Pesticide Tax, Cropping Patterns, and Water Quality in South Central Texas

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Abstract

The impact of an *ad valorem* pesticide tax on cropping patterns and pesticide use was examined in the South Central Texas Crop Reporting District. Output supply equations were econometrically estimated and used in the simulation. A 25 percent tax on pesticide was estimated to have major impacts on cropping patterns and on pesticide use. Assuming other input and output prices were unaffected, the supply of one important crop would fall by more than half. Demand for some of the highly soluble and persistent pesticides, which present the greatest threat to groundwater quality, would also decrease substantially (some as much as 50 percent).

Key Words: crops, dual model, pesticides, supply, water quality

Environmental degradation is a major societal concern. One environmental problem that has received much media and some scientific attention is pesticide usage (Carson; Batie). Pesticides were first introduced into U.S. agriculture in 1870 when paris green was developed to battle the potato beetle. Since that time, pesticides have become an important agricultural input and have contributed to major increases in the productivity of the sector (Osteen and Szmedra).

While pesticides have greatly enhanced agricultural output, they have come to be regarded as a "two-edged sword" (Taylor *et al.*). Considerable attention has turned to the potential hazards associated with pesticide use. These hazards include toxicity to humans, chronic health effects, food safety, fish and wildlife mortality, and groundwater and surface water pollution (Osteen and Szmedra). Although certainly not the only hazards of concern, food safety and drinking water quality are significant problems. Taylor *et al.* (p. 16) note that they "appear to dominate the current debate." Pesticide residues can pollute water and make it unfit or harmful for human consumption. They can reach and pollute groundwater through leaching, and they can pollute surface water through rainfall runoff and aerial drift.

In a 1990 national survey of more than 1300 drinking water wells, the U.S. Environmental Protection Agency (EPA) found at least one pesticide present in 10 percent of the community water system wells and 4 percent of the rural domestic wells (Briskin; Taylor *et al.*); 0.6 percent of the rural wells and none of the community wells had pesticide levels in excess of the EPA levels for health concern. While it is not clear that residues in small concentrations are harmful, this finding of little health risk from current pesticide concentration in drinking water wells warrants several cautions: (a) a more restricted 26-state, 89-county survey of

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drinking water wells in rural areas found a much larger proportion of wells contaminated with pesticides (Klein); (b) pesticide leaching through the soil is very slow (Griffin) which means that groundwater contamination could increase even if no additional pesticides are used; (c) unless an aquifer undergoes substantial drawdown and recharge, groundwater contamination by persistent pesticides is generally irreversible and the only effective option often is to abandon groundwater sources that reach health hazard levels (Griffin). Thus, with agricultural producers using more than twice as much pesticide as they used 25 years ago (Delvo), much attention in the debate over water quality is centering on agricultural practices.

The problem is that the debate, although intense, is not supported on either side by much hard scientific evidence. Rachel Carson's book focused media and public attention on agricultural chemical use and its potential risks in the early 1960s. Scientific and public concern resulted in the establishment of the Environmental Protection Agency (EPA) in 1970 and the banning of DDT in 1972. Scientific interest was heightened in the late 1970s when the herbicide aldicarb was first discovered in groundwater in Suffolk County, New York (Batie). Considerable monitoring of groundwater has occurred since then, but still little is known about chemical leaching rates, and the evidence on "carcinogenic, mutagenic, and neurological effects of pesticides [in low dosages] is not conclusive" (Batie, p. 5). There is also virtually no information concerning monetary measures of chemical-caused damages (Griffin).

While regulatory alternatives to deal with pesticide contamination of groundwater are currently being considered by the EPA, some extreme proposals have focused on either completely eliminating pesticides and other agricultural chemicals (or at least specific chemicals in certain locations or on particular crops) or maintaining the *status quo* (Taylor *et al.*). Several other alternatives have also been suggested for reducing pesticide use. One option includes a voluntary change in farming practices through use of integrated pest management or low input, sustainable agriculture programs. A second option encourages reduced chemical use through cross-compliance with government farm programs. A third alternative is to place an *ad valorem* tax on all pesticides.

The last option's purpose would be to effect voluntary reductions in pesticide use by increasing its private cost to more nearly approximate its social cost. It has three advantages over several of the alternative proposals: (a) Since it acknowledges a positive marginal externality cost of pesticide use but does not infer it is infinite, it desirably falls substantially between the extreme positions of *status quo* and a complete ban on all pesticides (Taylor *et al.*). (b) A management practice incentive (such as an *ad valorem* tax) is superior from an efficiency perspective to runoff incentives (e.g., tax on pesticides in water runoff), pesticide standards (e.g., limits on pesticides in runoff), or management practice standards (e.g., restrictions on number of pesticide applications) for reducing agricultural nonpoint pollution (Shortle and Dunn).[1] (c) Since political preferences favor management practice incentive schemes, a tax may also be politically acceptable (Shortle and Dunn). It is the option examined in this study.

Changes in policy affect various groups of people in different ways. In order to anticipate the distributional impacts of policy changes, analysis must be conducted at a relatively disaggregated level. For example, a tax on all pesticides will change crop mixes and impact various regions in unequal ways (McIntosh and Williams; Lim *et al.*). The voluntary decisions made by producers in response to the uniformly imposed tax will determine the nature of these outcomes as well as the impact on water quality and consumer prices of food and fiber.

Objective and Organization

The objective of this study is to estimate the impact of an *ad valorem* pesticide tax on cropping patterns, pesticide demand, and water quality in the South Central Texas Crop Reporting District (8-N) (Figure 1). This district includes 21 counties, many of which are environmentally sensitive with respect to water quality. They spread across four major aquifers, including the Edwards, Trinity, Carrizo-Wilcox, and Gulf Coast. Rivers flowing through the district include the Brazos, Colorado, Guadalupe, San Marcos, San Antonio, Navidad, and Lavaca.

Perhaps of greatest policy importance from a water quality standpoint is the fact that the district encompasses two-thirds of the San Antonio and Austin regions of the Edwards Aquifer. This underground storage facility supplies municipal, recreational, and industrial water to more than 1.3 million people in San Antonio, Austin, and nearby cities. It is recharged in a unique manner. Water enters the formation through fractured limestone, sinkholes, and caves, so the normal filtration effect of water passing through many feet of soil into an aquifer does not occur to the same extent here. Consequently, although Edwards Aquifer water currently is of excellent quality (based on EPA standards), there is a high potential for pesticides present in surface water to move directly into this aquifer (TAEX-SCS-ASCS).

Much of the agricultural production in the district occurs in areas at high risk for groundwater contamination. The susceptibility of groundwater in the entire district to contamination is reflected by moderate to high DRASTIC scores (Texas Water Commission 1989a). These scores depict groundwater pollution potential which may result from widespread, surface-applied pesticides and fertilizer.

An econometric approach is taken in this study to estimate actual voluntary production responses in the district. The approach is imprecise largely because of the limited data available. Nevertheless, important insights are generated about voluntary collective responses of economic agents in one environmentally sensitive area. The insights are relevant for policy efforts to internalize social costs of environmental degradation in the area.

The remainder of this paper is organized as follows: The analytical procedures are developed first. Data sources are identified next. They are followed by presentation of major findings and then the conclusions.

Method of Analysis

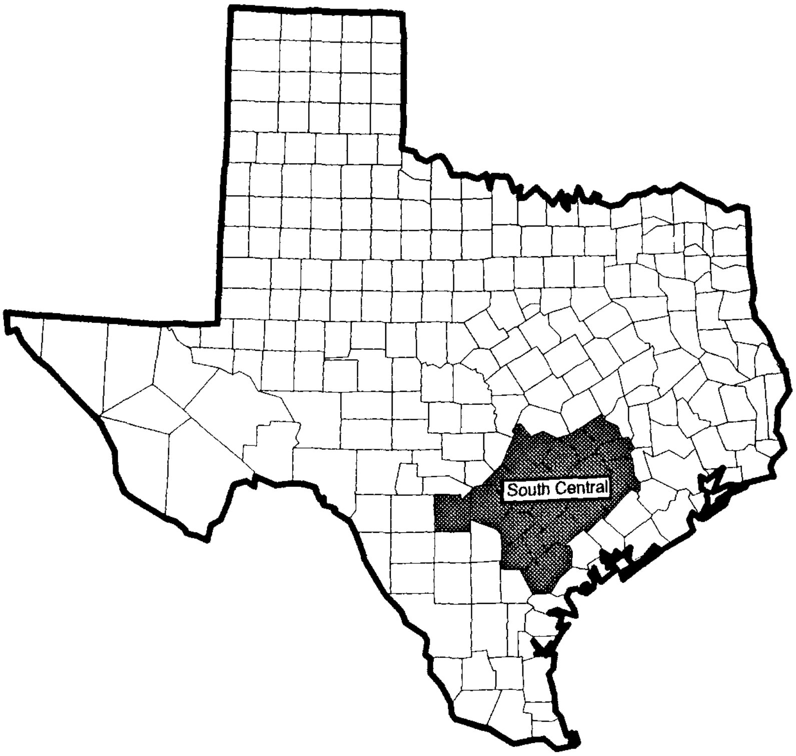
Crop supply equations for the district were estimated using time series data, elasticities were derived, and likely impacts of a 25 percent *ad valorem* pesticide tax on cropping patterns were simulated. Then using point estimates of major pesticides used on each crop in the district (and assuming fixed proportions of pesticide and land), expected impacts on pesticide use were derived. The assumption of fixed proportions production was imposed because of lack of time series data on input usage in the district. The direction of potential bias in the simulated results caused by this assumption was evaluated. Limited implications for groundwater quality were then drawn.

Supply Equations

The system of output-supply equations was econometrically estimated assuming that the producers in the district collectively behave like a price-taking, profit-maximizing firm with a twice-continuously-differentiable production function and some constraining input supplies. Lim conducted nonparametric tests of the profit-maximization hypothesis for the state-level aggregate of producers in Texas and found little empirical departure from this hypothesis. Parametric tests have also frequently failed to reject the implications of either of the above hypotheses using aggregate data (Rossi; Shumway and Alexander). Therefore, in estimating the systems of supply equations, two behavioral characteristics of price-taking, profit-maximizing firms (homogeneity and convexity) were maintained. A twice-continuously-differentiable production function for a profit-maximizing producer (i.e., symmetry of cross-price supply parameters) was also assumed.

Linear supply equations were estimated that are the first derivatives of a normalized quadratic form of the restricted profit function. This functional form was chosen to be consistent with Ornelas' finding (based on nested hypothesis tests, predictive accuracy, and statistical performance) that the normalized quadratic profit function was generally preferred over the translog and generalized Leontief for modeling Texas agriculture.

Figure 1. South Central Texas Crop Reporting District (8-N)



For consistency with short-run profit maximization, the independent variables were expected output prices for four individual crops (with highest value of production in the district) and an aggregate of other crops produced in the district, variable input prices for pesticides and an aggregate of other variable inputs, an aggregate fixed-input quantity, a farm policy variable (effective diversion payments), and time. Input-demand equations were not estimated due to lack of district-level data on most inputs.

Based on the results of Villezca and Shumway's (1992a) nonjointness tests, livestock quantities and prices were not included in the estimated model. Working with commodity aggregates, they found that short-run nonjointness was not rejected for Texas crops.[2] Assuming that their findings apply to this crop reporting district, livestock prices were ignored when examining supply response of crops in the district.

The equations estimated were of the following form:

$$(1)\qquad Q_i = b_{i0} + b_{i1}P_1 + b_{i2}P_2 + b_{i3}P_3 + b_{i4}P_4 + b_{i5}P_5 + b_{i6}P_6 + b_{i7}T + b_{i8}F + b_{i9}D_i,\ \ i = 1, ..., 5,$$

where Q_1-Q_5 is quantity supplied of rice, corn, grain sorghum, hay, and other crops, respectively; P_1-P_5 is price of commodity 1-5 divided by price of the variable inputs aggregate; P_6 is pesticide price divided by price of the other variable inputs aggregate; T is time; F is quantity of fixed inputs; D_1-D_5 is effective diversion payment for commodity 1-5; and b_{i0}-b_{i9} is the corresponding parameter estimate.

The "other crops" category was an aggregation of several minor crops (in terms of value of production). These crops were peanuts, cotton, wheat, oats, soybeans, sunflower, and barley.

To maintain homogeneity of degree zero in prices (for consistency with price-taking, profit-maximizing behavior), all prices in each supply equation were divided by the aggregate variable input price. This price was an aggregation of prices for hired labor, fertilizer, machinery operating inputs, capital services, feed, seed, and miscellaneous inputs. The fixed-input quantity was an aggregation of family labor and land. Aggregate variables were constructed because of the large number of inputs used and outputs produced and the limited number of observations available. These aggregations reduced the dimensions of the statistical model and conserved degrees of freedom. All independent variable aggregates were created using the Tornqvist index.[3]

The fixed-input aggregate quantity variable was dropped from the corn equation due to high collinearity among the regressors. Because this variable generally decreased over the data period, its most likely misspecification effect would be to bias the estimated temporal parameter, b_{27}, downward. Since government payments were not paid to restrict hay production, no diversion payment variable was included in the hay equation. The diversion payments variable included in the other crops aggregate equation was the simple average of diversion payments for wheat and cotton.

For consistency with previously noted assumptions, convexity was maintained by the Cholesky factorization (Lau; Talpaz *et al.*), and symmetry of cross-price parameters was maintained by linear restrictions. Error terms were assumed to be normally and independently distributed, with a constant contemporaneous covariance matrix across equations. The iterative version of Zellner's seemingly unrelated regression (*ITSUR*) was used to obtain the variance-covariance matrix which transformed the observation matrix. The estimates were iterated until the covariance matrix stabilized. Using the stabilized covariance matrix, the nonlinear constrained optimization procedures of Talpaz *et al.* using *MINOS* version 5.1 were employed to obtain final parameter estimates.

Pesticide Demand

Because time series data on pesticide use were not available for the district, no pesticide demand equation(s) were estimated. Instead, point estimates of the quantities of major pesticides used in the district were obtained. Because of data limitations, the following hypotheses were maintained to make tractable an analysis of the effects of an *ad valorem* tax on pesticide demand:

a. Yield does not respond in the short-run to pesticide price changes. Therefore, a 1 percent change in predicted output implies a 1 percent change in predicted harvested acreage.

b. Land and pesticides are used in fixed proportions. A 1 percent change in harvested acreage implies a 1 percent change in pesticide use.

c. The change in any specific pesticide depends on the change in harvested acreage of the crop(s) on which it is applied.

The likely biasing effects of these assumptions are somewhat offsetting. For example, Houck and Gallagher found that corn yield responds positively to the previous season's corn price. Both acreage and variable inputs used per acre likely change in the same direction as expected output price. Thus, the percentage change in output likely overestimates the change in harvested acreage, and assumption "a" would bias upward the estimated impact on pesticide use.

On the other hand, McIntosh and Williams found a significant complementary relationship between land and pesticides in Georgia. Although not included in their published paper, Villezca and Shumway (1992a) obtained the same result for Texas and Florida. So did Lim, Shumway and Honeycutt for Illinois and Minnesota.[4] Each of these relationships was elastic, suggesting that pesticide demand would move in the same direction as land use, and would change proportionately more (in most cases much more since three of the four elasticities exceeded 3.0) than would land. Therefore, the change in harvested acreage likely underestimates the change in pesticides, so assumption "b" would bias downward the estimated impact on pesticide use and would likely more than offset the upward biasing effect of assumption "a".

Finally, although many pesticides are registered for use on more than one crop, it is expected that an *ad valorem* tax on pesticides would be neutral as to which crops a particular pesticide is applied. Therefore, the final assumption should not seriously abstract from reality. The primary biasing effect of these assumptions on pesticide demand impacts is expected to be the underestimation due to assumption "b".

Pesticide Use and Water Quality

Herbicides accounted for more than 80 percent of all pesticide use in the U.S. in 1982 and 86 percent of pesticide use on U.S. field crops in 1992. Four herbicides (alachlor, atrazine, butylate, and metolachlor) accounted for more than half of herbicide usage in 1982 and two-thirds of field crop herbicide usage in 1992 (Nielsen and Lee; USDA 1993). Each has a moderate-to-high potential to leach (Nielsen and Lee). Atrazine is highly soluble (able to dissolve in water) and persistent (able to resist degradation) and thus is the pesticide most frequently found in groundwater (Griffin). It was found in 1.7 percent of community wells and 0.7 percent of rural wells in the 1990 EPA national survey of drinking water wells. Alachlor was the next most frequently found pesticide in wells (Briskin). Atrazine is currently being targeted by the EPA for possible regulatory action because of its potential for groundwater contamination. Alachlor is expected to be the next pesticide targeted. Both of these herbicides are used extensively in South Central Texas.

Insecticides are of less concern for groundwater contamination because they typically have low solubility and strong absorption (U.S. Congress; Griffin). However, surface water is also contaminated by pesticides. A national sampling of surface water and bed sediments for 18 insecticides and 4 herbicides found contamination in nearly 10 percent of water samples and 20 percent of bed sediment samples. Atrazine was the most detected pesticide in surface water as well as groundwater (Griffin).

Because scientific data on degradation of groundwater and surface water quality due to pesticide applications is extremely weak, it was presumed that degradation would be slowed in the same proportion as use of major contaminating pesticides is reduced. As their application on the surface is reduced, the amount of pesticide available for runoff or leaching is reduced. So is the opportunity for point source pollution of groundwater. Pesticides are most frequently regarded as a non-point source polluter of groundwater due to percolation and leaching through the soil. Point source pollution also occurs from mixing spills and cleanup, which generally take place near the farm well, and is regarded by some experts as the "most likely route of potential pollution at this time" (Texas Water Commission 1989b, p. 156). The well can provide chemicals easy access to the aquifer, especially if the casing is cracked or corroded (Griffin). Thus, while the number of potential non-point source contaminants is more limited, virtually all soluble and persistent pesticides are candidates for point source contamination.

Data

Annual production data for the years 1972-1986 for barley, corn, cotton, grain sorghum, hay, oats, peanuts, rice, soybeans, sunflower, and wheat as well as total acreage harvested in the South Central Texas Crop Reporting District were used to estimate the supply equations. These data were electronically acquired from the National Agricultural Statistics Service. They were supplemented by published data from *Texas Field Crop Statistics* and *Texas Small Grains Statistics* (Texas Crop and Livestock Reporting Service).

Texas annual prices for most of these crops were compiled by Evenson and associates at Yale University for 1972-1982 and by McIntosh at the University of Georgia for 1983-1986. Sunflower and hay prices were obtained from *Texas Field Crop Statistics*. All output price data were state-level rather than district-level because the latter were incomplete for our data period.

State-level price data for variable inputs and quantity data for labor were also obtained from Evenson and McIntosh's compilations. Their data sources were primarily USDA's *Agricultural Statistics; Agricultural Prices; State Farm Income and Balance Sheet Statistics; Field Crops Production, Disposition, and Value;* and the Chicago Board of Trade's *Statistical Annual*. Government commodity policy data for 1972-1986 were from McIntosh (1989).

Additional sources of data used for construction of missing values included the USDC's *Census of Agriculture* (for the years 1978, 1982, and 1987), USDA's *Agricultural Statistics*, unpublished data from the Texas Crop and Livestock Reporting Service, and Jones and Hexem. In the process of assembling data necessary for estimation, weighted sums, simple averages, straight-line interpolation, and regression analysis were used to construct estimates for a few missing sunflower prices when these values could not be found elsewhere for this minor crop. The same methods used by the original compilers of the state-level data were used in the supplementation when possible.

A weighted average of the anticipated market price and effective support price was used as the expected price of each farm program commodity (barley, corn, cotton, grain sorghum, oats, peanuts, rice, soybeans, and wheat). This procedure was adapted from Romain and was found by McIntosh (1991) to give better out-of-sample performance than either of two alternatives in predicting output supplies and input demands in Texas and three other states. Consistent with Lim's findings, one-year lagged output prices were used as anticipated market prices for each commodity.[5] Government policies designed to control commodity supplies were consolidated by McIntosh (1989) into two variables, effective support price and effective diversion payments, following Houck *et al.*

The fixed-input aggregate was computed as a Tornqvist index of total harvested acreage in the district and state-level labor. The latter was scaled by the ratio of district-to-state harvested acreage. Means of all data used in the estimation equations are reported in Table 1.

Data on pesticides used and their application rates on individual crops produced in this district were obtained from *Texas Crop Enterprise Budgets* (Texas Agricultural Extension Service 1991) for Extension Service Districts 10, 11, 13, and 14. Nine of the counties in the South Central Texas Crop Reporting District are in Extension Service District 10, two counties are in District 11, three in District 13, and seven in District 14. Additional details were provided through personal communications with Extension Management Specialists for Districts 10, 11, and 14 (Cornforth; Gerlow; Pena). Pesticide usage obtained from the Extension Service budgets and extension specialists were largely consistent with the Resources for the Future's pesticide use inventory for Louisiana[6] (Gianessi) and with the TAEX's Specialist Pesticide Use Survey (Texas Agricultural Extension Service, 1988).

Results

Supply Response

Monotonicity of the profit function in output prices was checked at each observation. No violations were found. The maintained hypothesis of convexity of the profit function in prices was relaxed and tested. It was not rejected at the .05 significance level. Thus, the estimated supply equations were fully consistent with the theory for price-taking, profit-maximizing firms.

Parameter estimates are reported in Table 2. There was a negative relationship between pesticide price and output quantity of all crops except rice. The empirical finding of some decreases and some increases in crop output levels in response to an increase in pesticide price was consistent with short-run expectations for multiple outputs when one or more allocatable input (such as land) constrains production (Moschini).

All crops were estimated to be short-run economic substitutes to corn. Rice, grain sorghum, hay, and other crops were all short-run economic complements to each other. While all normal jointly-produced outputs are gross economic complements in the long run, they may be complements or substitutes in the short run (Moschini; Leathers). We found evidence of both.

At the .05 level, significant own-price supply parameters were found for rice, corn, grain

Table 1. Summary Production Information, Data Means

Output or Input	Quantity	Expected Price	Receipts	EDP[a]	Acres Planted
	(thousands)	($/unit)	($1,000)	(¢/unit)	(thousands)
Rice	2,787 cwt.	8.715	24,289	6.939	52.91
Corn	10,645 bu.	2.377	25,303	6.667	187.5
Grain Sorghum	16,558 bu.	2.154	35,666	6.026	412.7
Hay	797.2 ton	55.09	43,918		382.3[b]
Other Crops:	266.3	94.58[c]	25,184	4.435	433.6
Peanuts	49,695 lb.	.1799	8,940		37.11
Cotton	15,051 lb.	.4648	6,996		41.73
Wheat	2,163 bu.	3.108	6,723		157.7
Oats	946.2 bu.	1.423	1,346		185.3
Soybeans	210.5 bu.	5.397	1,136		9.820
Sunflower	1.811 cwt.	13.11	24		.2667
Barley	9.007 bu.	2.014	18		1.626
Pesticides		10.57[c]			
Other Variable Inputs		.8217[c]			
Fixed Inputs	336.9[c]				

[a] EDP is the effective diversion payment.

[b] Acres harvested.

[c] Indexes: pesticide price = 10 in 1977; other crops price = 100 in 1982; other variable inputs and fixed inputs prices = 1.00 in 1982.

sorghum, and other crops. Eight of ten cross-price parameters were significant. They affected every crop which suggested that none of these crops was produced by a short-run nonjoint technology with respect to other crops. Significant parameters on diversion payments, fixed input quantity, and time were estimated in a majority of the supply equations. Pesticide price was significant in all but the hay supply equation.

Price elasticity estimates are reported in Table 3 along with standard errors. The standard errors are approximate and were computed based on first-order Taylor-series expansions of the elasticities (Miller *et al.*). Own-price response of rice, grain sorghum, and hay production was inelastic. It was elastic for corn and other crops production. Corn price played a particularly important role in the cropping decisions. Cross-price elasticities of both rice and grain sorghum with respect to corn price were larger in absolute magnitude than were either of their own-price elasticities.

Two-thirds of the elasticities were significant at the .05 level. Except for hay, all own-price elasticities were significant. Except for elasticities with respect to aggregate variable inputs price, most cross-price elasticities were also significant. Prices of hay and other crops were not significant in the rice supply equation, the price of rice was not significant in the hay or other crops equations, and the price of pesticides was not significant in the hay equation. These were the only nonsignificant elasticities.

Pesticide Tax

No specific pesticide tax rate has been proposed in the environmental debates. It is likely

Table 2. Parameter Estimates

		Equation				
Variable[a]	Unit	Rice (10,000 cwt.)	Corn (100,000 bu.)	Grain Sorghum (10,000 bu.)	Hay (1,000 tons)	Other Crops (100,000 units)
Constant		-.07432	.08098	-1.61881	.76837	.42850
		(.09184)	(.04048)	(.44028)	(.62199)	(.19715)
Rice Price	$/10 cwt.	.00065	-.00056	.00231	.00006	.00002
		(.00009)	(.00007)	(.00048)	(.00033)	(.00015)
Corn Price	$/100 bu.		.00111	-.00518	-.00080	-.00037
			(.00009)	(.00049)	(.00027)	(.00011)
Grain Sorghum Price	$/10 bu.	Symmetric		.02711	.00699	.00336
				(.00538)	(.00148)	(.00102)
Hay Price	$/ton				.00431	.00224
					(.00260)	(.00076)
Other Crops Price	$/100 units					.00162
						(.00057)
Pesticide Price	$/unit	.00594	-.00760	-.02389	-.02245	-.01356
		(.00275)	(.00257)	(.01097)	(.01614)	(.00515)
Time	year-1971	.00703	.00325	.00844	-.00098	-.00895
		(.00188)	(.00101)	(.00787)	(.01189)	(.00387)
Fixed Inputs Quantity	unit	.00029		.00684	-.00184	-.00115
		(.00021)		(.00107)	(.00162)	(.00051)
Effective Diversion Payment	¢/unit	-.00072	.00152	-.00322		.00049
		(.00015)	(.00032)	(.00157)		(.00079)

[a] All prices were divided by price of other variable inputs. To promote convergence in the nonlinear optimization, all dependent variable magnitudes were divided by 2238 (which was the largest dependent variable value). Thus, all scaled dependent variable values were equal to or less than 1.0.

Table 3. Elasticities at the Data Means

	Prices						
Quantity	Rice	Corn	Grain Sorghum	Hay	Other Crops	Pest-icide	Variable Inputs
Rice	.554	-1.308	.487	.032	.017	.613	-.394
	(.090)	(.189)	(.108)	(.180)	(.139)	(.289)	(.337)
Corn	-1.256	6.727	-2.856	-1.129	-.894	-2.055	1.462
	(.315)	(1.591)	(.689)	(.450)	(.336)	(.831)	(3.066)
Grain Sorghum	.331	-2.026	.961	.634	.523	-.415	-.007
	(.070)	(.214)	(.196)	(.138)	(.160)	(.192)	(.335)
Hay	.018	-.651	.515	.811	.725	-.811	-.606
	(.100)	(.241)	(.138)	(.508)	(.274)	(.598)	(.647)
Other Crops	.017	-.898	.741	1.264	1.570	-1.467	-1.226
	(.134)	(.303)	(.250)	(.469)	(.596)	(.598)	(.778)

Note: Approximate standard errors are in parentheses.

that a serious effort to address environmental concerns by altering private costs would result in a substantial tax. Therefore, we chose to examine the likely effects of a 25 percent *ad valorem* tax on all pesticides. This simulation was conducted subject to the admittedly tenuous assumption that our parameter estimates would be stable over such a wide range in this independent variable. However, while this tax rate may seem large, pesticide prices actually varied by more than twice this amount over our data period. Thus, the practical effect of evaluating this hypothesized tax was to conduct a simulation well within the range of our actual data.

The anticipated impacts on cropping patterns are reported in Table 4. A 25 percent *ad valorem* pesticide tax was estimated to decrease quantities supplied of corn, grain sorghum, hay, and other crops by 10 to 51 percent. Grain sorghum would decrease the least and corn the most. The second largest decrease would be for other crops; this category includes peanuts and cotton, both heavy pesticide users.

Although quantities of most crops were estimated to decrease significantly with a pesticide tax, one crop (rice) was estimated to increase (by 15 percent). Under multiple-output production, it is not a theoretical expectation for every output to decrease when an input price increases. In fact, with land and labor fixed, as assumed in this study, it is unlikely that all outputs would decrease. Nevertheless, it seems counterintuitive that rice would be the commodity whose output increases since it is also a heavy user of pesticides. By way of caution, it should be noted that harvested acreage of rice in Texas decreased nearly 40 percent over the data period (Texas Crop and Livestock Reporting Service 1973-1985a; Rister *et al.*). Although acreage in the South Central District did not decline so sharply, it did drop 16 percent while production increased 12 percent. Production generally rose during the first half of the data period followed by a decline to the previous low and a subsequent partial recovery. The recovery occurred entirely in the last four years of the data period, during which high-yielding semidwarf rice varieties were introduced throughout Texas. Ito *et al.* estimated that by 1986 the new varieties were planted on 76 percent of Texas rice acreage. Although the estimated pesticide price parameter in the rice supply equation was positive and significant, there is a reasonable likelihood that it may have also picked up some of the effects of omitted variables. Therefore, both its sign and magnitude should be interpreted with caution.

Our predicted district-level impacts on cropping patterns were much larger than state-level impacts previously estimated for Texas, Florida, California, Iowa, Illinois, Nebraska, Minnesota, or Georgia (Villezca and Shumway 1992b; Lim *et al.*; McIntosh and Williams). Except for Georgia, it was estimated that this level of tax on pesticides would not change any state-level crop supply by more than one percent. Even in Georgia, no crop supplies would change by more than 8 percent. These large differences between estimated state-level and district-level impacts suggest that geographic aggregation may diffuse the distributional impact of such a policy change.

Pesticides containing more than 30 major active ingredients are applied to crops in this district. They include herbicides, insecticides, fungicides, and growth regulators. Their estimated usage in 1991 is reported in Table 5. Also reported in that table are the primary crops on which each pesticide is used and the estimated impact of the pesticide tax. The estimated impacts are based on the assumption that harvested crop acreage and pesticide usage on a crop both change in proportion to the crop's output. It is also assumed that response estimates based on the 1972-1986 data are relevant for 1991.

No predicted pesticide impacts are made for the pesticides whose primary application is only on crops in the "other crops" category. It was predicted that the output of other crops, which includes peanuts, cotton, wheat, oats, soybeans, sunflower, and barley, would decrease by 37 percent (or 1-1/2 times the tax rate). If this category were separable, all seven of its crops would decrease proportionately; fixed proportions production would then imply a 37 percent decrease in each pesticide used on these crops. However, since the crops were aggregated based on their low production value rather than separability arguments, no attempt is made here to estimate the decrease in individual pesticides applied only to such crops.

Table 4. Estimated Impacts of a 25 Percent *Ad Valorem* Pesticide Tax at the Data Means

Crop	Percent Change in Quantity Supplied
Rice	15.3
Corn	-51.4
Grain Sorghum	-10.4
Hay	-20.3
Other Crops	-36.7

The tax would cause a reduction in application of most, but not all, pesticides. Because an increase in rice acreage was estimated, pesticides used only on rice are estimated to also increase.[7] They include the herbicides molinate and propanil and the insecticide iprodione. Use of all other pesticides would decrease. Among those that would decrease by the largest percent are the herbicide alachlor (which is the second most frequently detected pesticide in water wells [Briskin]) and the insecticides chlorpyrefos and terbufos. Each of these pesticides is used mainly on corn, the crop projected to decrease relatively the most.

Several of the pesticides would decrease proportionately more than the tax imposed. Others, including atrazine (the most frequently detected pesticide in both wells and surface water), would decrease nearly as much as the tax rate. Since the output of the "other crops" category was also predicted to decrease substantially, aggregate pesticide use in this district would also be expected to decline considerably (and perhaps proportionately more than the tax rate). These estimates of highly elastic pesticide demands contrast sharply with prior estimates of aggregate pesticide demands at the state level (McIntosh and Williams; Villezca and Shumway 1992b; Lim *et al.*; Fernandez). Their estimates of pesticide demand elasticities in nine states varied from -.04 to -.81, but none was elastic. Our district estimates of pesticide response also exceed Miranowski's estimates for herbicides and insecticides used in U.S. corn production and Carlson and Shui's estimates for herbicides used in U.S. corn and soybean production. They are similar, however, to Carlson and Shui's estimate for insecticides used in U.S. cotton production.

Assuming that the parameter estimates would be valid for a 25 percent increase in pesticide cost, it is more likely that the maintained hypotheses of this analysis would underestimate rather than overestimate responsiveness of pesticide demand to an *ad valorem* tax. Therefore, it is possible that geographic aggregation to the state or national level greatly diffuses the distributional impact of such a policy change. Since there is little likelihood that all areas would respond similarly to a tax on pesticides, the response in this area may be much larger than in some other agricultural producing areas. What is implied by this analysis is that in this environmentally sensitive district, a moderate tax on pesticides is expected to substantially reduce the use of many herbicides, insecticides, fungicides, and growth regulators. This reduction in pesticide use would markedly slow the degradation by agricultural production of both groundwater and surface water quality.

Conclusions

To achieve the objective of this study, five linear output supply equations were estimated as a system for South Central Texas, an environmentally sensitive part of the state. The equations were specified to be consistent with a normalized quadratic form of the restricted profit function. They were estimated while maintaining homogeneity, symmetry, and convexity properties in output prices. Impacts of a 25 percent *ad valorem* pesticide tax on cropping patterns, pesticide demand, and water quality were examined using the parameters of these estimated equations.

Table 5. Estimates of Pesticides Used and Lower Bound Impacts of a 25 Percent *Ad Valorem* Pesticide Tax, 1991

				Estimated Change	
Pesticide	Primary Crops Applied To	Unit	Quantity Applied	Quantity	Percent
Herbicides:					
Acifluorfen	Soybeans	oz.	49,100	[a]	
Alachlor	Corn, Peanuts	lb.	411,800	-206,300	-50
Atrazine	Corn, Sorghum	qt.	808,800	-160,700	-20
Bentazone	Soybeans	oz.	49,100		
Chlorsulfuron	Wheat	oz.	86,200		
Cyanazine	Cotton	pt.	20,900		
Glyphosate	Soybeans	pt.	26,500		
Molinate	Rice	lb.	105,800	+ 16,200	+15
Monosodium Methanearsonate	Cotton	pt.	20,900		
Picloram	Hay	pt.	382,300	- 77,600	-20
Prometryne	Cotton	lb.	33,400		
Propanil	Rice	lb.	158,700	+ 24,300	+15
Trifluralin	Cotton, Peanuts	pt.	141,400		
Insecticides:					
Azinphos-Methyl	Cotton	qt.	41,700		
Carbaryl	Peanuts	lb.	27,800		
Carbofuran	Rice, Corn, Sorghum	lb.	3,781,900	-412,200	-11
Chlorpyrefos	Corn	lb.	374,900	-192,700	-51
Dicrotophos	Cotton	lb.	16,700		
Methyl Parathion	Rice, Cotton	lb.	95,000	- 7,200	-8
Parathion	Wheat	pt.	172,400		
Pyrethrum	Cotton	lb.	41,700		
Terbufos	Corn	lb.	562,400	-289,100	-51
Fungicides:					
Chlorathalonil	Peanuts	pt.	445,300		
Esfenvalerate	Soybeans	oz.	15,700		
Iprodione	Rice	oz.	423,300	+ 64,800	15
Methomryl	Soybeans	pt.	2,900		
Propiconazole	Rice, Wheat	oz.	1,472,000	-402,300	-27
Growth Regulators:					
Butifos	Cotton	pt.	31,300		
Endothall	Cotton	pt.	33,400		
Ethephon	Cotton	pt.	4,200		
Thidiazuron	Cotton	oz.	208,600		

[a] A blank in the Estimated Change column means that the pesticide was used primarily on one or more of the seven crops in the "other crops" category.

The estimated impact of the pesticide tax would be a substantial decrease in the output supplied in this district of all crops except rice. Most of the estimated crop supply responses were significant and large in absolute magnitude. Quantities demanded of many pesticides would decrease substantially. Degradation of water quality would also be markedly slowed. These results demonstrate that an *ad valorem* tax on pesticide would affect supplies of different crops and demands of specific pesticides in very different ways. Because pesticides differ in solubility and persistence, their impact on water quality also differs. The results demonstrate that a moderate tax on an environmentally adverse agricultural input may substantially reduce some of its adverse consequences in at least one environmentally sensitive area.

Nevertheless, several important questions remain unanswered. For example, would producers in other environmentally sensitive areas also substantially reduce their use of pesticides in response to an *ad valorem* tax? If so, then the public and private efficiencies associated with imposition of such a simple policy instrument could result in its being favored over alternatives such as (a) different tax rates on different ingredients or (b) area-specific restrictions on specific pesticides. The dead-weight social welfare loss from enforcing either of the latter options would be great. Their enforcement could be justified only if the social cost of the *status quo* is substantial and if desired changes cannot be achieved by general incentives. To provide even a partial answer to the posed question, comparable analyses in other environmentally sensitive areas will be required. State-level analyses are not sufficient. Most states contain much land at low risk for groundwater contamination and relatively small areas at very high risk. Some prior state-level studies suggest that producers would collectively respond little to an *ad valorem* pesticide tax. However, there is also some recent evidence (e.g., Beach and Carlson) that farmers engaged in environmentally risky activities do partially internalize the public costs of their behavior. Additional research is needed to determine the extent to which, and reasons why, such economic agents voluntarily consider social consequences of their actions without explicit internalization of social costs.

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Endnotes

1. The management practice incentive is more efficient than other options because (a) it permits farmers to use all available knowledge of their specific farm operations, and (b) it can convey at least as much information to farmers about the expected external costs of their management decisions as can the alternatives (Shortle and Dunn, p. 675).

2. Short-run nonjointness of crops could be violated either by technical interdependence with livestock production or by the effects of a constraining allocatable input.

3. This index is not exact for the normalized quadratic profit function.

4. Competitive relationships between land and pesticides were found by the latter two studies in three other states, but none was significant.

5. Lim found that lagged output prices rendered less serious departures from the joint hypothesis of profit maximization, convex technology, and nonregressive technical change than did any of three alternative price expectation proxies for agricultural production data in two states (Iowa and Texas). The alternatives were futures prices, an ARIMA forecast from past prices, and a composite forecast.

6. Texas was not included in the Resources for the Future inventory. Although our study area exhibits many agroclimatic differences from Louisiana, it is more like this neighboring state than the other inventoried states.

7. Because of the structural changes that affected rice production during the data period, it is possible that this estimated increase is spurious. If so, then the overall decrease in pesticide use in this district due to the imposition of an *ad valorem* tax could be even greater than predicted by this study.