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The Effects of a Pesticide Tax on Agricultural Production and Profits

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Abstract: A multi-output, multi-input agricultural production system was estimated for the state of Alabama. The system was used to simulate the impacts of a tax placed on pesticide products. The results show which output and input markets would be most affected by such a policy and track the effect on farm-level profits. Profits are forecast to decline, but by a small amount. Other significant impacts are on the markets for pesticides and for labor, which appears to be the best substitute for pesticide use.

Key Words and Phrases: Duality, Food safety, Pesticides, Supply response.

Evidence of environmental degradation and health risks associated with chemical use has made food safety a priority on the public policy agenda. Alarmed by the widespread publicity about the use of Alar on apples and the Chilean grapes incident, consumers are increasingly concerned about pesticides in almost any form (Misra, Huang and Ott). Society is prepared to impose legislative control over the use of agricultural technology if necessary to protect the environment and the safety of food and water (Batie; Lichtenberg, Spear and Zilberman; Allen). New legislation may restrict the type and amount of chemical fertilizers and pesticides farmers can apply to crops. In November, 1986, California's voters overwhelmingly endorsed State Proposition 65, The Safe Drinking Water and Toxic Enforcement Act. The resulting California Food Safety Act of 1989 (AB-2161) was signed into law in October, 1989. The act increased efforts to monitor statewide pesticide use. In addition, the act legislated an in-depth review of current California law to ensure that the health of infants and children was adequately protected (Chitwood). These actions that directly and indirectly restrict pesticide use affect farmers' decisions to apply pesticides.

Proponents of legislation to reduce or regulate pesticide use argue it will increase food quality and safety. EPA administrator Carol Browner stated, "....We are confident we can reduce pesticide use and pesticide risk without

any decrease in the quality of our produce or the output of our farms" (Browner, Rominger and Kessler). Opponents argue the restriction of pesticide use will increase the costs of agricultural production. A reduction in pesticide use may lead to higher production costs, that, through competition, are passed along to processors, retailers and consumers of agricultural products. A study from The Fertilizer Institute suggests that a complete ban would boost consumer food prices by 45 percent and raise the general inflation rate by 5 to 7 percent. Corn output would fall 40 percent, wheat 50 percent, and a \$5-billion loss in export sales would result (*The Kiplinger Agriculture Letter*). More recently, a study by Knutson *et al.* found that restricting the quantities of pesticides used on fruits and vegetables would cause yields to decrease, in some cases as much as 100 percent.

As Archibald points out, actions to regulate pesticides involve several parties with conflicting interests: agricultural producers, agribusinesses, pesticide producers and consumers. Evaluating the impacts of pesticide restrictions through a multi-market equilibrium framework is essential to capturing the impact on all sectors. Previous studies have examined the effects of pesticide restrictions in agriculture (Dinan and Salassi; Gardner; Helmers, Azzam and Spilker; Olson *et al.*; Richardson *et al.*; Taylor *et al.*; McIntosh and Williams; Lim, Shumway and Honeycutt).

This study formulates a complete agricultural production system for the state of Alabama. The system contains supply and demand components for major outputs and inputs, and employs duality theory that facilitates a complete systems approach to examining interrelated demand and supply structures. The purpose of this study is to build an empirical multi-market agricultural production framework, and use simulation to evaluate the marginal changes in different markets due to pesticide restrictions. An indirect, restricted (short-run) profit function is used to provide the dual system of output supplies and input demands. Rather than analyze quantity restrictions here, we choose to examine the impact of a pesticide tax. This approach is the same as was used by McIntosh and Williams; however, this study focuses on different commodities. An environmental-impact tax seems at least as plausible a policy outcome as does a quantity restriction on pesticide use that would be much more difficult to enforce. Further, a quantity restriction would lead to a less efficient outcome than would a pesticide tax due to restricted production practices.¹

Theoretical Framework

The theoretical framework of this study finds its basis in the neoclassical theory of the firm. It is assumed here that Alabama's agricultural sector can be represented by a state-level profit function. Lau showed that there

is a one-to-one correspondence between the production function and the profit function for profit maximizing firms. Consequently, it is possible to derive output supply and input demand functions directly from the profit function. This implies that all of the relevant information about the use of inputs and the production of outputs can be derived through a profit function. In this study, a normalized quadratic functional form is used to specify and estimate the profit function at the state level. The details of this approach are presented in the Appendix.

Simulation of a Pesticide Tax

To address the impact of a tax placed on agricultural pesticides, the effect on production from different tax rates can be simulated by solving the theoretical profit model for the profit-maximizing inputs and outputs given the postulated set of prices (including the effect of the tax on pesticide prices). The predicted output and input levels show the new optimal behavior under different price levels of pesticides.

The impacts of a pesticide tax are evaluated as percentage changes comparing simulated values with a tax imposed to corresponding values without a pesticide tax. Econometrically estimated parameters are used to determine the impact of a pesticide tax. Thus, confidence intervals can be calculated for each simulated impact. The confidence intervals show the range for which there is a 95 percent probability that the true value falls within the upper and lower limits. Following Dorfman, Kling and Sexton, a Taylor's series approach was used to calculate the confidence intervals (Appendix).

Data

The variables in the profit function include output price expectations, observed prices of the variable inputs, quantities of fixed inputs, weather variables, and time. Expected prices used in the aggregate output groups, with the exception of field crops, were lagged cash prices. The price expectation for the field crops aggregate was calculated using a weighted average of lagged cash and support price (Romain). Previous research has tested many specifications for expected prices and found that a lagged output price performs as well or better than many more complicated formulations such as moving averages, Koyck lag structures, or futures prices. Lim, using non-parametric techniques, found that a one-year lag was an appropriate specification. Studies by Shideed and White and Orazem and Miranowski have shown that no single price expectation

mechanism dominated the tested alternatives, according to non-nested hypothesis tests, for modeling supply and acreage response.

Five output aggregates are constructed: a field crops aggregate; a fruit-vegetable aggregate; an "other crops" aggregate; a dairy and poultry aggregate; and an aggregate of meat animals. Most of the aggregates are self-explanatory, but we note that the "other crops" aggregate includes peanuts and tobacco, along with all agricultural products that were not specifically accounted for in other commodity equations. All aggregates were constructed using the Tornqvist index (Chambers, p. 233).

The five variable inputs include hired labor, a variable capital input (fuel; lubricants; repairs to machinery, equipment, and buildings), fertilizer, pesticides, and miscellaneous inputs (items such as seed, feed, and products produced and consumed on the farm). The numeraire was the price index for hired labor. Fixed (or exogenous) inputs are family labor, land, service flows from capital stock, precipitation, and temperature. Because land, family labor and service flows from capital stock were considered fixed, the results from this study are short-run in nature.

The data used here begins with Evenson's state-level data set of annual observations on the prices and quantities of agricultural outputs and inputs covering 1949-1982. This data set was extended through 1986 by McIntosh. Weather data are from Teigen and Singer, including the monthly temperature and precipitation by state and farm production region. The temperature variable included in the model is measured as the average for the month immediately preceding normal planting dates plus the following months of the growing season. The precipitation variable is the total for the months of the growing season. Time is included as a proxy for disembodied technological change.

The family labor data is from *Farm Labor* for the period 1965-1980 and unpublished USDA data for 1949-1964 and 1981-1986. Service flows from capital stocks are estimated by a weighted aggregate of depreciation and real interest charges (calculated at current replacement costs). Sources include *Agricultural Prices*; *State Farm Income and Balance Sheet Statistics*; and unpublished USDA data. The land input is the total number of acres of land in farms, with data from *Farm Real Estate Market Developments* for 1951-1980 and *Agricultural Statistics* for 1981-1986, Statistical Reporting Service, and Agricultural Census reports. Quantities and prices for both outputs and inputs come from the above-mentioned references as well as *Meat Animals, Production, Disposition and Income*, and *Feed Situation* (see Evenson; and McIntosh for further details).

Empirical Results

The supply and demand functions were estimated using a nonlinear, seemingly unrelated regression procedure. Symmetry, homogeneity and convexity were maintained (see Appendix for a discussion of the estimation procedure). Table 1 presents the elasticities of supply and demand calculated at the mean of the respective prices and quantities.

Among the output supplies, the livestock products and other crops were relatively more responsive to own-price movements than the rest of the categories, but were still less than 0.67. These small responses indicate very moderate short-run flexibility in the output mix. The demand for variable capital inputs (the operation and maintenance cost of machinery and buildings) and the demand for fertilizer and pesticides were the most responsive input demands.

The demands for capital, fertilizer, pesticides and other inputs increased with increases in the price of hired labor, holding all other variables constant. The demand for hired labor increased with the unit price of capital, fertilizer, pesticides, and the other inputs aggregate. Capital was complementary with fertilizer, pesticides, and other inputs while competitive with hired labor. All variable inputs are gross substitutes with hired labor.² The price of hired labor has rose more than the price of other inputs. This explains the dramatic decline in the use of labor during the observation period (Moschini). Fertilizer was competitive with hired labor and other inputs but complementary with pesticides and variable capital inputs.

It is worth noting that the own-price elasticity of pesticides is much more elastic than the other inputs. The demand for pesticides was also quite responsive to price changes of fruits and vegetables. This could explain why the own-price elasticity for pesticides is elastic.

Pesticide Tax Simulation Results. The simulated impacts of a pesticide tax on the input demand and output supply levels are presented in Table 2 along with confidence intervals (calculated by Taylor series expansion). Because the impacts of different tax rates follow a linear relationship, the results can be conveyed with a single tax level. The level chosen for Table 2 is a one percent tax on pesticides.

All estimated impacts from a pesticide tax were small, with the exception of pesticide use. The only input substitute for pesticides was hired labor, which has a positive elasticity. Previous studies have also shown that hired labor is a substitute for pesticides (McIntosh and Williams; Lim, Shumway and Honeycutt). During the period represented by the data in this study, an evolution occurred regarding labor and pesticides. Over the years, hand labor (weeding with hoes) declined as

Table 1.

Output Supply and Input Demand Elasticities for Alabama

Variable	Elasticity with Respect to the Price of									
	Hired Labor	Capital Inputs	Fertilizer	Pesticides	Other Inputs	Field Crops	Fruits & Vegetables	Other Crops	Dairy & Poultry	Live-stock
Hired Labor	-0.199	0.111	0.030	0.080	0.033	0.025	0.012	0.083	0.055	0.068
Capital Inputs	0.855	-1.147	-0.051	-0.549	-0.646	-0.220	0.067	0.866	0.813	0.012
Fertilizer	0.281	-0.061	-0.907	-0.058	0.235	0.040	-0.109	0.397	-0.107	0.289
Pesticides	1.799	-1.595	-0.143	-2.418	-1.393	0.488	1.032	0.659	1.429	0.140
Other Inputs	0.064	-0.160	0.049	-0.119	-0.174	-0.003	0.032	0.029	0.166	0.115
Field Crops	-0.182	0.201	-0.031	-0.154	0.014	0.185	0.135	-0.214	-0.074	0.119
Fruits & Vegetables	0.040	-0.028	0.039	-0.151	-0.056	0.063	0.095	-0.009	0.045	-0.037
Other Crops	0.362	-0.489	-0.189	-0.128	-0.066	-0.131	-0.012	0.665	0.226	-0.234
Dairy & Poultry	0.073	-0.139	0.015	-0.084	-0.114	-0.013	0.018	0.068	0.121	0.054
Livestock	-0.168	-0.003	-0.077	-0.015	-0.147	0.041	-0.028	-0.131	0.109	0.430

Table 2.

Impact on Each Market in Alabama from a One Percent Tax on Pesticides

Market	% Change	95% Confidence Intervals	
		Lower Limit	Upper Limit
Hired Labor	0.080	-0.052	0.212
Capital Inputs	-0.594	-0.633	-0.465
Fertilizer	-0.058	-0.143	0.027
Pesticides	-2.418	-2.713	-2.123
Other Inputs	-0.119	-0.145	-0.094
Field Crops	-0.154	-0.552	0.244
Fruits & Vegetables	-0.151	-0.187	-0.116
Other Crops	-0.128	-0.207	-0.049
Dairy & Poultry	-0.084	-0.097	-0.014
Livestock	-0.015	-0.041	0.011
Profit ^a	-0.075	-0.104	-0.045

^aProfit was calculated to indicate the change in the total value of the profit function due to a one percent tax on the price of the pesticides.

herbicide usage increased. Later in the data period, there was an increase in the substitution of insect scouting (labor) for insecticides. At the present time, virtually all of the cotton is scouted while a third of the peanuts and tobacco are scouted. Carlson and Wetzstein find that the theory as presented supports the substitution of scouting labor for pesticides.

A one percent tax on the price of pesticides results in a 0.154 percent decrease in the supply of field crops. This finding is contrary to those of Helmers, Azzam and Spilker and Lim, Shumway and Honeycutt. They found that the output of feedgrains increases very slightly when a pesticide restriction is imposed. In contrast, McIntosh and Williams found that wheat production increased in response to a pesticide tax, while corn production decreased. This decrease in the production of field crops could be due to the expected decrease in yields resulting from the restriction on using pesticides.

Since fruit and vegetable production relies greatly on the use of pesticides (especially in the humid South), the impact here is particularly important. The results of this study show a small, statistically significant

negative impact of -0.151 percent. Most likely this small impact is due to continued use of pesticides in fruit and vegetable production, with farmers simply incurring the additional costs imposed by the tax.

A statistically significant decrease in dairy and poultry production was indicated with an impact of -.084 percent. While this impact was statistically significant, it was very small. This tends to indicate that the impact on the dairy and poultry industries would be minimal, with the decrease in production probably resulting from adjustments in prices and quantities in the input and output markets.

The simulation results indicate mild impacts on the profit level. The profit level is reduced by 0.075 percent due to a one percent tax on pesticides. However, this impact was significantly different from zero, indicating that a loss in farm income is a very probable outcome of even a small tax on pesticides.

The general findings of this study were in agreement with those of Helmers, Azzam and Spilker. Contrary to some perspectives, reducing pesticide usage in the United States allows output to be largely unaffected for two reasons: 1) because of significant substitution of other resources (mainly labor), and 2) because of the inelasticity of most of the own-price and cross-price effects.

The model estimated here is quite detailed in terms of inputs and outputs; however, it is still a very general empirical model when compared to real agricultural production. Because of this generality, the model cannot reflect all of the important effects of any specific pesticide restriction policy. It is apparent from this analysis that pesticide taxes or restrictions would impact production patterns in several ways, as well as influencing farm income. While many of the simulated changes in production and input use patterns were not statistically significant, the results demonstrate the prospect for substantial reallocation of inputs across commodities and indicate that producers will make significant adjustments in response to any pesticide restricting policy.

Conclusion

A multi-market dual framework was constructed to describe the production of major agricultural outputs and inputs for Alabama. An econometric model was estimated to quantify the causal relationship, and, by using a simulation technique, the net effects of a hypothetical tax on pesticides under multi-market equilibrium conditions were studied.

Significant negative impacts on output levels and profits were indicated. It is apparent from this analysis that any policy changes such as pesticide taxes or restrictions would have an impact on production patterns.³

This study is a step toward a clearer understanding of the effects of one possible policy on agricultural production in Alabama, both in terms of farm income and output and input levels. The demonstrated crop-specific results make the formulation of any large-scale pesticide reduction policy difficult. The policy process must take into account the diversity of outputs produced and inputs used, as well as geographically specific production patterns, in order to achieve the goals of reducing health risks and increasing water quality and food safety.

Notes

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1. A reviewer made the point that U.S. environmental policy has always been characterized by "command and control" mechanisms such as quotas or bans on inputs or outputs. Although this has been the case historically, a tax-based approach is advocated here. The advantage of using taxes for restricting input use is that they would require relatively less administrative and enforcement efforts than a quota. In addition, because producers are allowed to adjust to the new prices rather than adhering to a mandated level of input use, a tax is a more efficient means of reducing pesticide use.
2. The finding that hired labor is a good substitute for pesticides agrees with previous research by McIntosh and Williams and Lim, Shumway and Honeycutt.
3. A reviewer pointed out that pesticide taxes or quotas might be levied at the national level. This could result in major adjustments in output and input markets, including large changes in output and input prices. Potentially, producers and suppliers of quasi-fixed factors could actually gain from a pesticide quota if, by reducing output, output prices were driven high enough.

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Appendix

Given competitive behavior and regularity assumptions on the production function, a one-to-one correspondence between a set of concave production functions and the set of convex profit functions exists. Thus, it is possible to use Hotelling's lemma to derive product supply and factor demand equations directly from an arbitrary profit function.

An indirect profit function relates profit to prices and fixed (or exogenous) input levels. If profits are normalized by the price of an arbitrary numeraire netput and a second-order Taylor's series expansion is taken, a normalized quadratic profit function results:

$$\Pi = \alpha_0 + \beta'p + \gamma'\theta + \frac{1}{2}p'Bp + \theta'\Gamma p + v, \quad (1)$$

where p is an $(n \times 1)$ vector of netput prices normalized by the price of a numeraire netput; θ is a vector of fixed factors and exogenous variables such as weather; α_0 , β , γ , B , and Γ are parameters to be estimated; and v is a stochastic term representing random departures from profit maximization. The second order terms in the fixed factors were not included in equation (1). The quadratic terms for exogenous inputs are frequently ignored in order to reduce multicollinearity.

The first derivative of (1) with respect to the normalized netput prices gives product supply and factor demand equations (except for the numeraire netput) which are linear in normalized prices and in quantities of fixed inputs. These output supply and input demand functions take the form:

$$x_i = \partial \Pi / \partial P_i' = \beta_i + Bp + \Gamma'\theta + v_i, \quad i=1, 2, \dots, n-1, \quad (2)$$

where the x_i are the netput quantities and the v_i are stochastic error terms.

The demand equation for the numeraire input is obtained by differentiating non-normalized profit with respect to the numeraire price. This equation is quadratic rather than linear in normalized prices:

$$x_n = \alpha_0 + \gamma'\theta - \frac{1}{2}P'BP + v_n, \quad (3)$$

where the subscript n denotes the numeraire netput.

Estimation. The system of input and output equations outlined in (2) and (3) was estimated by nonlinear, seemingly unrelated regression (NSUR). Nonlinear regression was necessary to impose the convexity of the profit function which gives rise to a set of inequality constraints on the parameter matrix (Shumway, Saez and Gottret).

The resulting estimates are consistent with competitive profit-maximizing behavior. Symmetry is imposed by stacking of the data matrix, and homogeneity results automatically from using a normalized profit function. Convexity was tested using the approximation test developed in Shumway, Alexander and Talpaz. Convexity was not rejected at the 0.05 level (F statistics of 0.42 with a critical value of $F_{(105, 255)} = 1.32$), and therefore is imposed. The property of monotonicity was not imposed, but was checked and not found to be violated at any observation.

Simulations of a Pesticide Tax. The estimated elasticities were used to simulate the impact of a tax on pesticides. To express mathematically the simulation approach employed, let x be the vector of profit-maximizing netputs for a given set of prices, let P represent a matrix containing the appropriately stacked right-hand side variables from the netput supply equations given in equations (2) and (3), and let Φ be the vector of parameters from the netput supply equations. Then the expected profit-maximizing production response to a set of prices can be written as,

$$\tilde{x} = P\Phi, \quad (4)$$

where \tilde{x} represents the expected value of x , $\tilde{x} = E(x)$, and (4) follows directly from the assumption that $E(v) = 0$, i.e., the stochastic disturbances have zero expectation. To complete the notation, let \tilde{x}_i the i^{th} expected netput quantity, P_i the corresponding row of exogenous variables, and Φ_i the associated vector of parameters.

The impacts of a pesticide tax are evaluated as percentage changes comparing simulated values with a tax imposed to corresponding values

without a pesticide tax. Let the subscript t denote variables under a pesticide tax regime and the subscript 0 denote the base case solution. Then the vector of percent changes, Δ , has elements of the form:

$$\Delta_i = \frac{\tilde{x}_{it} - \tilde{x}_{i0}}{\tilde{x}_{i0}} = \frac{P_{it}\Phi_i - P_{i0}\Phi_i}{P_{i0}\Phi_i}, \quad i = 1, 2, \dots, n. \quad (5)$$

Due to the nonlinear nature of the percent change formula, the calculation of standard errors or confidence intervals for these results is more complicated than usual. However, approximate variances for the Δ_i can be calculated from the covariance matrix of the estimated parameters in Φ using a Taylor's series expansion as outlined in Dorfman, Kling and Sexton. These approximate variances can then be used to place confidence intervals around the expected percent changes resulting from a given pesticide tax level.