Evaluating Agricultural Research and Productivity

Proceedings of a Symposium
Atlanta, Georgia
January 29-30, 1987

Miscellaneous Publication 52-1987
Minnesota Agricultural Experiment Station
University of Minnesota

RESEARCH BIAS EFFECTS FOR INPUT AND OUTPUT DECISIONS: AN APPLICATION TO U.S. CASH-GRAIN FARMS

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INTRODUCTION

Duality theory and static multi-product technology have been applied to analyze aggregate agricultural data by Shumway; Weaver; and McKay, Lawrence and Vlastuin. Several studies (e.g., Antle; Binswanger; and Lopez, 1985a) have indexed technology with a time trend, but no study has attempted to investigate the effects of agricultural research, extension, and education in the multiple-output dual static framework.

The objectives of this paper are (i) to assess the bias effects in cash-grain farmers' production decisions caused by public agricultural research, public extension, and farmers' schooling and (ii) to present new estimates of the shadow values of agricultural research, extension, and schooling obtained from the static dual model of agricultural production. The model is fitted to data for 42 states, pooled over Agricultural Census years 1949-74, containing the cash-grain farm type.

The organization is as follows: The econometric model of production is first presented. Second, the empirical analyses, which contain a discussion of the data and empirical results, are presented. Conclusions and implications are in the final section.

THE ECONOMETRIC MODEL

The objective of cash-grain farmers is assumed to be best represented by maximizing expected profit. Thus, farmers are assumed on average to be risk neutral, farm production decisions are assumed separable from farm household consumption decisions, and production is assumed static rather than dynamic. There is mixed evidence in the literature on each of these issues.

Consider the production decisions of a multi-product firm making choices on n+m+1 net outputs y_i (Lau 1976). They supply n+1 outputs ($y_i > 0$, $i=0,\ldots,n$) and employ m variable inputs ($y_i < 0$, $i = n+1, \ldots, n+m$). There are q fixed or environmental factors, including governmental policies, that are denoted by $z_\ell \geq 0$, $\ell=1, \ldots, q$. Denote P_0 as the numeraire price, which could be set equal to 1, and define the normalized expected price of outputs and inputs as $p_i = P_i/P_0$, $i=1, \ldots, n+m$. All p_i are positive.

With competitive behavior and regular technology, a one-to-one relationship exists between the technology and its dual transformation, the normalized restricted profit-function (Nadiri; Diewert 1973; Lau 1976). Although the characteristics of the technology can be examined directly through the primal approach or indirectly by the dual formulation, the dual approach is computationally easier to manipulate; it yields a set of choice functions that are determined by variables that are exogenous to individual firms, and it permits a wider range of hypotheses to be tested. The normalized restricted profit-function, hereafter called the profit-function, is

$$(1)\quad \pi = G(p,z)$$

where π is a firm's normalized variable profit (i.e., nominal profit deflated by P_0), G is the profit-function, and p and z are vectors of the n+m normalized prices and q fixed and environmental factors, respectively. The profit-function is assumed to be twice continuously differentiable, convex, and monotonic in p and z.[1] Applying Hotelling's lemma, the system of (profit maximizing) output supply and input demand functions are directly obtained by differentiating the profit-function with respect to p:

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(2) $\frac{\partial G}{\partial p_i} = y_i^* (p,z), \ i=1, \ \ldots, \ n+m$

The shadow-value equations for the q fixed and environmental factors (z_k) can be obtained. The shadow value of z_k, or λ_k, is obtained by differentiating the profit-function with respect to z_k (Nadiri, p. 452; Diewert 1974, p. 140):

(3) $\lambda_k = \frac{\partial G}{\partial z_k} = \lambda_k (p,z), \ k=1, \ \ldots, q.$

Derivatives of the profit-function and transformation function with respect to z_k are equivalent. The optimal choice and the shadow-price equations are functions of the normalized prices associated with current choices and the fixed and environmental factors, including governmental policies (Lau 1976).

From the available flexible forms, the normalized quadratic profit-function is chosen for this study because it has some net advantages over other flexible forms. It imposes homogeneity in prices and is self-dual. It has a Hessian matrix of constants, which means that local convexity in prices implies global convexity. Additional implications for the production technology are weak separability between inputs and outputs and quasi-homotheticity (Lopez 1985b). The latter conditions imply linear expansion paths in input and output space, but they need not start at the origin.

The normalized quadratic profit-function is:

$$(4) \quad \pi = \alpha_0 + \sum_{i=1}^{n*} \alpha_i p_i + \sum_{k=1}^{q} \delta_k z_k$$

$$+ \frac{1}{2} \sum_{i=1}^{n*} \sum_{j=1}^{n*} \beta_{ij} p_i p_j + \frac{1}{2} \sum_{k=1}^{q} \sum_{\ell=1}^{q} \phi_{k\ell} z_k z_\ell$$

$$+ \sum_{i=1}^{n*} \sum_{k=1}^{q} \gamma_{ik} p_i z_k,$$

where $n* = n+m$, and αs, βs, γs, and δs are the unknown parameters of the profit-function. The net-output equations, with random disturbance terms added, for the n+m current choices are:

$$(5) \quad y_i^* = \alpha_i + \sum_{j=1}^{n*} \beta_{ij} p_j + \sum_{k=1}^{q} \gamma_{ik} z_k + \mu_i, \ i=1, \ \ldots, \ n*.$$

These n* optimal choice equations are each linear in the variables - net output, normalized prices, and fixed and environmental factors - and in the unknown parameters and disturbances. The equation for optimal numeraire output can, in principle, be obtained residually. Recall that $y_0^* = \pi - \sum_{i=1}^{n*} p_i y_i^*$, and substituting equation system (5) for y_i^*, the optimal quantity of y_0 is:

$$(6) \quad y_0^* = \alpha_0 + \sum_{k=1}^{q} \delta_k z_k - \frac{1}{2} \sum_{i=1}^{n*} \sum_{j=1}^{n*} \beta_{ij} p_i p_j + \frac{1}{2} \sum_{k=1}^{q} \sum_{\ell=1}^{q} \phi_{k\ell} z_k z_\ell.$$

Because the profit-function is assumed to be twice continuously differentiable, its partial derivatives are invariant to the order of differentiation. Given that the net supply equations are first derivatives of the profit-function, the slopes of the net supply equations are the second partial derivatives. The cross-equation symmetry conditions (i.e. $\beta_{ij} = \beta_{ji}$, $i \neq j$, i, j=1, ..., n+m) are imposed to reduce the number of unknown parameters to be estimated and to ease the burden imposed on the data.

The responsiveness of net outputs to prices is summarized in elasticities:

$$\eta_{ij} = \frac{\partial \ln y_i^*}{\partial \ln p_j} = \beta_{ij} p_j / y_i^*, \; i, j=1, \ldots, n+m;$$

$$\eta_{i0} = \frac{\partial \ln y_i^*}{\partial \ln p_0} = -\frac{1}{y_i^*} \sum_{j=1}^{n^*} \beta_{ij} p_j, \; i=1, \ldots, n+m;$$

$$\eta_{0j} = \frac{\partial \ln y_0^*}{\partial \ln p_j} = -(p_j/y_0^*) \sum_{i=1}^{n^*} \beta_{ij} p_i, \; j=1, \ldots, n+m_j;$$

$$\eta_{00} = \frac{\partial \ln y_0^*}{\partial \ln p_0} = \frac{1}{y_0^*} \sum_{i=1}^{n^*} \sum_{j=1}^{n^*} \beta_{ij} p_i p_j .$$

Convexity of the profit-function implies that the own-price elasticity of output supply is expected to be positive and of input demand is expected to be negative. Cross-price elasticities can be positive, negative, or zero. If y_i^* and y_j^* are inputs (outputs), i and j are designated "substitutes" when $\eta_{ij} > 0$ and "complements" when $\eta_{ij} < 0$.

The shadow-value equations for the fixed and environmental factors associated with the normalized-quadratic profit-function are as follows:

$$(7) \quad \lambda_k = \frac{\partial \pi}{\partial z_k} = \delta_k + \sum_{\ell=1}^{q} \phi_{k\ell} z_\ell + \sum_{i=1}^{n^*} \gamma_{ik} p_i, \; k = 1, \ldots, q$$

(Nadiri). These equations give the marginal change in normalized profit for an increment in z_k. Given estimates for δ_k, $\phi_{k\ell}$, and γ_{ik}, the shadow-value equations can be evaluated at the sample mean of p and z.

Several measures of bias effects induced by technical change or other nonprice factors, for example z_k, have been used in the literature. A Hicksian measure, based upon marginal rates of technical substitution (transformation), has the disadvantage that bias effects must be measured between every pair of net outputs. When there are a large number of outputs and inputs, this set of calculations is difficult to summarize. Antle proposes a single measure of the bias effect on each optimal choice caused by a change in technology or z_k. Although he employs a translog profit-function and single-output technology, his methodology can be adapted to multiple-output technology to obtain a net summary measure of the bias effect induced in optimal choice y_i^* relative to all optimal choices due to change in z_k.

To facilitate the presentation, consider the dual implicit transformation function $F(y_0, \ldots, y_{n+m}, z_1, \ldots, z_k) = 0$, which can be represented in unsymmetric form as $y_0 = f(y_1, \ldots, y_{n+m}, z_1, \ldots, z_k)$, $y_0 > 0$ (Diewert 1973, pp. 286-87). The unsymmetric form gives maximum output of y_0 as a function of the other n+m outputs and the k fixed or environmental factors. Define the i-th elasticity of transformation as $\epsilon_i = \frac{y_i}{y_0} \frac{\partial f}{\partial y_i}$ where $\frac{\partial f}{\partial y_i} < 0$, i = 1, ..., n+m, $\epsilon_i < 0$ for $y_i > 0$, $\epsilon_i > 0$ for $y_i < 0$, and define $\epsilon = \sum_{i=1}^{n^*} \frac{y_i}{y_0} \frac{\partial f}{\partial y_i}$.

Furthermore, for a profit maximizing competitive equilibrium, $\epsilon_i = - p_i y_i^*/y_0^*$, and $\epsilon = -\pi^*/y_0^*$ where $\pi^* = \sum_{i=1}^{n^*} p_i y_i^* < 0$.[2] The <u>change in the transformation elasticity share or profit share</u> $\epsilon_i/\epsilon = p_i y_i^*/\pi^*$ can be employed to define the relative bias in y_i^* caused by a change in z_k. The profit share approach is consistent with the netput framework where the same item can be an input or output, depending on whether it is sold or purchased. Furthermore, if only one output (y_0) is produced, then ϵ_i/ϵ is the factor cost share for y_i^*.

The bias effect is measured here as:

$$\Gamma_{ik} = \left\{ \frac{z_k}{\epsilon_i/\epsilon} \right\} \frac{\partial(\epsilon_i/\epsilon)}{\partial z_k}, \quad i = 1, \ldots, n{+}m, \; k = 1, \ldots, q.$$

For outputs and inputs, the bias effect is said to be toward (against) y_i^* if $\Gamma_{ik} > 0$ $(\Gamma_{ik} < 0)$. Thus, when z_k increases, a favorable bias effect on y_i^* means that its profit share (using $\pi^* = \pi - y_0^*$) has increased. The bias effect is neutral if $\Gamma_{ik} = 0$. Furthermore, a weighted average of the Γ_{ik}s equals zero where the weights are optimal profit shares, $\sum_{i=1}^{n^*} (p_i y_i^*/\pi^*) \, \Gamma_{ik} = 0$.

Equivalent bias effects can be derived directly from the normalized profit-function. Using $\epsilon_i = - p_i y_i^*/y_0^*$ and equation (1), then

$$\epsilon_i = - \frac{\pi}{y_0^*} \frac{\partial G}{\partial p_i} \frac{p_i}{\pi}, \quad \epsilon = - \frac{\pi}{y_0^*} \sum_{i=1}^{n^*} \frac{\partial G}{\partial p_i} \frac{p_i}{\pi}, \text{ and } \epsilon_i/\epsilon = \frac{\partial G}{\partial p_i} \frac{p_i}{\pi} \Big/ \sum_{i=1}^{n^*} \frac{\partial G}{\partial p_i} \frac{p_i}{\pi}.$$

For the normalized quadratic profit-function, the bias effect is obtained by exploiting the profit-share statement of Γ_{ik} and equation system (5):

$$(8) \quad \Gamma_{ik} = \left\{ \frac{\partial\left(p_i y_i^* \Big/ \sum_{i=1}^{n^*} p_i y_i^*\right)}{\partial z_k} \right\} \frac{z_k}{p_i y_i^* \Big/ \sum_{i=1}^{n^*} p_i y_i^*} = \gamma_{ik} \frac{z_k}{y_i^*} - \frac{z_k}{\pi^*} \sum_{i=1}^{n^*} \gamma_{ik} p_i,$$

$i = 1, \ldots, n{+}m$, $k = 1, \ldots, q$.

Because the normalized-quadratic profit-function has a dual technology with input-output separability, these bias effects are due to shifts of "expansion paths."[3]

The random disturbance terms (μ_is) that enter the net output equations arise from weather conditions and agricultural pest problems deviating from normal. They are assumed to be homoscedastic, uncorrelated, and normally distributed. Because these production decisions are affected by similar shocks, contemporaneous cross-equation correlation of the disturbances in the n+m equations is likely and is permitted.

THE EMPIRICAL ANALYSES

A set of six equations for output supply and input demand functions are to be jointly fitted to data for 42 U.S. states pooled over the six census years 1949-1974.[4] The parameter estimates of these equations are used to derive the estimates of own-price elasticities of supply and demand, estimates of bias effects of U.S. public policy on farmers' production decisions, and shadow values of the public policy variables.

The Data

The data are for cash-grain farms in 42 U.S. states derived from the six Agricultural Censuses between 1949 and 1974.[5] Farms in the past have been classified into 6-8 major types based upon the primary sources(s) of farm sales, e.g. cash-grain, general livestock, dairy, cotton. Farms in any one of these type classes can be expected to have more similar technology than all farms. Cash-grain farms--farms having ≥ 50 percent of their sales from grain and beans--represent a large and increasing share of U.S. farm types, except for the New England region. Thus, the New England states are excluded from our analysis, and the remaining 42 states in the contiguous 48 states are included.

The current production decisions of cash-grain farmers are condensed into seven major aggregate (per farm) quantity indexes. There are four variable inputs: fertilizer (commercial), fuel, machinery services, and labor (farmer and hired) and three outputs: wheat, soybeans, and feed grains (corn, grain, sorghum, oats, barely). These are the major outputs of cash-grain farms, and we have chosen to ignore a large number of outputs (e.g., livestock, cotton, tobacco, vegetables, fruits) that are of secondary importance on these farms. The independent variables for explaining these choices are the expected product prices, current variable input prices, and fixed and environmental factors, including research, extension, education, and farm-commodity policies.

The variables entering the supply and demand functions are summarized in Table 1. The quantity of fertilizer was derived by dividing expenditures on fertilizer (U.S. Dept. Comm.) by a state level weighted price index. The state price index was obtained by applying state quantity weights to national average prices for the primary nutrients N, P, and K.[6] Prices for separate components were weighted by expenditure shares. The price of fertilizer, the independent variable, is the one-year lagged state-level price of the composite fertilizer quantity. The quantity of fuel for agricultural use was derived by dividing expenditures on gasoline, diesel fuel, LP gas, and oil and grease (U.S. Dept. Comm.) by a state-level weighted fuel price. Regional expenditure shares for 1964 were applied in earlier years. The petroleum price, the independent variable, is the one year lagged state price of the composite fuel quantity.

The quantity of machinery services was derived by dividing an estimate of rental expenditures for owned and hired machinery services by a state price index for machinery services. Expenditures on machine hire were taken directly from the Census of Agriculture. The implicit rental expenditures for owned machinery in year t is computed as $\sum_{i=1}^{n} p_{it} (r_t+d_{it}) K_{it}$, where p_{it} is the "new price" of the i-th type of machine in year t, k_{it} is the number of machines of type i in year t, r_t is the PCAs annual average interest rate on loans outstanding (Agricultural Statistics), and d_i is the straight-line depreciation rate on the i-th type of machine (Am. Society of Agr. Engineers). The types of farm machinery were limited to ones reported in the Census of Agriculture; i.e., farm trucks, wheel and crawler tractors, balers, combines, corn pickers, and forage harvesters. The "new prices" of machines were derived from prices of machines reported in the Official Tractor and Farm Equipment Guides. The state rental price index of machine services is $W_{pt} (r_{t-1}+\bar{d}_t)$ where W_{pt} is the wholesale price index for agricultural machinery and equipment at the beginning of t (U.S. Dept. Labor), and $\bar{d}_t$ is the weighted average depreciation rate for the set of machines on farms.

The farm labor input is measured as the annual hours of farm operator and hired labor employed on farms. Farm operators were assumed to work an average of 300 days per year at on-farm and off-farm work combined and to work an average of 8 hours per day at farm and off-farm work, and their farm hours were derived by subtracting an estimate of their annual hours of off-farm work. Annual hours of hired labor are derived as annual expenditures on hired labor plus expenditures on contract labor (U.S. Dept. Comm.) divided by the state average annual hourly farm wage (Farm Labor). The wage rate for hired farm labor is arbitrarily assumed to be the marginal cost of operator employed farm labor. The wage rate for farm labor, the independent variable, is the state average wage rate for hired labor lagged one year.

The bushels of grain harvested were used to construct measures of the outputs of wheat, soybeans, and feed grains. The feed grain quantity index is a Fisher-quantity index constructed by using the quantities of corn, oats, barley, and grain sorghum harvested (U.S. Dept. Comm.) and state average prices received for the commodities (Agr. Prices). The expected output prices, the independent variable, are the average closing futures market prices in the planting month for harvest month contracts, adjusted for state differences in average transportation costs.[7] The planting months are March or April, except for winter wheat for which it is September. The (expected) feed grains price is the numeraire price in the empirical analysis, and the other output and input prices are divided by it.

Fixed factors that affect output-input choices are the land stock, pre-season precipitation, and time trend. The land stock is measured in constant quality units as a price weighted quantity index of five land-use types on cash-grain farms (Hoover). The weights are fixed for all years. Relative weights were taken from Hoover and expressed at the 1949 average land-price levels (U.S. Dept. Comm.). Preseason precipitation is known at planting time, and it is measured as the total of the state average precipitation received during the months of October through March before planting. The trend and trend squared are included to remove the effects of unmeasured variables that are correlated with time and that otherwise might cause spurious estimates of coefficients of included variables.

The policy variables are (public) agricultural research, extension, farmers' education, and feed grain and wheat program variables. The agricultural research variable is constructed as the real stock of public agricultural research per-commodity-subregion. Research expenditures in year t are assumed to have trapezoidal shaped weights--first linearly increasing, constant, and then linearly decreasing and to sum to unity (Evenson 1978, pp. 202-205).[8] For each state, these variables represent both indigenous research and borrowable research from other states located in similar geoclimatic regions. The agricultural extension variable is the stock of extension per-commodity-subregion. The stock of extension is obtained using geometrically declining weights. (.5, .25, .125, etc.) of current and past expenditures on extension and on farm management and agricultural engineering research (Evenson 1978, p.204).

Schooling of farmers may have allocative as well as general efficiency effects on production (Welch 1970; Huffman 1977). The schooling level of cash-grain farmers is proxied by a Welch-type weighted (Welch 1966, 1970) average number of years of schooling completed by all farmers in a state (Census of Population).

The government program variables are rather crude. They concentrate on the loan rate but ignore acreage restrictions. They are derived as $(p_i/P_{Li})\ D_i$, where p_i is the normalized price of the i-th output, i=5 (wheat), 7 (feed grains); P_{Li} is the national average loan rate (Cochrane and Ryan) for wheat (i=5) and for corn (i=7); D_i is a dummy variable taking the value of 1 if output i is produced, and 0 otherwise. To the extent that these programs have resource allocation effects, the coefficient of the wheat program variable is expected to be negative in the wheat supply equation, and the coefficient of the feed grain program variable is expected to be negative in the feed grains supply equation.

Several other variables are included in the output supply and input demand equations. First, the share of the farm operators that are 65 years of age or older is included to represent the effects of partial retirement and possible short-term planning horizon of older farmers on production decisions. Second, the three outputs are not always produced by cash-grain farmers in all 42 states. In particular, the number of states in which soybeans are produced (by cash-grain farms) is rather small in 1949, and the number of states in which farmers produce soybeans increases over time. For the whole sample, sixty-five percent of the states have cash-grain farms reporting positive quantities of soybeans harvested. In all supply-demand equations, variables are added to permit the intercept and coefficients of the normalized soybean and wheat prices to differ because of the practical problem of truncation at zero for soybean and wheat supply decisions. This is a crude attempt to incorporate structural change.

Econometric Estimation

The estimation proceeds in steps. The set of supply and input demand equations are estimated by 3-stage least squares subject to within- and cross-equation restrictions and to the predicted value of a farm-type selectivity variable. The cross-equation restrictions are the symmetry condition, $\beta_{ij} = \beta_{ji}$. The within-equation restrictions arise from restricting the coefficient of the normalized price of soybeans (wheat) to being zero in all supply and input demand equations when soybeans (wheat) are not produced. The restricted 3-stage least-squares estimator is consistent and efficient, conditional on the farm type selectivity variable.[9] This step provides the estimates α_i, β_{ji}, and γ_{ik}. Estimates of δ_k and $\phi_{k\ell}$ are obtained by fitting the following equation:

$$(9) \quad \pi^r = \alpha_0 + \sum_{k=1}^{q} \delta_k z_k + \frac{1}{2} \sum_{k=1}^{q} \sum_{\ell=1}^{q} \phi_{k\ell} z_k z_\ell + v$$

where the dependent variable is derived as $\pi^r = \pi - \sum_{i=1}^{n^*} \hat{\alpha}_i p_i - \frac{1}{2} \sum_{i=1}^{n^*} \sum_{j=1}^{n^*} \hat{\beta}_{ij} p_i p_j - \sum_{i=1}^{n^*} \sum_{j=1}^{q} \hat{\gamma}_{ik} p_i z_R$ and where v is a random disturbance term that is assumed to have a zero mean in large samples, except for farm-type selectivity.

Observed farm output or sales is the result of production decisions and random shocks to technology and prices. Thus, the probability that a farm is classified as a cash-grain farm depends on p and z (Huffman 1987). Thus, E(ϵ/the farm type classification), $\epsilon = \mu_i$, v, are unlikely to be zero. This condition could bias all the estimated coefficients (Heckman). To ameliorate selectivity biases, a new variable which is the predicted relative frequency of (not) observing cash-grain farms to each aggregate supply and input demand equation and to equation (9).[10]

Estimates of the Product Supply and Input Demand Equations

Estimates of the parameters of the six equations, derived from the normalized quadratic profit-function and fitted to the 296 pooled observations for U.S. cash-grain farms, are reported in Table 2. All own-price coefficients have the expected sign, and all are significantly different from zero at the 5 percent level, except for the coefficient of the soybean price. The coefficients of the fixed factors are plausible. Increasing the average land input per farm causes the quantity of all variable inputs demanded and all outputs supplied to increase, except for soybeans. Greater preseason precipitation decreases the demand for all variable inputs, except fertilizer, and increases the quantity supplied of all outputs. As the share of older farmers (≥ age 65) increases, the demand for all inputs and supply of outputs are reduced. The soybean supply equation has a statistically significant cash-grain farm-type selectivity effect.[11]

Only estimates of the own-price input demand and output supply elasticities, evaluated at the sample means, are presented. All demand elasticities are negative as expected and less than one in absolute value. The demand elasticities are -0.73 for fertilizer, -0.74 for fuel, -0.60 for machinery, and -0.44 for labor. The own-price supply elasticities are 2.64 for wheat, 0.80 for soybeans, and 1.49 for feed grains.

It is useful to compare these estimates of demand and supply elasticities to ones obtained by others that employ a similar methodology, although they used different data. Shumway (1983) and Weaver (1983) have the similarities of applying a profit-function framework, disaggregating output, treating land as fixed, and time period analyzed. Weaver's model for the Dakotas produced larger demand elasticities for fertilizer, machinery services, and labor. His estimates for these inputs exceeded one in absolute value. Our estimate of the demand for fuel is, however, sizably larger than his. On the other hand, Shumway's model for Texas field crops produced almost exactly the same estimates of demand elasticities for fertilizer and labor. Our estimate of the demand elasticity for machinery services is sizably larger in absolute value than his estimate for machinery input. Weaver's and Shumway's estimates of the supply elasticities for feed grains and wheat (foodgrains) are roughly one-half as large as our estimates. Neither includes soybeans as an output.

Estimates of the bias effects in cash-grain farmers' production decisions attributed to a change in an increment to agricultural research, extension and farmers' schooling are presented in Table 3. These estimates are obtained by evaluating equation (8) at the sample mean for z_k, y_i^*, p_i and π^*. The estimates of γ_{ik} are taken from Table 2. These results show, other things equal, that additional agricultural research has a bias effect in favor of all inputs and all outputs in the sense that their profit shares are increased. Although it may seem unusual that all six of these measures of bias can be positive, this can occur when an increase in agricultural research increases the size of π^*, which is negative (-2.482 at the mean of the sample). This makes π^* smaller in absolute value, and each of the $p_i q_i/\pi^*$ can (but need not) increase. Except for wheat, for which agricultural research has an approximately neutral effect, the favorable bias effects of agricultural research are relatively large in the sense that the elasticities of the profit shares range between 0.64 and 1.4. (Recall that for a neutral effect, $\Gamma_{ik} = 0$.) The most favorable bias, however, is toward fertilizer and soybeans.

Agricultural extension has bias effects that are generally smaller than those of agricultural research, and additional extension is biased against some choices. An increase of agricultural extension reduces the profit shares of fertilizer, wheat, and fuel, although the bias of the latter is not economically different from zero. Additional extension has bias effects in favor of machinery, labor, and soybeans. Farmers' schooling, like agricultural research, is the source of favorable bias toward all six choices. The magnitudes of the bias effects are very large for the inputs, ranging between 3.1 and 3.7. The favorable bias effect is even larger for wheat (7.9) but only 0.8 for soybeans. Thus, additional farmers' schooling is a source of extremely large "favorable" bias effects.

Although alternative estimates of the bias effects could be computed, the estimates just reported suggest that public agricultural research, public extension, and farmers' schooling have non-neutral effects on production decisions of cash-grain farmers. Furthermore, the sizes of these effects are not directly comparable to earlier measures reported by Antle (1984) and by Binswanger (1974) because they used single output technology and by Weaver because of different definitions of bias effects and because they index technology with time.

Estimates of shadow values of agricultural research, extension, and schooling are obtained by evaluating equation (7) at sample mean values of the zs and ps. Estimates of γ_{ik}s are taken from Table 2 and estimates of δ_k and $\phi_{k\ell}$ are obtained by fitting equation (9) with a sample selectivity term added by ordinary least squares. The fitted equation is not reported here.[12] The benefit-cost comparison is performed by using a mean number of commodities per state of 7.24 and a zero real discount rate. Likely choices of the discount rate are small (0-2 percent), and the choice of a zero rate makes the computation much easier.

The shadow values of agricultural research, extension, and farmers' schooling are all positive. An increase of research expenditures by $1,000 in a state allocated across 7.24 commodities has benefits in that state and in other states because of spillover effects into similar regions and subregions. The within-state shadow value is an increment to profits of $0.0157 per cash-grain farm. An approximately equal value of benefits comes from the spillover effects on cash-grain farms of other states. Thus, with an average of 9,320 cash-grain farms per state, the total benefits to cash-grain farms from a $1,000 increase in agricultural research stock of one state is $292. An increase of expenditures on extension by $1,000 (allocated across 7.24 commodities) has a shadow value of $0.023 per cash-grain farm. There is no spillover effect into other states, but with an average of 9,320 cash-grain farms per state, the increment in profits of cash-grain farms is $217 per state. Although benefits to cash-grain farms are less than the cost for both research and extension, farms of other types, which are an average of 81.7 percent of all commercial farms, are expected to obtain positive benefits too. Thus, the total benefits to farms of all types may be positive.

The shadow value of one year of schooling (a .14 increase of the education index) for cash-grain farmers is $1,074. When this real return is projected over a 45-year horizon, the return to one year of schooling of cash-grain farmers compares favorably with the cost.

These computations of shadow values should be viewed with some caution. They are computed assuming that output and input prices remain unchanged in the face of adjustments caused by an increment to one of these variables. Also, we have assumed that market prices of outputs and inputs reflect marginal social value.

CONCLUSIONS

A conceptual model of production decisions on cash-grain farms has been developed in this paper based upon competitive farm output and input markets and a normalized quadratic profit-function. The empirical analysis focuses upon four variable inputs and three outputs. The model is fitted to data for 42 U.S. states pooled over census years 1949-1974.

Some of the results are:

(1) Input demand functions are own-price inelastic, but supply functions for two of three outputs are own-price elastic.

(2) Additional agricultural research and farmers' schooling have had relatively large bias effects--measured by change in profit share--in favor of all inputs and outputs of cash-grain farms. Additional extension has caused biases in favor of machinery demand, labor demand, and soybean supply but against wheat supply and fertilizer demand. Extension has had an essential neutral effect on fuel demand.

(3) Agricultural research, extension, and farmers' schooling have positive shadow values (marginal effects on farm profits). The marginal benefits seem to compare favorably with the marginal costs.

FOOTNOTES

*The author is Professor of Economics, Iowa State University. Helpful suggestions were obtained from the discussions at the Symposium. This study is part of a much larger project that Robert E. Evenson and I have under way to analyze the development and performance of U.S. agricultural research and education. Financial assistance from USDA-CSRS and the Iowa Agriculture and Home Economics Experiment Station is acknowledged. Journal Paper No. 12642 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project 2516.

[1] The profit-function is convex if its matrix of cross-partial derivatives $[\pi_{ij}]$ is positive semi-definite or if all its characteristic roots are positive or zero.

[2] In the discussion that follows, $\pi^* (= \pi - y_0^*) \neq 0$.

[3] Antle and Capalbo show that the interpretation of bias effects are simplified when the technology in input-output separable.

[4] We have proposed a theoretical model of farm-level behavior and are planning to fit this model to aggregate average data. Linear aggregation of variables over farms is appropriate when the individual profit-functions are normalized quadratic. Output and input prices may, however, not be exogenous at the state level of aggregation.

[5] The five-year interval between successive <u>Censuses of Agriculture</u> reduces the number of observations available on each state from what annual data would provide. Annual data are <u>not</u> available for farms by type, only for all farms.

[6] See Huffman and Evenson for more details on the derivation of variables.

[7] Although there is not uniform agreement about the appropriate output prices to use, the futures' markets efficiently incorporate information. Gardner (1976) has shown that own-price elasticities of supply are much larger when futures prices are used rather than one-year lagged actual prices.

[8] The research variable for each state is the summation of an applied research stock and a basic research stock. The total stock of each type of research for a state in a year t is constructed as:

$$S(a,b,c)_t + \alpha\ SSR(a,b,c)_t + \beta\ SR(a,b,c,)_t$$

where $S(\ )_t$ = within-state stock of research in $_t$, and $SSR(\ )_t$ = research stock of other states in a similar geoclimatic region in t, and $SR(\ )_t$ = research stock of other states in the same geoclimatic region in t. The parameters a,b, and c refer to the length (years) of segments in the trapazoidal weight pattern; a is the number of years of rising linear weights, starting at zero for the year of investment; b is the number of years of constant (peak) weight; and c is the number of years of declining linear weights, ending with zero weight. These weights sum to one and differ by major census region (Northern, Southern, Western). The parameters α and β are borrowability parameters, taking values of 0, .25, or .5.

[9] The estimated coefficients of the demand and supply equation may be affected by the choice of the equation to delete.

[10] The equation fitted to explain the cash-grain proportion of all farms contained all the variables included in the output supply and input demand equations (see Table 2), except for feed-grain program and wheat program variables. However, the land and share of farm operators ≥ age 65 variables are defined for all farms, not just cash-grain farms.

[11] The Hessian matrix fails the test for convexity. One of the eigen values was negative, and the other five were positive.

[12] The set of zs included in this regression are land, preseason precipitation agricultural research, extension, education, feed grain program, wheat program, share of farmers ≥ 65, and time. The equation also includes the selectivity variable. Symmetry of the $\phi_{k\ell}$s is imposed (i.e., $\phi_{k\ell} = \phi_{\ell k}$, in the estimation) and a total of 56 coefficients are estimated. The R^2 for the fitted equation is 0.70.

Table 1. Sample Mean Value of Quantities, Prices, and Other Variables: U.S. Cash Grain Farms, 42 States, 1949-1974

Variables	Unit	Mean
Normalized profit (π)	\$1,000/farm	2.178
Quantities		
Fertilizer	1,000 weighted lbs/yr.	-1.571
Fuel	1,000 weighted gal/yr.	-0.918
Machinery	1,000 weighted machine yrs/yr.	-1.338
Labor	1,000 hrs/yr.	-2.532
Wheat	1,000 bu/yr.	3.462
Soybeans	1,000 bu/yr.	1.487
Food grains	1,000 weighted bu/yr.	4.660
Normalized prices		
Fertilizer	\$/weighted lb.	0.764
Fuel	\$/weighted gal.	0.906
Machinery	\$/weighted machine yr.	1.505
Labor	\$/hr.	1.016
Wheat	Expected \$/bu.	0.843
Soybeans	Expected \$/bu.	1.947
Feed grains[a/]	Expected \$/weighted bu.	1.362[b/]
Other		
Land	\$/farm	40,075.0
Preseason precipitation	Inches/season	15.6
Agricultural research	\$1,000/per commodity	16,814.9
Extension	\$1,000/per commodity	4,826.9
Education	Weighted yrs/farm opr.	1.390
Feed grain program	\$/bu.	0.352
Wheat program	\$/bu.	0.629
Share farm opr ≥ age 65	Unit free	0.117
Selectivity	Unit free	0.834
D_1 (1 = no wheat)	-	0.060
D_2 (1 = no soybeans	-	0.345

a/ Numeraire price, not normalized.

Table 2. Three-Stage Least Squares Estimate of System of Aggregate Product Supply and Input Demand Functions: U.S. Cash Grain Farms, 42 States, 1949-1974[a]

Variable	Demand Equations ($y_i<0$) Fertilizer	Fuel	Machinery	Labor	Supply Equations ($y_i>0$) Wheat	Soybean
Normalized Prices:						
Fertilizer	1.610	-0.510	-0.204	-0.235	1.701	0.229
	(2.87)	(2.71)	(1.41)	(1.15)	(2.45)	(0.39)
Fuel	-0.510	0.780	-0.467	0.323	0.284	0.571
	(2.71)	(2.87)	(4.15)	(2.32)	(0.99)	(2.27)
Machinery	-0.204	-0.467	0.539	-0.676	-0.097	0.798
	(1.41)	(4.15)	(5.76)	(7.09)	(0.40)	(3.89)
Labor	-0.235	0.323	-0.676	1.124	0.942	0.417
	(1.15)	(2.32)	(7.09)	(6.96)	(2.63)	(1.33)
Wheat	1.701	0.284	-0.097	0.942	10.253	-6.775
	(2.45)	(0.99)	(0.40)	(2.63)	(3.84)	(5.15)
Soybean	0.229	0.571	0.798	0.417	-6.775	1.260
	(0.39)	(2.27)	(3.89)	(1.33)	(5.15)	(0.87)
Wheat x D_1	-1.701	-0.284	0.097	-0.942	-10.253	6.775
	(2.45)	(0.99)	(0.40)	(-2.63)	(3.84)	(5.15)
Soybean x D_2	-0.229	-0.571	-0.798	-0.417	6.775	-1.260
	(0.39)	(2.27)	(3.89)	(1.33)	(5.15)	(0.87)
Fixed Factors:						
Land	-1.58×10^{-5}	-1.02×10^{5}	-1.30×10^{-5}	-1.96×10^{-5}	8.79×10^{-6}	-6.25×10^{-7}
	(9.69)	(15.08)	(22.09)	(21.80)	(1.40)	(0.18)
Preseason precipitation	-0.001	0.019	0.007	0.013	0.124	0.069
	(0.18)	(5.99)	(2.38)	(2.97)	(4.17)	(4.12)
Time	0.633	0.047	0.066	0.169	-0.423	0.494
	(1.94)	(0.35)	(0.56)	(0.94)	(0.34)	(0.71)
Time^2	-0.202	-0.039	-0.068	-0.026	0.307	-0.038
	(3.05)	(1.44)	(2.86)	(0.71)	(1.19)	(0.27)
Policy:						
Agr. research	-1.69×10^{-5}	-1.79×10^{-6}	3.30×10^{-6}	1.32×10^{-7}	1.29×10^{-4}	1.82×10^{-5}
	(2.82)	(0.73)	(1.55)	(0.40)	(5.76)	(1.44)
Extension	1.66×10^{-5}	1.79×10^{-6}	-1.12×10^{-6}	-7.81×10^{-6}	-1.29×10^{-4}	3.27×10^{-5}
	(0.88)	(0.47)	(0.17)	(0.75)	(0.48)	(0.81)
Education	0.750	0.308	-0.031	0.602	9.685	-3.122
	(2.10)	(2.07)	(0.24)	(3.04)	(7.08)	(4.17)
Feed grain program	0.051	-0.104	-0.162	-0.004	1.234	-1.006
	(0.24)	(1.17)	(2.09)	(0.03)	(1.57)	(2.32)
Wheat program	-0.228	0.161	-0.190	0.233	0.937	-0.842
	(0.58)	(0.98)	(1.34)	(1.07)	(0.62)	(1.01)

a/ Asymptotic t-statistics, conditioned on the selectivity variable, are in parentheses under the estimate of the coefficients.

Table 2. Three-Stage Least Squares Estimate of System of Aggregate Product Supply and Input Demand Functions: U.S. Cash Grain Farms, 42 States, 1949-1974[a/]
-Continued-

	Demand Equations (y_i<0)				Supply Equations (y_i>0)	
Variable	Fertilizer	Fuel	Machinery	Labor	Wheat	Soybean
Other:						
Share f.o. ≥ age 65	2.051 (1.32)	3.932 (6.11)	1.820 (3.27)	5.430 (6.30)	-17.408 (2.87)	-10.441 (3.12)
Selectivity	-0.331 (0.33)	0.595 (1.40)	0.354 (0.99)	0.369 (0.67)	2.792 (0.78)	-4.209 (2.10)
D_1	1.549 (2.09)	0.353 (1.15)	-0.352 (1.36)	0.500 (1.29)	9.699 (3.41)	-7.803 (5.47)
D_2	0.564 (1.00)	0.389 (1.63)	0.564 (2.89)	0.265 (0.89)	-2.904 (2.15)	0.514 (0.38)
Intercept	-3.321 (1.93)	-2.682 (3.74)	-0.949 (1.56)	-5.385 (5.89)	-18.781 (3.16)	11.572 (3.38)

[a/] Asymptotic t-statistics, conditioned on the selectivity variable, are in parentheses under the estimate of the coefficients.

Table 3. Bias in Choices Induced by Changes in Fixed Factors and Government Policy Variables: U.S. Cash-grain Farms, 1949-1974

Fixed factors and government policy z_k	Current Choices[a/] Inputs: Fertilizer	Fuel	Machinery	Labor	Outputs: Wheat	Soybeans
			Γ_{ik}			
Agricultural research	0.860	0.716	0.641	0.683	0.012	0.887
Extension	-0.035	-0.004	0.019	0.030	-0.037	0.105
Education	3.062	3.245	3.734	3.383	7.876	0.828
<u>Profit share</u>						
$p_i y_i^* / \pi^*$	0.495	0.336	0.796	1.047	-1.097	-0.575

[a/] A positive (negative) sign indicates a bias effect in favor of (against) an output or an input.

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