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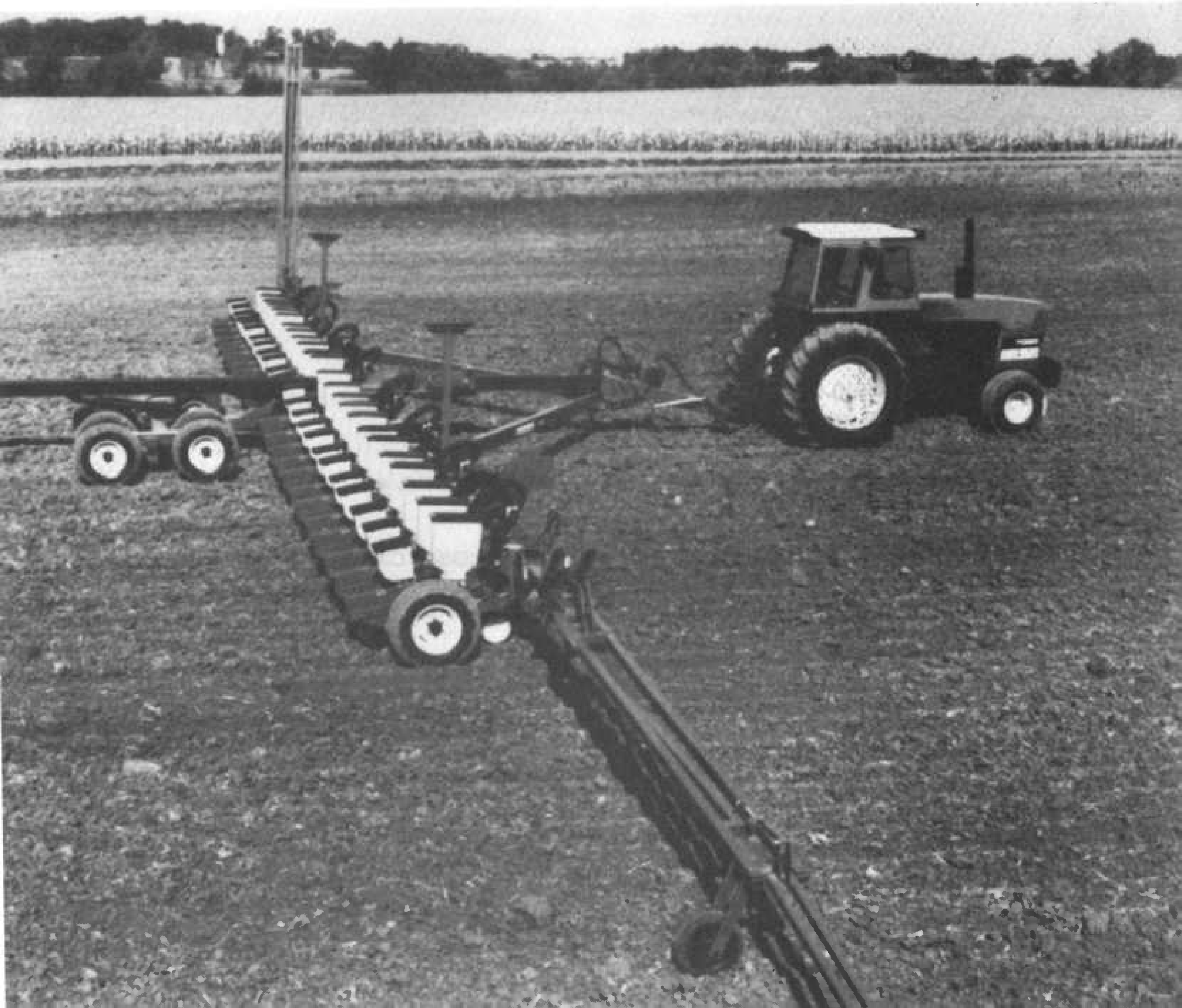
A Direct Approach for Estimating Nitrogen, Phosphorus, and Land Demands at the Regional Level

Harry Vroomen
Bruce Larson



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Abstract

Water quality issues have focused public policy on the use of inputs such as fertilizer in agriculture, since nitrogen and phosphorus use in agriculture can contribute to the contamination of the Nation's water supplies. Estimates of profit-maximizing input price elasticities of demand are needed to assess the impacts of potential regulatory policies on input use. Also, because the structure of agricultural technology may differ across locations, location-specific elasticity estimates are needed. To this end, this paper uses a direct approach for estimating nitrogen, phosphorus, and land demands at the regional level, based on the first-order conditions for expected profit maximization. The direct approach is applied to State-level data on corn production in the Corn Belt. Results suggest that technologies differ across the Corn Belt States, own-price demand elasticities conform to theoretical expectations, and input demands have become less responsive to price over the 1964-89 period.

Keywords: Nitrogen, phosphorus, land, Marshallian price elasticity, technology, input demand, nonlinear three-stage least squares, cross-equation restrictions.

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Summary

Public concern exists that U.S. farmers' use of nitrogen and phosphorus contributes to the contamination of the Nation's water supplies. Both nutrients are carried with soil erosion into surface waters, while nitrogen may also leach into groundwaters. Consequently, the demand for fertilizer is currently a topic of great interest as water quality problems have risen to the top of the agricultural-environmental policy agenda.

Water quality concerns have raised the possibility of various policies targeted to reduce fertilizer use in agriculture. However, efforts to assess the effects of policy alternatives such as taxes or limits on fertilizer use require information regarding the responsiveness of fertilizer nutrient demands to changes in relative prices. Consequently, estimates of profit-maximizing input price elasticities of demand--Marshallian or uncompensated elasticities--are needed to measure the potential effects of environmental policies on input use in agriculture.

An issue related to the demand for fertilizer is the demand for land in the production of specific crops. In theory, acreage reduction programs increase land rents on the remaining acreage and can thereby induce changes in the use of other inputs such as fertilizer. Thus, the potential substitution of fertilizer for land may imply more nutrient leaching into groundwater or a higher nutrient content in remaining soil erosion. On the other hand, if higher fertilizer prices induce substitution of land for fertilizers, sediment loadings in surface water could rise.

This report presents a direct approach for estimating input demands and profit-maximizing price elasticities of input demands at the regional level. The modeling approach is based on the first-order conditions for expected profit maximization and entails estimating the parameters of the production technology. A restricted form of the model is used to estimate the demands for nitrogen, phosphorus, and land in corn production. Marshallian price elasticities are then derived from the estimated parameters. The approach is applied to State-level data in the Corn Belt for the period 1964-89.

Estimated results indicate that own-price elasticities of demand for nitrogen, phosphorus, and land in corn production tend to be negative, as expected. Nitrogen demand tends to be most responsive to the price of nitrogen in Missouri. The demand for phosphorus is most responsive to price in Illinois (aside from Ohio, where elasticities differ widely from the other Corn Belt States). Own-price elasticities of demand have also become less responsive to price over the period of study, while respective cross-price elasticities have remained fairly constant.

In addition, technologies in corn production were found to differ significantly across the Corn Belt States; thus, the responsiveness of fertilizer demands to price changes, as measured by the elasticities, varied by State. For example, estimated elasticities indicate that a uniform incentive-based

program like a nitrogen tax would have the least effect on nitrogen use in Illinois, where application rates are the highest, and the greatest effect in Missouri, where the soil is less vulnerable to leached nitrates than in Illinois, Indiana, or Iowa. Consequently, a uniform national-level incentive program to reduce fertilizer use in agriculture will likely have varying results on environmental goals such as water quality protection.

A Direct Approach for Estimating Nitrogen, Phosphorus, and Land Demands at the Regional Level

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Introduction

Public concern exists that agricultural practices are contributing to the contamination of the Nation's water supplies. Evidence suggests that agriculture may be a significant source of ground and surface water contamination (Nielsen and Lee, 1987; Environmental Protection Agency, 1984; Office of Technology Assessment, 1984). Fertilizer and pesticide contamination of groundwater has already led to numerous policy proposals affecting agriculture. The 1987 Water Quality Act, for example, instructs States to identify nonpoint source pollution contributing to waterway degradation and to recommend best management practices to improve waterway quality (Reichelderfer, 1988).

While certain measures, such as the blending of water for drinking purposes, can reduce concentration levels of contaminants ex post, water quality concerns have raised the possibility of various policies targeted to reduce fertilizer use in agriculture. In an examination of the relative efficiency of four general strategies for achieving agricultural nonpoint pollution abatement, Shortle and Dunn (1986) found that an appropriately specified management practice incentive (for example, a tax on fertilizer) would generally outperform estimated runoff standards, estimated runoff incentives, and management practice standards for reducing agricultural nonpoint pollution. However, efforts to assess the effects of policy alternatives such as taxes on fertilizer use require information regarding the responsiveness of fertilizer nutrient demands to changes in relative prices.

The structure of agricultural technology across regions will also play a central role in programs to alter input use and reduce agricultural externalities. For example, several articles consider the use of taxes or quantity restrictions on fertilizer inputs in agriculture (Burrell, 1989). Since technologies may differ across locations, the effects of a uniform ad valorem nitrogen tax, such as a national U.S. policy, may vary across regions. Thus, farmers across locations will be affected differently by a uniform policy. If fertilizer demands are unresponsive to price changes in areas where water quality is a concern, quantity restrictions may be a more viable alternative for targeting policies to reduce fertilizer use in those specific locations.

A second issue, related to the demand for fertilizers, is the demand for land in the production of specific crops. In the United States, acreage reduction programs are used for supply control and to meet environmental goals (that is, the Conservation Reserve Program (CRP) is targeted to highly erodible lands). In theory, acreage reduction programs increase land rents on the remaining acreage, thereby inducing changes in the use of other inputs such as fertilizer. Thus, while the CRP may reduce total soil erosion by removing highly erodible soil from production, the potential substitution of fertilizer for land may imply more nutrient leaching into groundwater or a higher nutrient content in remaining soil erosion. Even if land and fertilizers are complements, per-acre applications of fertilizers could still increase, thereby intensifying nutrient leaching in specific locations. On the other hand, the environmental effects of nitrogen or phosphorus reduction programs must take into account the potential substitution of land for fertilizers. If higher fertilizer prices induce substitution of land for fertilizers, sediment loadings in surface water could rise.

Estimates of profit-maximizing input price elasticities of demand--Marshallian or uncompensated elasticities--are needed to measure the potential effects of environmental policies on the total use of nitrogen, phosphorus, and land. To this end, the main objective of this report is to investigate a direct approach for estimating profit-maximizing fertilizer (nitrogen and phosphorus) and land demands at the regional level.

Modeling Fertilizer Demand in Agriculture

The demand for production inputs such as fertilizer is a derived demand based on the demand for the final product. This section presents a summary of previous studies of the demand for fertilizer and outlines a direct approach for estimating the parameters of the production technology and profit-maximizing input demands.

Previous Literature

Burrell (1989) provides a recent summary of the main approaches previously used to estimate fertilizer demands. This literature can be roughly separated into two broad categories: (1) specifications that are interpreted as reduced-form equations for a profit-maximizing farm; and (2) more theoretically based equations derived from dual cost or profit functions. While duality approaches allow estimation of a theoretically based model, Burrell (1989) notes that the empirical results are difficult to evaluate when the underlying theoretical assumptions appear to be invalid.

Examples of the first approach include Gunjal, Roberts, and Heady (1980), Roberts and Heady (1982), Carman (1979), and Roberts (1986). For example, Gunjal and others (1980) estimated per-acre total fertilizer expenditures for major U.S. crops as linear functions of harvested acres, gross income, a measure of physical assets, an index of fertilizer price, lagged crop price, a time trend, and a lagged endogenous variable. Similarly, Roberts and Heady (1982) estimated per-acre demand functions for nitrogen (N), phosphorus (P_2O_5), and potash (K_2O) in total corn, wheat, and soybean production. A linear model was specified for each nutrient as a function of own price, lagged output price, diverted acres, and a time trend. Using data on a single U.S. State, Roberts (1986) estimated total demand functions for each fertilizer nutrient (not per-acre) for all crops as a linear function of own price, weighted average price of the other two nutrients, acres harvested, and the ratio of soybean acreage to other harvested acreage. Burrell (1989) notes that these single-equation linear models (or systems of equations where there are no cross-equation restrictions) have several disadvantages: lack of theoretical restrictions apart from *a priori* expectations about the sign of coefficients,[1] the use of R^2 as a measure of model validity, and the fact that estimated elasticities are model specific and cannot be compared meaningfully with estimates from other models.

Examples of the duality-based demand models, which aggregated fertilizer demand as a separate input category, include Boyle (1981), Burrell (1989), Shumway (1983), Weaver (1983), and Huffman and Evenson (1989). Using a cost-function approach suffers from two problems: only Hicksian measures of price elasticities can be obtained, when Marshallian elasticities are needed for policy purposes; and there is the sticky but ignored question of using actual output as an exogenous variable in the cost function. Weather, pests, and other uncertainties imply that actual output will always differ from planned output. However, inputs in agriculture are chosen before output is realized and, thus, are based on planned output. For example, nearly 80 percent of the nitrogen and 99 percent of the phosphate applied to the 1988 corn crop were applied at or before seeding (Taylor and Vroomen, 1989).

While most duality-based analyses of fertilizer demand consider only aggregated demand, Boyle (1982) provides a disaggregated analysis of nutrient demand. Boyle (1982) assumes that nitrogen, phosphorus, and potash are weakly separable from other inputs in the production function and that the fertilizer aggregator function is homothetic (specifically, homogeneous of degree one).

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[1] For example, since Gunjal and others (1980) posit a static theory of the profit-maximizing firm, it is unclear from their theory why gross income or a lagged endogenous variable are used as explanatory variables in their fertilizer demand equations.

These two assumptions allow direct estimation of a unit-fertilizer cost function that is a function only of the three nutrient prices. The unit-fertilizer cost function is, in effect, a price index for the aggregate fertilizer input. This approach has also been used, for example, in disaggregated analyses of energy demand (for example, Uri, 1988).

A Direct Approach

In contrast to the previous literature on estimating fertilizer demands and price elasticities, we suggest the following direct approach for estimating the parameters of the production technology and profit-maximizing input demands across regions. In each region i, i = 1,...n, agricultural output is stochastic due to weather, pests, and other uncertainties. Assuming farmers are risk neutral and maximize expected profits, the farmer's decision problem in each region can be written as:

$$\max_{\underline{x}} \; E[pf(\underline{x}';\epsilon) - \underline{r}'\underline{x}], \qquad (1)$$

where the symbol (') is the transpose operator, $\underline{x}' = (x_1,.....,x_m)$ are inputs; $\underline{r}'$ are input prices; p is the output price; ϵ is a random component in the technology; and E is the expectation operator, which is conditional on the farmer's information set when input choices are made.

The first-order conditions for expected profit maximization are:

$$E[p \; \delta f/\delta \underline{x} - \underline{r}] = 0 \qquad (2)$$

Assuming farmers know input prices when inputs are chosen and that expected output prices are not correlated with the random variable ϵ, equations 2 can be rearranged as:

$$E[\delta f/\delta \underline{x}] - \underline{r}/E(p) = 0, \qquad (3)$$

which implies that a farmer chooses inputs to equate the expected marginal product with the expected real input price. We assume second-order conditions are satisfied.

Equations 3 form a simultaneous system of implicit nonlinear equations that define the optimal input demand functions $\underline{x} = \underline{x}(\underline{r}',E(p);f)$, where f in the input demand functions is used to emphasize that the input demands were derived from a specific technology f. The input demand model defined by equations 3 also provides hypotheses about parameters across equations for a given region that can be tested or directly imposed. For general production functions f, such systems can be estimated using nonlinear least squares for simultaneous implicit equations

(Gallant, 1977; and Gallant and Jorgenson, 1979). In some situations, it is possible to rearrange equations 3 into an explicit equation system.

For example, consider the following cases where the expected production function f is assumed to be quadratic in $\underline{x}$, $\underline{x}^{1/2}$, and $\ln\underline{x}$:

$$Ef(\underline{x}') = \alpha + \underline{\beta}'\underline{x} + .5\underline{x}'\Gamma\underline{x}, \qquad (4.1)$$

$$Ef(\underline{x}') = \alpha + \underline{\beta}'\underline{x}^{1/2} + .5\underline{x}^{1/2}{}'\Gamma\underline{x}^{1/2}, \text{ and} \qquad (4.2)$$

$$Ef(\underline{x}') = \alpha + \underline{\beta}'\ln\underline{x} + .5\ln\underline{x}'\Gamma\ln\underline{x}, \qquad (4.3)$$

where the vectors $\underline{\beta}' = (\beta_1,\ldots,\beta_m)$ and the matrices $\Gamma = \{g_{ij}\}$, i,j = 1,...,m, are parameters to be estimated, and it is assumed that Γ is symmetric.

Using the technology defined by 4.1 and imposing symmetry of Γ, the general model defined by equations 3 can be written as a system of structural equations that are linear in variables but nonlinear in parameters:

$$x_i = (1/g_{ii})[r_i/E(p) - g_i - \sum_{\substack{j=1 \\ j \text{ not equal to } i}}^{n} g_{ij}x_j\ ] \qquad (5.1)$$

Using the technology defined by 4.2 and imposing symmetry of Γ, the general model defined by equations 3 can be written as an explicit system of structural equations that are nonlinear in parameters and variables:

$$x_i = .25[\ g_i + \sum_{\substack{j=1 \\ j \text{ not equal to } i}}^{n} g_{ij}x_j^{1/2}\ ]^2 / [\ r_i/E(p) - .5g_{ii}\ ]^2 \qquad (5.2)$$

Using the technology defined by 4.3 and imposing symmetry of Γ, the general model defined by equations 3 can be written only in implicit form, for example, as:

$$[\beta_1 + g_{11}*\ln x_1 + g_{12}*\ln x_2 + \ldots + g_{1m}*\ln x_m]/x_1 - r_1/E(p) = 0$$
$$\ldots$$
$$[\beta_i + g_{1i}*\ln x_1 + g_{2i}*\ln x_2 + \ldots + g_{im}*\ln x_m]/x_i - r_i/E(p) = 0$$
$$\ldots$$
$$[\beta_m + g_{m1}*\ln x_1 + g_{2m}*\ln x_2 + \ldots + g_{mm}*\ln x_m]/x_m - r_m/E(p) = 0.$$

(5.3)

Equations 5.1 to 5.3 form three structural models which, assuming additive errors and a model of expected output prices, can be estimated using three-stage nonlinear least squares. While equations 5.1 are nonlinear in parameters and equations 5.2 are nonlinear in both parameters and variables, equations 5.3 are linear in the parameters to be estimated. Therefore, parameter estimates should converge in one iteration when estimating the system of equations 5.3. Given the estimated parameters, equations 5.1 to 5.3 define the profit-maximizing input demands.

Profit-maximizing price elasticities can be derived from equations 5.1 to 5.3 via Cramer's Rule. Since these equations identify all the parameters of the production technologies except the intercept, various measures of input substitution can also be calculated directly from the production functions. Chambers (1988) provides a review of alternative measures of input substitution, that is, direct, Allen, and Morishima. The Hicksian price elasticities of demand can be obtained by multiplying the Allen elasticities of substitution by the input cost shares. Thus, the modeling approach based on equations 5.1 to 5.3 can be used to derive both Marshallian and Hicksian measures of price elasticities of demand.

While equations 5.1, 5.2, or 5.3 form a structural model for one region, a multiregion analysis can make use of contemporaneous correlation in the errors across regions. By stacking the equations for each region, the total system of first-order conditions for multiple regions can be estimated using three-stage nonlinear least squares. This estimation method also provides a convenient approach for testing hypotheses about technologies across regions, since it is relatively straightforward to impose across-region restrictions on the stacked system of equations. In the following section, we estimate a modified form of equations 5.3 for nitrogen, phosphorus, and land used in corn production at the State level for the Corn Belt.

Application to the Corn Belt

Corn is a major crop in the United States, accounting for 65 million acres planted, 7.1 billion bushels, and about 36 percent of farm receipts from crops in 1987 (Mercier, 1989). Farmers in the United States also use more fertilizer in the production of corn than in the production of any other crop. For example, during 1988, corn production accounted for an estimated 44 percent of total U.S. fertilizer nutrient use (Vroomen, 1989). And, as a result, it is not surprising that fertilizer reduction policies and slippage in the United States have been discussed in the context of corn production in the main corn-producing States of Iowa, Missouri, Illinois, Ohio, and Indiana--the Corn Belt.

Major input categories in crop production include land, labor, machinery, seed, pesticides, and fertilizer. Thus, a full input demand model based on equations 3 would include these inputs. However, due to data availability, we estimate a restricted form of equations 3 for nitrogen, phosphorus, and land for the five Corn Belt States over the period 1964-89. While the resulting parameter estimates may suffer from omitting relevant variables, such problems are no more or less relevant for the analysis here than in previous studies, which also omit theoretically relevant variables. For example, in the review of the previous disaggregated studies of fertilizer demand, most of the models do not include the prices of all potential substitutes and complements. Following Roberts and Heady (1982), where some input prices are excluded for practical reasons (multi-collinearity), we include a time trend to capture several correlated influences in one proxy variable. As a result, we are cautious about interpreting the time trend solely as a technology trend.

In summary, the following structural (statistical) model of nitrogen, phosphorus, and land demand in corn production is estimated for the five Corn Belt States:

$$\epsilon_1 = -x_1r_1/p + [\beta_1 + g_{11}*\ln x_1 + g_{12}*\ln x_2 + g_{13}*\ln x_3 + g_{14}*\ln t]$$

$$\epsilon_2 = -x_2r_2/p + [\beta_2 + g_{12}*\ln x_1 + g_{22}*\ln x_2 + g_{23}*\ln x_3 + g_{24}*\ln t]$$

$$\epsilon_3 = -x_3r_3/p + [\beta_3 + g_{13}*\ln x_1 + g_{23}*\ln x_2 + g_{33}*\ln x_3 + g_{34}*\ln t], \qquad (6)$$

where, for corn production in each State, x_1 is total nitrogen use, x_2 is total phosphorus use, x_3 is total land use, r_1 is nitrogen price, r_2 is phosphorus price, r_3 is the per-acre land rental price, p is expected price of corn, t is a time trend, and it is assumed that the error terms $\underline{\epsilon}$ are independent and identically distributed with mean vector zero and a positive definite covariance matrix (Gallant and Jorgenson, 1979).

The Data

Previous fertilizer demand studies encountered a lack of appropriate data from published sources to generate a time series of sufficient length for econometric purposes. For example, in their study of nutrient demand functions for corn, wheat, and soybeans from 1952 through 1976, Roberts and Heady (1982) used various assumptions to develop a continuous time series for per-acre nutrient application rates. The authors interpolated between data points and extended ratios of data sources when necessary to ensure that national totals developed for each nutrient by crop conformed with published national totals. Similarly, Gunjal and others (1980) used interpolation and projections of past nutrient application rates to develop a continuous time series in their study of fertilizer demand functions for five crops in the United States.

The time series used in this study represents a significant improvement in the quality of fertilizer-use data used by earlier researchers. Annual time series data for 1964 through 1989 are used to estimate the input demand functions for corn for the Corn Belt States. This period was determined by the availability of detailed fertilizer-use data specific to the major corn-producing States. Fertilizer nutrient application rates and the percentage of corn acres receiving each nutrient for the major producing States have been collected since 1964 by the U.S. Department of Agriculture (USDA). Fertilizer-use data for 1964-88 were taken from Vroomen (1989), while data for 1989 were obtained from Agricultural Resources: Inputs Situation and Outlook Report, published by USDA. This information was used to construct data series for total nitrogen and total phosphate use at the State level. Total nitrogen (and phosphate) use in corn production for each State was computed as the product of the average nitrogen (phosphate) application rate per acre, the percentage of corn acres receiving nitrogen (phosphate), and corn acres planted.

Fertilizer price data are for May (1977-85) and April (1964-76; 1986-89) and were obtained from annual issues of Agricultural Prices, published by USDA. The price of nitrogen was calculated as a weighted national average of the nutrient prices of anhydrous ammonia, urea, ammonium nitrate, ammonium sulfate, and nitrogen solutions (30 percent). The price of phosphorus is based on the U.S. average price of concentrated superphosphate (44-46 percent P_2O_5) and was also converted to a nutrient basis.

Jones and Hexem (1990) report farm rents per acre by State for 1960-89, but cropland rents are reported beginning only in 1967. To generate cropland rents for the earlier years required for this study, cropland rents were regressed against farm rents from 1967-89, since these rates move together. The estimated equations were then used to develop cropland rents for the 1964-66 period.

The futures price of corn at planting time is used as a proxy for the expected corn price. The futures price used is the March price of a December contract on the Chicago Board of Trade, where the closing price of the December contract averaged over March is used to reduce short-term price fluctuations. Corn acreage data by State are from annual issues of Crop Production, also published by USDA. Table 1 provides a brief summary of the data used in this study.

Results of the Estimation

The results of estimating equations 6 for the five Corn Belt States as a 15-equation model (three equations, five States) using nonlinear three-stage least squares are reported in table 2. Cross-equation restrictions within States implied by the profit-maximization hypotheses (symmetry of the second derivatives of the expected production function) have been imposed on the model. The full 15-equation model has 60 estimated structural parameters and 316 degrees of freedom. The numbers in parentheses are asymptotic t-statistics, which

Table 1--Sample means and standard deviations for 1964-89

Variable	Unit	Illinois	Indiana	Iowa	Missouri	Ohio
Nitrogen	1,000 tons	680.50	359.61	681.17	150.41	215.76
		(160.93)[1]	(90.35)	(217.37)	(23.66)	(73.72)
Phosphorus	1,000 tons	374.85	206.16	316.87	62.17	131.86
		(79.37)	(36.40)	(71.42)	(10.68)	(21.93)
Land	Mil. acres	10.62	5.63	12.21	2.73	3.62
		(.91)	(.62)	(1.54)	(.47)	(.41)
Nitrogen price	$/ton	----------------	----------------	285.53	----------------	----------------
		----------------	----------------	(106.85)	----------------	----------------
Phosphorus price	$/ton	----------------	----------------	340.63	----------------	----------------
		----------------	----------------	(145.74)	----------------	----------------
Land rent	$/acre/year	71.84	65.33	71.01	42.21	51.63
		(34.19)	(30.29)	(33.50)	(19.15)	(25.58)
Corn futures price	$/1,000 bu.	----------------	----------------	2,133.08	----------------	----------------
		----------------	----------------	(768.43)	----------------	----------------

[1] Numbers in parentheses are standard deviations.

indicate that 40 parameters are significant at the 5-percent level or less.[2]

While the magnitudes of the parameter estimates vary across the five States, 7 of the 12 parameters have consistently the same sign across States (β_1, g_{11}, g_{12}, g_{22}, g_{23}, g_{24}, and g_{33}) and are generally significantly different from zero at the 5-percent level. Of the parameter estimates that differ in sign across States, the State-level estimates for β_2 are not significantly different from zero, while the opposite sign on β_3 for Illinois compared with the other States is also not significantly different from zero. The parameter estimates for g_{13}, g_{14}, and g_{34} tend to follow no pattern across States and are generally not significantly different from zero.

[2] Given the parameter estimates, marginal products at the sample means are positive for all inputs except land in Missouri. While not sufficient for a full characterization for convexity, the second derivatives with respect to nitrogen at the sample means are almost zero, ranging from -0.00012 in Missouri to 0.00014 in Ohio. Similarly, second derivatives for phosphorus ranged from -0.00016 in Indiana to 0.00055 in Missouri. Second derivatives for land are all negative and ranged from -0.143 in Illinois to -1.991 in Missouri.

Table 2--Structural parameter estimates for corn production functions in the Corn Belt States (equations 6)

Parameter	Illinois	Indiana	Iowa	Missouri	Ohio
β_1	-639.01	-170.27	-236.57	-13.21	-115.56
	(-3.49)[1]	(-7.27)	(-3.20)	(-.92)	(-8.83)
β_2	127.99	7.17	-17.24	19.54	-8.81
	(1.27)	(.20)	(-.31)	(1.67)	(-.45)
β_3	16.60	-34.63	-41.13	-42.52	-13.85
	(.58)	(-3.31)	(-2.39)	(-5.39)	(-2.22)
g_{11}	202.18	66.50	105.66	17.47	37.51
	(4.04)	(17.65)	(5.62)	(3.65)	(13.94)
g_{12}	-86.83	-29.35	-66.07	-15.16	-9.22
	(-3.54)	(-8.59)	(-4.50)	(-4.32)	(-4.47)
g_{13}	-12.61	-4.89	8.78	6.82	-2.51
	(-1.61)	(-2.52)	(1.72)	(2.30)	(-1.95)
g_{14}	-16.88	-2.70	.63	.61	-2.77
	(-1.43)	(-1.42)	(.09)	(.66)	(-1.66)
g_{22}	65.52	27.04	71.18	12.58	11.22
	(3.59)	(4.99)	(5.96)	(3.19)	(2.81)
g_{23}	16.94	16.46	8.52	7.19	6.31
	(4.20)	(9.15)	(2.57)	(3.37)	(4.30)
g_{24}	28.89	10.45	27.41	2.97	6.70
	(4.30)	(5.15)	(4.79)	(4.41)	(4.81)
g_{33}	-15.55	-15.27	-22.15	-15.46	-3.47
	(-3.95)	(-5.31)	(-5.49)	(-5.40)	(-1.37)
g_{34}	.98	.97	-3.71	-2.47	.42
	(.52)	(1.37)	(-1.99)	(-3.85)	(.83)

[1] Numbers in parentheses are asymptotic t-statistics.

One main purpose of this study is to investigate the potential differences in State-level technologies. As a result, we conducted two levels of hypothesis tests. First, the null hypothesis was tested that all technologies across States are identical. And second, the same hypothesis was tested for all pairs of States (10 different tests). Based on the test statistic T^o developed in Gallant and Jorgenson (1979), which is distributed Chi-square with degrees of freedom equal to the difference in the number of parameters between the unrestricted and restricted model, all hypotheses were rejected at the 1-percent level. Rejection of these hypotheses indicates that State-level differences in technologies exist in the Corn Belt. Thus, the responsiveness of input demands to price changes resulting from a tax will differ across States.

Using Cramer's rule on the derivatives of equations 6, Marshallian elasticities were calculated with the parameter estimates in table 2.[3] The resulting input demand elasticities are reported in tables 3-5 for the sample mean over the period 1964-89, as well as for the means of three subperiods within the sample (1964-69, 1970-79, and 1980-89). Since relative prices and levels of inputs vary over the time period of the study, it seems most useful to report elasticities over a range of actual price and use relationships found in the data.

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[3] Profit-maximizing price elasticities are derived by taking differentials of equations 6 with respect to the desired input and price variables, and then using Cramer's Rule to solve for the partial derivative of the inputs with respect to an input price, holding all other prices constant. This derivative is then multiplied by the relevant ratio of input price to input demand to obtain the elasticity.

Table 3--Marshallian demand elasticities with respect to nitrogen price

Input	Illinois	Indiana	Iowa	Missouri	Ohio
Nitrogen:					
1964-89	-0.301	-0.583	-0.618	-0.848	-0.230
1964-69	- .661	-1.193	-1.244	-1.002	-3.075
1970-79	- .403	- .703	- .687	- .885	- .597
1980-89	- .121	- .386	- .409	- .871	.616
Phosphorus:					
1964-89	-1.272	-1.729	-1.629	-1.701	-2.286
1964-69	-1.635	-2.145	-1.946	-1.706	-6.074
1970-79	-1.319	-1.748	-1.610	-1.700	-2.413
1980-89	-1.280	-1.845	-1.836	-1.704	-3.057
Land:					
1964-89	-1.116	-1.658	- .856	-1.162	-3.897
1964-69	-1.225	-1.915	-1.227	-1.231	-8.691
1970-79	-1.089	-1.641	- .876	-1.177	-3.875
1980-89	-1.262	-1.840	- .850	-1.173	-5.830

Table 4--Marshallian demand elasticities with respect to phosphorus price

Input	Illinois	Indiana	Iowa	Missouri	Ohio
Nitrogen:					
1964-89	-0.836	-1.183	-0.904	-0.839	-1.666
1964-69	-1.006	-1.498	-1.192	- .775	-5.238
1970-79	- .891	-1.267	- .920	- .826	-1.935
1980-89	- .812	-1.128	- .928	- .820	-1.882
Phosphorus:					
1964-89	-1.009	- .681	- .258	- .023	-1.267
1964-69	-1.425	-1.371	-1.009	- .060	-8.105
1970-79	-1.118	- .942	- .378	- .040	-2.189
1980-89	- .773	- .230	.155	- .010	.211
Land:					
1964-89	- .412	- .352	- .449	- .379	-1.073
1964-69	- .724	- .991	- .850	- .369	-10.786
1970-79	- .560	- .604	- .501	- .381	-2.530
1980-89	- .179	.112	- .301	- .365	1.693

Three general results emerge from tables 3-5. First, own-price elasticities of demand for nitrogen, phosphorus, and land tend to be negative, as expected. Excluding Ohio, which is discussed separately below, nitrogen demand tends to be most responsive to the price of nitrogen in Missouri, with an estimated elasticity at the sample mean of -0.848. Phosphorus demand tends to be most responsive to the phosphorus price in Illinois, with an estimated elasticity at the sample mean of -1.009.

Second, there are major differences in many of the elasticities between Ohio and the other four States. Ohio is the easternmost State in the Corn Belt, and besides corn and soybeans, also produces a more diverse set of products than the other States. For example, 40 percent of Ohio corn acreage in 1988 had been in other crops besides corn or soybeans during 1986 or 1987. For the other Corn Belt States, only 14 to 25 percent of 1988 corn acreage had been in corn or soybeans since 1986.

And third, own-price elasticities of demand for nitrogen and phosphorus have become less responsive to price over the period of the study, while the respective cross-price elasticities have remained fairly constant. For example, nitrogen demand remained least responsive to price in Illinois over the period of the study, where the estimated own-price elasticity of demand for nitrogen fell from -0.661 in the 1960's to -0.0121 in the 1980's.

Table 5--Marshallian demand elasticities with respect to land price

Input	Illinois	Indiana	Iowa	Missouri	Ohio
Nitrogen:					
1964-89	-0.004	-0.006	-0.004	-0.003	-0.012
1964-69	- .005	- .006	- .006	- .003	- .028
1970-79	- .004	- .006	- .004	- .003	- .013
1980-89	- .005	- .006	- .003	- .003	- .015
Phosphorus:					
1964-89	- .002	- .002	- .004	- .002	- .004
1964-69	- .004	- .005	- .006	- .002	- .040
1970-79	- .003	- .003	- .004	- .002	- .010
1980-89	- .001	- .001	- .002	- .002	.007
Land:					
1964-89	- .022	- .011	- .021	- .006	- .024
1964-69	- .018	- .011	- .016	- .005	- .068
1970-79	- .020	- .012	- .020	- .006	- .031
1980-89	- .024	- .011	- .023	- .006	- .007

The empirical result that fertilizer demand elasticities have become less responsive during the 1970's and 1980's is consistent with structural and technological changes in U.S. agriculture. Agricultural operations became less diverse during the period of the study, with fewer crops being grown on each farm and fewer opportunities for crop rotations. Farm programs may have contributed to this trend by reducing economic risks associated with specialized farming and limiting crop substitution abilities to maintain farm program eligibility. At the same time, technological breakthroughs provided hybrid corn varieties, which depended on higher fertilizer application rates to reach new output potentials. Production on more specialized farms also reduced the availability of farm-level fertilizer substitutes such as manure in some areas. In sum, changes in farm structure, programs, and technology created the technical ability and economic incentives for less responsive fertilizer input demands.

In total, the elasticity estimates tend to reinforce the conclusion that technologies differ across States in the Corn Belt and that, therefore, the adjustments in input demands to prices also differ. Aggregate analyses of fertilizer demands may, thus, be based on an invalid assumption of identical technologies across States. Estimates of aggregate response to input price changes, whether due to market changes or environmental policy, may mask differences across locations. As a result, a uniform national-level incentive program to reduce fertilizer use in agriculture will likely have varying results on environmental goals, such as water quality protection. For example, depending on the data and definitions used, Iowa, Illinois, and Indiana tend to have higher vulnerability to leached nitrates than Missouri and Ohio (Nielsen and Lee, 1987; and Algozin, 1990).

Based on the elasticity estimates presented here for the Corn Belt States, a uniform incentive program like a tax on nitrogen would have the least effect in Illinois in the short run, where elasticities are small and application rates are high. Such a policy would have the greatest impact in Missouri, where fertilizer demands are relatively more responsive to price, but land is less vulnerable to leached nitrates.

Conclusions

Public concern exists that U.S. farmers' use of nitrogen and phosphorus contributes to the contamination of the Nation's water supplies. Consequently, the demand for fertilizer is currently a topic of great interest as water quality problems have risen to the top of the agricultural-environmental policy agenda. Concerns over water quality have raised the possibility of various policies targeted to reduce fertilizer use in agriculture. However, efforts to assess the effects of policy alternatives, such as a tax on fertilizer use, require information regarding the responsiveness of fertilizer nutrient demands to changes in relative prices. Consequently, estimates of profit-maximizing input price elasticities of demand--Marshallian or uncompensated elasticities--are needed to measure the potential effects of environmental policies on input use in agriculture.

This report has presented a direct approach for estimating input demands and profit-maximizing price elasticities of input demands at the regional level. The modeling approach is based on the first-order conditions for expected profit maximization and entails directly estimating the parameters of the production technology. A restricted form of the model was used to estimate State-level demands for nitrogen, phosphorus, and land in corn production in the Corn Belt for the period 1964-89.

Own-price elasticities of demand for nitrogen, phosphorus, and land in corn production were found to be negative, as expected. Excluding Ohio, nitrogen demand tends to be most responsive to the price of nitrogen in Missouri, while the demand for phosphorus tends to be most responsive to its own price in Illinois. The estimated elasticities for Ohio were, in most cases, significantly larger than those estimated for the other Corn Belt States. This may be due to the fact that more crop substitution possibilities exist in Ohio, which produces a more diverse set of products than the other States. Estimated own-price elasticities for nitrogen and phosphorus were also found to have become less responsive to price over the period of study, while respective cross-price elasticities have remained fairly constant.

Results also indicate that aggregate analyses of input demands may be based on an invalid assumption of identical technologies across regions. Technologies in corn production were found to differ significantly across the Corn Belt as the responsiveness of fertilizer demands to price changes varied widely. For example, estimated elasticities indicate that a uniform nitrogen tax would have the least effect on nitrogen use in Illinois, where application rates are the highest, and the greatest effect in Missouri, where the soil is less vulnerable to leached nitrates than in Illinois, Indiana, or Iowa. Consequently, a uniform national-level incentive program to reduce fertilizer use in agriculture will likely have varying results on environmental goals such as water quality protection.

The objective of this study has been to suggest and implement a direct approach for estimating input demands and profit-maximizing price elasticities of input demand. The direct approach is straightforward and not necessarily novel but seems to have been overlooked in most studies of fertilizer demand. Given the widespread availability of nonlinear estimation methods, the approach based on directly estimating first-order conditions needs to be more thoroughly considered. Future research, for example, can focus on such issues as developing the structural model for alternative objective functions or exploring the robustness of the empirical results using alternative functional forms.

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