FARM PROGRAMS AND PESTICIDE DEMAND

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Pesticides

ABSTRACT

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Frequently, the claim is made that farm commodity programs increase pesticide use and potential externalities associated with this expanded use (Dabrakow and Reichelderfer, Cook and Hinkle). Legislative changes such as "triple base" and expenditure increases for LISA research were made in the 1990 farm bill with the premise that pesticide externalities are expanding under current farm programs. Yet, during the 1984 to 1988 period, a period when corn acreage diversion and price supports were high, herbicide use in corn and soybeans, the largest two pesticide markets, has shown a decline as measured by both applications and expenditures (See Figure 1). Further, herbicide use per acre grown in real dollars has also declined so more than mere reduction in acreage is involved. Environmental policies (pesticide bans, ground water safety initiatives) and changes in commodity program instruments (ARP's, deficiency payment levels, long-term land retirement) may affect long-term trends in pesticide use. Potential externalities associated with pesticides heightens the need to understand the linkages between farm programs and pesticide use.

There are only a few studies which attempt to model or quantify the effects of commodity program provisions on pesticide use. Miranowski suggests three ways that government programs might increase pesticide use: (a) higher product prices induce increased rates to satisfy the first order condition of marginal pesticide benefits equal to marginal pesticide costs, (b) more acreage may be planted to crops with relatively high pesticide use per acre, and (c) acreage allotments will not allow crops to shift to regions with relatively lower pest populations. Also, Miranowski indicates that acreage limitations may partially offset some of the pesticide increasing effects of the three other factors (Osteen and Szmedra). Evaluations using pesticide use in the 1960's by Dixon et al. and Richardson found significant positive effects of government provisions. For example, Richardson estimated that a 12 percent decrease in cropland use from acreage restrictions would increase pesticide use by 50 percent based on elasticities of substitution believed to apply in the late 1960's. However, farm programs, agricultural technology, pest threats and pesticide technology have changed drastically since that time.

This paper presents a theoretical model that shows how acreage diversion, relative prices, input substitution and biological variables might lead to reduced as well as increased pesticide use in the presence of price supports. Following this, an empirical model is derived and estimated to quantify effects of farm programs on herbicide use in corn and soybeans and insecticide use in cotton with three different measurements of pesticide quality.

Input Use Incentives with Farm Programs

A wide range of commodity and other programs make up "the farm programs". However, output price supports utilizing deficiency payments, together with minimum acreage diversion requirements are the two primary market interventions used for U. S. corn, cotton, and small grain crops. Pesticide bans or use restrictions administered by EPA and individual states effect availability of individual pesticides; these are incorporated as quantity or quality shifters. Long-term acreage retirement such as by the Conservation Reserve Program is included in the analysis as part of land diversion.

Gardner presents a model that separately shows how price supports and land diversion requirements might influence input use. Consider a production process for a single crop (Y) with two inputs (X1 = pesticides, X2 = land). A price support by means of a deficiency payment program (superscript d) and a given demand (D_Y) can reach a price support level $\hat{P}_Y$ with output supply, S_Y as shown in Figure 2a.

The derived demands for the two inputs without the deficiency payment program are shown as D_{x1} for pesticides and D_{x2} for land, respectively (Figures

2b and 2c). If there is no substitution between pesticides and land, then pesticide price is a residual, $P_{x1} = P_Y - P_{x2}$, given exogenous input supply functions, S_{x1}, S_{x2}. Derived demand for inputs with the price support program is shown as D^d for both land and pesticides. The demand for the two inputs is unambiguously above the original demand curves because output price is above the original price. Equilibrium input price will increase more for the input with the more inelastic supply.

Alternatively, the same level of output price ($\hat{P}_Y$) can be obtained by an input use restrictions such as setting acreage allotments or minimum land diversion requirements (superscript a). Land use is set at $X^a{}_2$ and output is at Y^a. In this case the derived demand for pesticides may either increase or decrease relative to the no diversion case, D_{x1}. Demand for pesticides, D^a will decline if the price elasticity of output demand is larger than the elasticity of substitution between land and pesticides (Gardner).

More formally, assume the agricultural technology for crop Y can be represented by the homogeneous production function

$$(1) \quad Y = f(X_1, X_2),$$

where X_1 is pesticides and X_2 represents land and other inputs. The supply of land is given by S_{x2} with elasticity e_{x2}, σ is the elasticity of substitution of pesticides for land, k_1 is the cost share for pesticides, k_2 is the cost share for land and D_Y is the output demand with elasticity $\tilde{n}$. Using linear, constant elasticity demand functions, Gardner shows that the elasticity of pesticide use for changes in output price with a deficiency payment (E is the percentage change operator) is

$$(2) \quad EX_1/EP_Y = e_{x1} (\sigma + e_{x2}) / (\sigma + k_2 e_{x2} + k_1 e_{x1}).$$

Pesticide use increases with support price because all terms in (2) are positive. In contrast, an acreage restriction (X_2) can lead to pesticide use which can increase or decrease depending on the relative size of σ and $\tilde{n}$ since all other variables in (3) are unambiguously positive

$$(3) \quad EX_1/EX^a{}_2 = e_{x1} (\sigma + \tilde{n}) / (\sigma + e_{x1}).$$

If demand elasticity ($\tilde{n}$) is large relative to σ, the net effect of acreage restrictions could be reduced total pesticide use. Gardner does not consider cases in which simultaneous acreage restrictions and price supports are operative. Over the past 25 years for most commodities and years when deficiency payments are present, there are also acreage limitations. A method is needed that will examine pesticide use changes with both provisions in effect. In addition, because pesticides can be replaced by other inputs (labor, machinery, management) we present a more complete production structure.

Expand the two variable homogeneous, production function to

$$(4) \quad Y = f(X_1, X_2, X_3)$$

where X_1 is pesticides, X_2 is machinery and own labor, and X_3 is land with all other inputs assumed to be used in fixed proportion to land. Let σ_{ij} be the partial elasticities of substitutions between the pairs of inputs, e_i are input supply elasticities on inputs $i = 1, 2, 3$, and k_i represent the input cost shares. With linear, constant elasticity demand functions the partial elasticities of demand $\tau_{ij} = k_j (\sigma_{ij} - \tilde{n})$ show the effect of the change in the price of the jth input on the ith input quantity holding prices of the other inputs constant. Effects of changes in a farm or pesticide policy can be evaluated by constructing a model with an input demand and input supply equation for each of the three inputs, an output supply equation and an output demand equation. Equating supply and demand for output and each input yields the following four-equation system:

$$(5) \quad \begin{bmatrix} \eta & -k_1 & -k_2 & 0 \\ 0 & 1-\gamma_{11}/e_1 & -\gamma_{12}/e_2 & -\gamma_{13} \\ 0 & -\gamma_{21}/e_1 & 1-\gamma_{22}/e_2 & -\gamma_{23} \\ 0 & -\gamma_{31}/e_1 & -\gamma_{32}/e_2 & -\gamma_{33} \end{bmatrix} \begin{bmatrix} EP_Y/E_3 \\ E_1/E_3 \\ E_2/E_3 \\ EP_3/E_3 \end{bmatrix} = \begin{bmatrix} k_3 \\ 0 \\ 0 \\ -1 \end{bmatrix}$$

where E_i represent percent changes in inputs 1, 2, output price or own price, and E_3 is the exogenous policy shift from a required land diversion. Changes from a pesticide tax or ban (ET_1) can also be computed by evaluation E_i/ET_1. Equilibrium prices can be found since $EY = \tilde{n}EP_Y$, and $EP_i = 1/e_i \; E_i + ET_i$.

Pesticide use can theoretically decline with reduced land use if output demand is sufficiently price elastic as discussed in the two input models above. Also, if labor cultivation or machinery (X_2) substitutes easily for pesticides (σ_{12} = large) and if supply elasticities for machinery and labor (e_{x2}) are relatively high, then machinery and labor may be used to substitute for pesticides as land use is reduced from increased land diversion requirements. This effect is enhanced if farms are operating with rather fixed machinery to land ratios (σ_{23} is low). Each of these conditions seems to fit with estimates of substitution elasticities and supply elasticities of Corn Belt agriculture (Huffman and Evanson, Kislev and Peterson, Capalbo and Vo).

A simulation exercise was undertaken to see what happens to E_1/E_3 when both set aside restrictions and price supports occur. By placing parameter estimates (k_i, σ_{ij}, e_i, $\tilde{n}_j$) from the literature in equation set (5) and changing EP_Y and E_3 it was possible to find decreases in pesticide use with recent (1985-88) levels of ARP and price supports if product demand elasticities $>|.3|$. The substitution of machinery, labor or cultivation for pesticides might be enhanced with on-farm substitutions if there are relatively inflexible levels of operator labor and equipment available when ARP's are increased. Farmers may use excess labor and machinery to reduce pesticide use when land diversions occur. This would take the form of field scouting for pests, better timing of cultivation and pesticide applications, and more use of non-chemical controls. These substitutions are confirmed in general by the observed expansion of IPM in insect and weed control (Frisbie and Adkisson).

Empirical Models

To quantify effects of farm programs on pesticide use, a pest control model is needed for econometric estimation. As simple as it may seem it is very difficult to consistently measure pesticide use over time, across regions or between classes of chemicals. Problems arise because (a) there are very rapid changes in the mixture of available chemicals, (b) there is a very large set of different brands, mixtures and classes of pesticides that are used for different pest complexes, and (c) pesticides differ greatly in the dosages used per applications and per crop season. When quality varies, the demand for quantity may be a very misleading. Furthermore, pesticide use levels are measured in many different ways, for example, pesticide expenditures, pounds of active materials, percent of area treated, number of applications, or total application acres including multiple applications per acre of cropland. Hence, this study emphasizes effectives of pesticide use and the demand for quality.

For an individual farmer producing a single crop Y, assume there is a general production process

$$Y = f\ (c,X), \tag{6}$$

where X is the vector of conventional inputs and c is a pest control process assuming $\partial Y/\partial c > 0$. In general, the pest control process can be defined as

$$c = g\ (n,g,Z,X_c), \tag{7}$$

where n is number of separate applications of pesticides, q is the quality of the pesticide application, Z is a vector of exogenous pest characteristics and X_c are the conventional inputs which influence pest control. Quality of pesticide products for a particular brand are homogeneous, but we will be measuring more aggregate bundles of pesticides such as all herbicides used for soybean weed pests, and quality per application will vary due to the mixture of products, and dosage per application.

Both direct pesticide material costs and application costs are components of the cost (P_c) of pest control

$$P_c = nqP_q + nP_n, \tag{8}$$

where P_q is the quality price of the pesticide material, and P_n is the direct application costs and indirect costs of management time for determining type, dosage, timing and other aspects of pesticide use. Farmers can adjust both quality and quantity of pesticides. At one extreme a farmer might use a high dosage of a mixture of several chemicals applied once per season, or alternatively, he might apply several separate applications at a very low dosage.

Given this focus on pesticide quality we can express the farmers profit (π) maximization problem as

$$\text{Max} \quad \pi = P_Y Y - P_c - wX. \tag{9}$$

All terms are described above except P_Y and w which are output price and conventional input prices, respectively. The objective of the producer is to maximize expected profit by choosing optimal numbers of treatment and quality. By substituting (7) into (6) and then (6) and (8) into (9) we have a general per acre profit equation for the typical farm:

$$\pi = P_Y f(g(n, q, Z, X_c), X) - nqP_q - nP_n - wX. \tag{10}$$

Farmers are assumed to include deficiency payments (Price Support) and market prices (if not participating) in forming their expectations of output price P_Y (Chavas, et al.), and include the extra land and other costs that come from setting aside land (Diversion) as part of the input price vector w.

By applying the Hotelling lemma, that is, taking derivatives of the equation (10) with respect to quality price (P_q) and application price (P_n) we can obtain input demand functions for quality (q) and application (n), respectively

(11) $q = q\ (P_q,\ P_n,\ P_Y,\ Z,\ X,\ w)$,

(12) $n = n\ (P_n,\ P_q,\ P_Y,\ Z,\ X,\ w)$.

Three versions of (11) and (12) are estimated. The first model (Simple Model) merely assumes that the pesticide expenditure is a good measure of quality without consideration of application methods. The second model (Number-Quality) explicitly allows for farmers to consider effects of application method on pesticide use effictiveness which results in the application cost (P_n). The third model is a Hedonic Model where quality is the measure of pest control effectivenesss and the quality price is the incremental improvement in the value of pest control $[P_Y*(\partial Y/\partial c)*(\partial c/\partial q)]$. Following Goldman and Grossman, the strategy used to estimate quality and quality adjusted-price is as follows. Let per treatment expenditure be $V = P_q q$, where q is quality and P_q is quality price. Quality is expressed as some function of measurable characteristics (Q_i), so $\ln q = B_o + \Sigma B_i Q_i$. Estimation of $\ln V = B_o + \Sigma B_i Q_i + \ln P_q + \mu$ allows one to compute both the quality from the predicted expenditure for a given observation and the quality-adjusted price from the regression residual. These estimated quality and quality prices are then used for P_q and q in the two equation system (11) and (12).

The data are annual observations for cotton insecticides, soybean herbicides and corn herbicides taken from surveys of growers (1500-5000 for each crop) conducted by a private marketing firm. The cotton data extends from 1965 to 1988, for three major regions of the U.S. while the herbicide data is for the 22 major corn-soybean states for the 1984-1989 period. Information on other inputs, output prices, diverted acreage, price supports come from USDA sources. Application cost is constructed from input prices and pesticide application budgets. Pest density indices and the corn rotation variable are based on the private pesticide survey. The characteristics and functional forms (Box-Cox) used in the first stage of the Hedonic models are available from the authors.

The three sets of two equation models were estimated by two-stage, least-squares for each of the three crops. Following other input demand studies, all equations were assumed to be linear in logs. (Carlson, Lichtenberg and Zilberman)

Tables 1 and 2 give parameter estimates for the Simple, Number-Quality and Hedonic models for cotton insecticides and soybean herbicides. The Hedonic model for corn herbicides was not as successful but the Number-Quality model gives similar results to that for soybeans. The Hedonic models are superior to the Number-Quality models which are in turn better than the Simple models which ignore application costs. The Hedonic equations for quality and treatments have a higher degree of fit, signs are correct for all four equations for application cost, and only one sign is incorrect for quality price (however the coefficient is not different from zero).

The effects of the acreage diversion provision on per acre pesticide demand is consistently negative for both quality (expenditure) and number of treatments. For soybeans the effect is statistically significant, but for cotton only the Hedonic quality measure is significant. For corn (not shown) the coefficients were negative with t values = -1.0. The small negative effect of acreage diversion shows that asset fixities and input substitution possibilities outweigh any tendency of farmers to attempt to increase yields by raising pesticide use rates.

For price supports we found a positive effect on quality (Hedonic Model) for soybeans, and positive coefficients for both expenditures and number for corn (not shown). For cotton increases in price supports were associated with small negative use rates per acre for both quantity and quality demanded.

Increases in application costs tend to decrease number of treatments, and increase the quality for the Hedonic model. Output price elasticities are small positive values (.07 - .16), while own price elasticities for numbers of applications are -.41 for soybean, -.47 for cotton insecticides and -.15 for corn herbicides; reasonable magnitudes for input demand elasticities (Capalbo and Vo). Corn rotation tends to decrease soybean herbicide treatments and quality, but it does not have any effect on corn herbicide use; this is consistent with weed selectivity studies (Frisbie and Adkisson).

Conclusions

Earlier assertions that price supports together with acreage restrictions would greatly increase pesticide use intensity are not found in three major U.S. pesticide markets. Theoretically, it is possible for asset fixity and input substitution to lead to reductions in pesticide use rates with increase in land diversion and price supports. Analysis of data for the past six years shows small increases in soybean herbicide expenditures per application and corn herbicide demand (quantity and quality) with price supports, but also statistically significant declines in use rates (quantity and quality) for increases in corn land diversion. For cotton insecticides over the past 25 years, demand is decreased slightly by either increases in price supports or diversion rates. Quantities and prices of pesticides are difficult to measure, and demand is best approximated by simultaneous quantity and quality equations with adjustments for quality (Hedonic Model) and application costs.

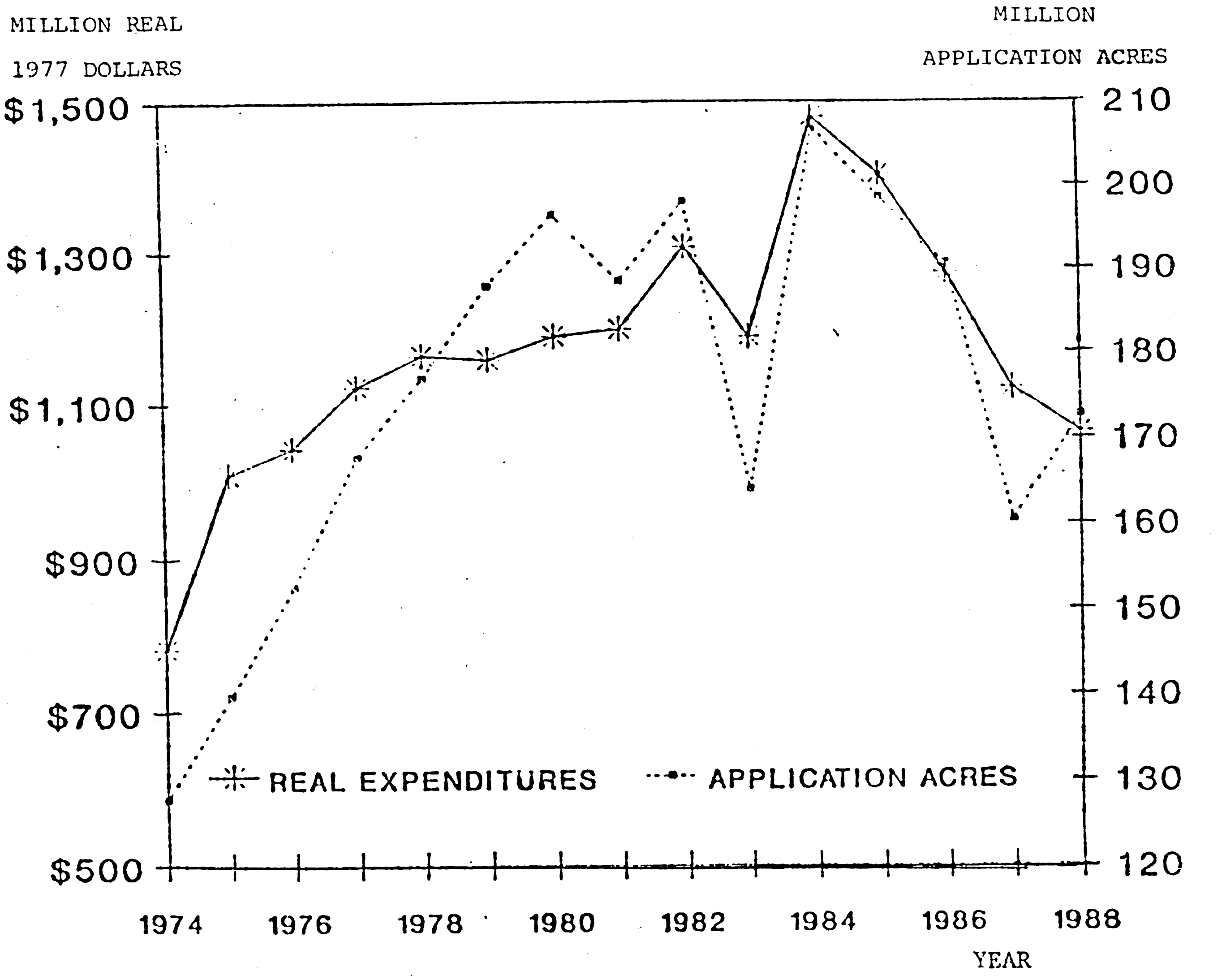

Figure 1: Applications and Real Expenditures for Soybean Plus Corn Herbicides All U.S.

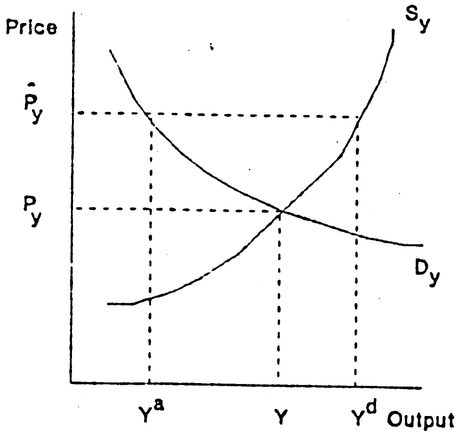

Figure 2a. Output Market with Price Support, $\hat{P}_y$

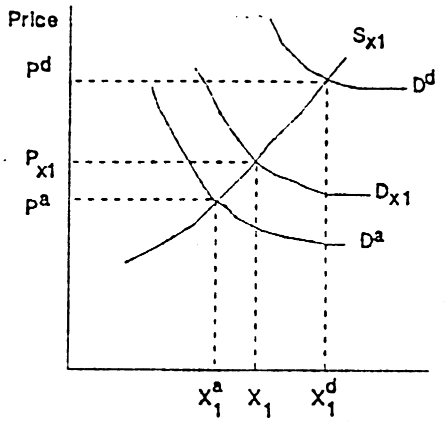

Figure 2b. Derived Demand for Pesticides

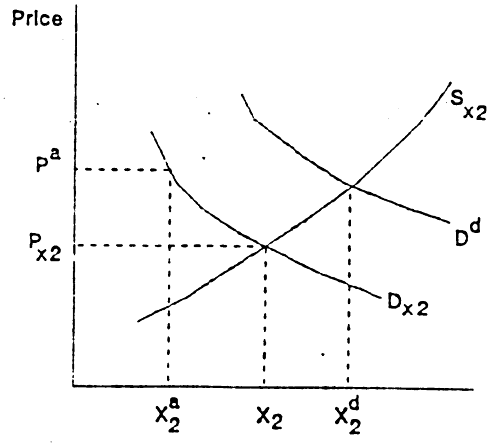

Figure 2c. Derived Demand for Land

Two-Stage Least-Squares Estimates of Alternative Demand Models

Table 1. Cotton Insecticides

Variable	Simple Model		Number-Quality Model		Hedonic Model	
	No. of Treatments	Expenditure	No. of Treatments	Expenditure	No. of Treatments	Quality
Intercept	-1.676	3.361	-0.161	-6.100	0.363	-4.442
	(-1.061)	(2.703)	(-0.046)	(-1.756)	(0.122)	(-4.802)
No. of Treatments	---	-0.417	---	-1.045	---	---
	---	(-0.719)	---	(-1.993)	---	---
Expenditure	0.057	---	-0.264	---	---	---
	(0.177)	---	(-1.140)	---	---	---
Quality Price	---	---	---	---	-0.474	-0.059
	---	---	---	---	(-1.901)	(-1.706)
Application Cost	---	---	-0.027	1.753	-0.174	1.464
	---	---	(-0.032)	(2.202)	(-1.155)	(6.339)
Pest Index	0.112	0.036	0.088	0.146	0.100	0.013
	(0.086)	(0.416)	(1.500)	(1.990)	(1.735)	(0.653)
Cotton Price	0.375	-0.618	0.109	0.169	0.161	0.066
	(1.041)	(-2.082)	(0.414)	(0.557)	(0.616)	(0.729)
Acreage Diversion	0.014	-0.010	0.008	-0.002	0.008	-0.007
	(1.922)	(-1.088)	(1.176)	(-0.274)	(1.324)	(-3.447)
Price Support	0.001	-0.029	-0.016	-0.031	-0.011	-0.020
	(0.110)	(-5.648)	(-1.969)	(-3.276)	(-1.666)	(-8.596)
Regional Dummy 1	2.107	-0.863	2.230	2.372	2.196	0.095
	(17.038)	(-0.705)	(25.462)	(2.033)	(25.688)	(3.203)
Regional Dummy 2	1.639	-0.681	1.757	1.848	1.754	0.012
	(15.139)	(-0.741)	(23.180	(2.001)	(23.676)	(0.480)
Adjusted R^2	0.860	0.304	0.941	0.342	0.944	0.812

Table 2. Soybean Herbicides

Intercept	2.166	1.907	1.147	2.625	1.191	2.022
	(2.193)	(6.541)	(2.795)	(3.550)	(4.085)	(14.613)
No. of Treatments	---	-0.748	---	-1.031	---	---
	---	(-2.130)	---	(-1.244)	---	---
Expenditure	-1.125	---	-0.203	---	---	---
	(-2.196)	---	(-2.224)	---	---	---
Quality Price	---	---	---	---	-0.410	0.119
	---	---	---	---	(-1.764)	(-1.002)
Application Cost	---	---	-0.829	-0.870	-0.873	0.005
	---	---	(-6.245)	(-1.096)	(-5.842)	(0.063)
Soybean Price	0.425	0.361	0.127	0.349	0.131	0.115
	(1.915)	(2.423)	(1.287)	(2.116)	(1.362)	(2.335)
Acreage Diversion	-0.748	-0.650	-0.271	-0.701	-0.301	-0.138
	(-1.983)	(-3.168)	(-1.677)	(-2.907)	(-1.942)	(-1.751)
Price Support	0.064	0.056	-0.036	0.008	-0.124	0.287
	(0.342)	(0.370)	(-0.413)	(1.565)	(-1.176)	(5.298)
Irrigation Dummy	-0.564	-0.481	-0.132	-0.430	-0.064	-0.354
	(-2.788)	(-6.421)	(-1.624)	(-5.385)	(-1.689)	(-8.204)
Corn Rotation	-0.334	-0.282	-0.074	-0.237	-0.087	-0.032
	(-2.496)	(-3.585)	(-1.283)	(-2.889)	(-1.510)	(-1.098)
Adjusted R^2	0.185	0.359	0.324	0.353	0.338	0.823

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