δ37	0.0035	0.0021	0.0422	0.0056	-0.0071	0.0066
ψ55	-0.0573	0.1707	-0.0057	0.0289	0.0172	0.1454
ψ56	-1.2686	1.0139	2.7230	0.3144	-18.9610	18.2970
δ57	0.0021	0.0010	0.0518	0.0002	-0.0159	0.0143
ψ66	1.0368	1.0000	1.0288	1.0000	2.2097	1.1084
δ67	0.8198	0.0460	-0.0441	0.0395	0.5212	0.4322

where π is U.S. profit, I is U.S. research investment, p_4 is unnormalized U.S. price of the numeraire input, p_m is U.S. price of research type m, δ is a parameter estimated from the equation system (1a)–(1c) in the jth region, and λ is the weight of the real-dollar research investment in computing the research stock variable. *MPI* is time dependent. Hence *MPI* is likely to vary with the year in which the change in research investment is set to occur. To overcome this problem, the general practice in past studies has been to set the exogenous variables (p, z, r) at their geometric means. That practice was followed here.

Estimates of the marginal value of public investments in soybean and corn research and of checkoff investments in yield-enhancing and cost-reducing soybean research are contained in table 4. Upper-bound estimates of the standard errors on all types of research are also included in the table. These standard errors were computed assuming

Table 3. Bias Effects from Changes in Research Stock Variables, Computed at Data Means

	Soybean Research Type						Corn Public Research	
	Public		Yield-Enhancing		Cost-Reducing			
Output Supply or Variable Input Demand	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
ATLANTIC REGION								
Chemicals	-0.552	0.571	0.330	0.482	0.053	0.387	-0.308	0.354
Capital	-0.532	0.518	0.204	0.498	-0.297	0.433	0.118	0.597
Other Purch'd Inputs	0.964	0.808	-1.071	0.685	0.383	0.573	0.187	0.270
Labor	-0.413	0.349	0.557*	0.295	-0.206	0.231	-0.645	0.527
Land	0.699	0.647	0.012	0.575	0.048	0.501	0.645*	0.209
CORN BELT REGION								
Chemicals	0.219	0.720	0.050	0.585	0.143	0.500	1.429*	0.136
Capital	-0.589	0.448	0.349	0.366	-0.358	0.315	0.629*	0.191
Other Purch'd Inputs	1.217*	0.506	0.255	0.332	0.053	0.271	-1.285*	0.074
Labor	-0.063	0.269	0.353*	0.154	-0.122	0.118	0.676*	0.071
Land	0.648*	0.137	-0.347*	0.092	0.141*	0.075	-1.199*	0.069
DELTA REGION								
Chemicals	2.186*	0.664	-0.810	0.553	0.687*	0.420	-0.698*	0.239
Capital	-1.555*	0.316	0.558*	0.278	-0.350	0.224	4.506*	1.135
Other Purch'd Inputs	-1.813*	0.748	0.290	0.632	-0.162	0.535	-1.779*	0.537
Labor	0.811*	0.388	0.006	0.269	0.112	0.206	1.010*	0.561
Land	1.463*	0.428	-0.344	0.358	0.007	0.306	-2.093*	0.466
LAKE STATES REGION								
Chemicals	-0.223	0.727	0.279	0.571	-0.238	0.502	-0.238	0.278
Capital	-0.023	0.506	0.021	0.405	0.028	0.355	-0.850*	0.203
Other Purch'd Inputs	-1.382*	0.472	0.404	0.285	-0.071	0.233	-1.963*	0.117
Labor	-0.127	0.337	0.399	0.190	-0.197	0.148	-1.194*	0.484
Land	0.573	0.147	-0.317*	0.085	0.126*	0.066	2.408*	0.229
OTHER REGION								
Chemicals	-165.880*	72.683	-6.990*	3.107	-3.436	2.765	0.501*	0.059
Capital	-87.409*	37.541	-3.654*	1.589	-3.811*	1.384	-0.900*	0.390
Other Purch'd Inputs	77.557*	31.252	2.595*	1.324	2.206*	1.212	0.805*	0.169
Labor	72.604*	31.816	3.423*	1.322	2.317*	1.150	-0.069	0.198
Land	73.094*	32.731	3.253*	1.336	2.277*	1.185	-1.040*	0.177
PLAINS REGION								
Chemicals	-1.492	0.969	-0.066	0.663	0.117	0.569	2.761*	0.109
Capital	0.397	0.443	0.279	0.340	-0.193	0.292	-1.725*	0.143
Other Purch'd Inputs	-0.440	0.477	0.174	0.220	-0.144	0.163	0.793*	0.074
Labor	-0.460	0.297	0.436*	0.159	-0.089	0.113	-2.769*	0.075
Land	0.412*	0.226	-0.409*	0.142	0.203*	0.115	-0.134*	0.079
SOUTH REGION								
Chemicals	1.132*	0.416	-0.513	0.344	0.535*	0.244	-1.169*	0.607
Capital	-1.171*	0.307	0.371	0.283	-0.312	0.218	1.382*	0.393
Other Purch'd Inputs	-2.556*	0.713	1.288*	0.562	-1.433	0.439	0.375*	0.203
Labor	0.775*	0.354	-0.175	0.216	0.324*	0.170	1.152	1.328
Land	2.011*	0.493	-0.949*	0.372	0.903*	0.314	-0.186	1.017

Note: An asterisk (*) denotes significance at the 10% level.

Table 4. Marginal Returns to U.S. Public Research Expenditure and to Checkoff Investment in Research, Computed at Data Means

	Present Value per Dollar Invested	
Type of Research	Present Value	Standard Error [a]
	($)	($)
Soybean Research		
Public Expenditure	0.57	0.17
Checkoff Yield-Enhancing	-5.20	1.44
Checkoff Cost-Reducing	29.14	6.20
All Soybean Research	0.68	0.52
All Checkoff Research	2.22	1.89
Corn Public Expenditure Research	0.84	0.08

[a] Upper-bound estimates of standard errors. They assume independence among the regional returns and among the types of research investment, and do not account for the likely positive covariance between them.

independence in estimated returns across regions. Since there is very likely a positive covariance in the estimated returns among the pairs of regions, these estimates may overestimate the true standard errors.

There are three very striking results. First, the estimated marginal return to public research on both commodities was significantly less than 1.0. This means that farmers did not accrue as much benefit from public soybean and corn research as it cost the taxpayers. This finding is unusual, but not unprecedented. For example, similar results were found by Wennergren and Whitaker for wheat research in Bolivia during the period 1966–75, and by Hertford et al. for cotton research in Colombia during the period 1953–72. Second, yield-enhancing research supported by the soybean checkoff program not only failed to recover its investment, it actually had a significant negative impact on farmer net returns. Each dollar invested by the checkoff program in yield-enhancing research cost farmers an additional $5 in reduced profits. This result is also consistent with some prior findings [e.g., Huffman and Evenson's (1993) estimates for U.S. public livestock research during the period 1950–82]. Third, cost-reducing research supported by the soybean checkoff program yielded a very high marginal return. The present value of the marginal return to cost-reducing research supported by the soybean checkoff program was a remarkable and highly significant $29 per dollar invested.

Although these empirical marginal return estimates are surprising, they were robust to a variety of alternative specifications. One of the specification issues for which the estimated rate of return can be quite sensitive is the lag structure used to specify the research variables. Thirteen alternative models for Corn Belt soybean production were estimated with different lag structures on the public and checkoff-supported research variables. Generalizing this one region's performance to the entire U.S. (based on production share), the major qualitative findings noted above were generally supported. With 12 of the 13 models, the estimated marginal return was less than 1.0 for public research, and exceeded $29 for cost-reducing research supported by the checkoff program. The impact on farmer profits of yield-enhancing research supported by checkoff was consistently negative.

Because the actual checkoff investments in soybean research before 1978 were unknown, several alternative data assumptions were considered in reestimations of the Corn Belt soybean model. They included backcasting with alternative regression equations as well as the extreme assumption that no checkoff investments in research were made prior to 1978. To determine whether the results were sensitive to modeling each crop independently of the other, we also estimated a joint soybean-corn model for the Corn Belt region. All gave the same qualitative implications for the U.S.—present value of marginal returns to public research less than 1.0 for both crops, negative returns to checkoff investments in yield-enhancing soybean research, and very high marginal returns to checkoff investments in cost-reducing soybean research.

The only issue that had substantial impact quantitatively on the estimated returns was accounting for autocorrelation present in the error terms of the estimated models. Although the qualitative results were the same, failure to account for autocorrelation reduced the estimated returns to public research of both crops and gave higher estimated returns to cost-reducing soybean research and more negative returns to yield-enhancing soybean research. Using a very different modeling approach, Williams, Shumway, and Love arrived at the same conclusions. Thus, although somewhat surprising, the empirical findings of this study are very robust to alternative model specifications and imperfect data assumptions.

The present value of marginal returns to all soybean research and to research supported by the soybean checkoff program are also reported in table 4. These were computed by weighting marginal returns from each type of research by its cost share in the respective research budget for the period 1990–94. The marginal return to all research was $0.68, suggesting that the increase in present value of farm income was less than the research cost taxpayers and soybean farmers. For research supported by the checkoff program, it was increased more than $2, which suggests that continued checkoff support of research could be a productive investment. However, based on our upper-limit estimates of standard errors, neither of these marginal return estimates was significantly different from 1.0.

Conclusions

Marginal returns to U.S. soybean and corn research investments have been estimated in this study. Considered were public research investments on both commodities and soybean yield-enhancing and cost-reducing research supported by the soybean farmers' checkoff program. Impacts on farmer profits were evaluated by estimating the parameters of a restricted profit function for each of seven production regions. The restricted profit function was specified for consistency with the results of several specification pretests.

Using the estimated parameters of this model, technical change biases and the present value of marginal returns to the various types of research investments were computed. Public research and both types of checkoff research on soybeans were labor using in all regions where the bias estimates were significant. Public and cost-reducing checkoff research were land using, while yield-enhancing checkoff research was land saving. The qualitative estimates of land bias from both types of checkoff research were as expected. With only a few exceptions, the technical change on other inputs from soybean and corn research varied by region.

The farmer return to public research in both soybeans and corn was estimated to be significantly less than the public investment, and so was not judged to be a socially productive investment. If the objective of such research investments was to increase farmer profits, direct transfers could have been less expensive to U.S. taxpayers. Yield-enhancing research supported by the checkoff program was consistently estimated to actually reduce farmer profits, which made it an even worse investment. This conclusion was statistically significant and robust to a wide variety of alternative specifications. If valid, yield-enhancing research should be discontinued as one of the Soybean Board's investments.

The present value of the marginal return to a dollar of cost-reducing research was the only bright spot—a significant $29. Its high magnitude was also robust to all alternative specifications. Thus, one inference based on statistical significance as well as robustness of the results is that the Soybean Board should continue supporting cost-reducing research and move funds from yield-enhancing to cost-reducing research. The marginal return to all research supported by the soybean checkoff program was also greater than its cost. It had an estimated present value of approximately $2 per dollar invested, but without clear statistical significance.

Thus, if public and checkoff research are independent activities, and increasing farm income is the primary objective of research allocations, these findings render a very important social welfare implication: It would be better to transfer research funds from the public sector to the Soybean Board for purposes of allocation to specific research efforts. However, because decisions by one set of research portfolio managers may not be independent of those made by another, such information on investment returns must be interpreted cautiously. It may have policy value only at the margin—that is, for small rather than large changes in portfolio management.

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