Trade-Off Analysis of Herbicide Withdrawals on Agricultural Production and Groundwater Quality

Shiping Liu, Gerald A. Carlson and Dana L. Hoag*

Abstract

This study examines the trade-off between agricultural production and groundwater contamination potential for ten potential herbicide cancellations. Theoretical and empirical models are developed for estimating losses in consumer and producer benefits in the agricultural commodity market and changes in groundwater quality. Using corn and soybean production in the southeastern Coastal Plain as a study area, the analysis concludes that (1) effects of herbicide cancellations on groundwater quality can be very significant; (2) a cancellation does not guarantee groundwater quality improvement; (3) effects of a multiple cancellation are different from the summation of the effects of independent cancellations; and (4) weed density has a very strong effect on losses to farmers and consumers from cancellations, but output demand and supply elasticities do not.

Key Words: herbicide cancellations, corn/soybean supply shifts, and groundwater quality.

Introduction

Groundwater is an important resource in the United States that is sometimes threatened by contamination from agricultural pesticides (Nielson and Lee 1987; USEPA 1990). More than 70 pesticides have been found in groundwater in 38 states (NGA 1989). One regulatory response to pesticide residuals in groundwater is to suspend or cancel use registrations for those pesticides that may lead to groundwater contamination. Herbicides are an important part of crop production, and cancellation can increase production costs if higher cost herbicides are substituted or if the substitutes are not as effective in controlling weed damage. A cancellation, however, does not always guarantee a reduction in risk of contamination by pesticides. Cancellations sometimes lead to increased human risk through replacement pesticides (National Research Council 1987). The United States Environmental Protection Agency (USEPA) has the responsibility under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) to formulate policies for the use of agricultural pesticides to balance the benefits of use against environmental risks (Osteen and Kuchler 1987; Gianessi et al. 1989).

The social impact of banning, canceling, or voluntary withdrawal of a pesticide can be determined through a detailed analysis of changes in costs and benefits. The costs to society are the consumer and producers' losses (reduced pest control benefits) in the related agricultural

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commodity market.[1] The losses occur because of a downward shift in the supply curve of pesticide-using crops[2] (Just et al. 1987). The benefit (risk reduction) for the society of a pesticide cancellation is an improvement in environmental quality. These could include to protect groundwater, to protect surface water, to protect applicators (for applicator's safety), or to protect wildlife. The focus of this study is groundwater, which is frequently cited as a rationale for cancellation (Batie et al., 1989).

The purpose of this study is to evaluate the impact of hypothetical corn and soybean herbicide bans (cancellations) on crop output, herbicide use, economic returns and potential groundwater contamination. Seven single or multiple cancellations of corn herbicides are considered: Atrazine (atrazine), Banvel (dicamba), Dual (metolachlor), Atrazine and Banvel, Atrazine and Dual, Banvel and Dual, and Atrazine, Banvel and Dual. The three soybean herbicide cancellations considered are: Lasso (alachlor), Dual (metolachlor), and Lasso and Dual. These hypothetical cancellations were chosen because each of these herbicides has been found in groundwater and their pesticide leaching potentials (*PLP*) are high relative to those of other corn and soybean herbicides (Danielson et al. 1993).

The primary contributions of this paper are (1) to provide new methods for computing potential economic costs in agricultural commodity markets of pesticide cancellations and (2) to analyze the effects of both single and multiple herbicide cancellations in corn/soybean markets and groundwater quality for the study region, using detailed data about different weeds by crop. We proceed with a discussion about the calculation of the costs and benefits of a cancellation, followed by a detailed discussion of estimated costs and benefits for the hypothetical cancellations in North Carolina, and three nearby states (Georgia, South Carolina, and Virginia). We conclude by presenting tradeoffs or comparisons of the costs and benefits of various cancellations and a sensitivity analysis to examine major factors influencing the results.

Calculating Costs and Benefits

To conduct a cost-benefit analysis for pesticide cancellation decisions, costs and benefits must be both defined and measured. On the cost side, it is difficult to predict the management response that farmers will undertake to compensate for a pesticide cancellation. The most common assumption is that other competitive pesticides will take a share of the sales of the canceled pesticide proportional to their current share of the market (Grube 1992; Liu, 1993). This method, however, fails to account for the uniqueness of the substitutes for controlling the primary pests targeted by the canceled product or for cropping or output adjustments that would occur. After a detailed comparison and discussion of different methods, Liu (1993) developed an index that will be used here to estimate potential substitute herbicides and their final use levels for the ten herbicide cancellations.

The shifts in agricultural product supply associated with a withdrawal of a herbicide can be decomposed into three parts: shifts due to yield loss, those resulting from an input cost increase, and those attributable to cropping adjustments. The most commonly used method cited in the literature for estimating yield losses and changes in control costs is expert opinion (Kennedy et al. 1975; Taylor et al. 1979; Smith et al. 1990; LAPIAP 1993). One major problem with expert opinion is the wide variation among different experts (Osteen 1992). In addition to this technical problem, the expert opinion method has been challenged in court cases (Jennings 1992; Housenger 1992). However, expert opinion is still the most widely used method in most case studies for estimating yield effects and changes in production costs of herbicide cancellations (Ferguson et al. 1992; Stemeroff et al. 1993). The major reason for the wide usage of expert opinion is limited options (Osteen 1992).

Analytical models, such as the weed competition model called HERB (Modena et al. 1991; Wilkerson et al. 1991; Coble and Mortensen 1992), can be used rather than expert opinion to estimate yield losses. These models account for specific weed species and the differential impacts of alternative pesticides on each weed type. However, they are rarely used because they are designed for the field level, and most FIFRA cancellation studies are regional or national in scope. In this study we do have farm survey information about weeds and pesticide use for four states from a private firm, Maritz Marketing Research, Inc.[3] Therefore, we are able to utilize the HERB weed competition models together with weed specie information to estimate shifts in supply due to yield changes for a region.

On the benefit side, it is difficult to obtain a precise estimate of physical environmental quality improvements with a pesticide cancellation because so many factors vary across cropland sites—chemical-physical and biological properties of herbicides, properties of soils, agricultural practices, and climatic and hydrogeologic conditions—and affect groundwater contamination potential (Cheng and Koskinen 1986; Helling and Gish 1986; Jury et al. 1987; EPA 1987; Nielsen and Lee 1987; Weber 1990; Weber and Warren 1993). Lack of knowledge about factors affecting pesticide leaching potential and the complexity of the process make it difficult to make precise estimates of the content of groundwater pollution. Several indices and models have been developed, such as GUS, DRASTIC, *PLP*/SLP matrix, screening models, simulation models, metamodels and Ground Water Contamination Potential (GWCP) (Aller et al. 1986; Gustafson 1989; Jury et al. 1987; Weber 1990; Hoag and Hornsby 1992; Bouzaher et al. 1993; Danielson et al. 1993; Weber and Warren 1993), but none of these has emerged as clearly superior to others. To be suitable for measuring potential groundwater quality improvement by a pesticide cancellation for most economic analyses, a model that is structurally simple and physically meaningful is desired. After a careful comparison, the pesticide leaching potential model *PLP* (Weber and Warren, 1993) was used to estimate groundwater pollution potential from pesticide uses in large scale (four states in the Southeastern Coastal Plain—Georgia, North Carolina, South Carolina and Virginia).

Cancellation Costs

The major changes in private production and consumption costs due to regional or national pesticide cancellations are decreases in crop yield and increases in pesticide material and application costs. These two effects can be expressed through shifts in the supply curve due to the cancellation. For simplicity, several assumptions are made. First, there are n identical farmers involved in agricultural production of corn or soybeans. Second, both the pre- and post-regulation marginal cost functions (short-run supply functions) are linear in the range relevant for the cancellations (Kopp and Krupnick 1987; Gianessi et al. 1988; Danielson et al. 1993). Third, a regional level demand function is linear. With these assumptions, supply curves before and after cancellations can be obtained by using the following quadratic profit-maximization function

$$\begin{aligned} Max\ \pi &= P{\cdot}Q - C(Q) \\ &= P{\cdot}Y{\cdot}A - m{\cdot}Y{\cdot}A \\ &\quad - 0.5{\cdot}k{\cdot}(A{\cdot}Y)^2 - R(A)\,, \end{aligned} \tag{1}$$

where

Y is yield per acre,
A is acres used for the production,
P is the output price,
Q is the output ($=Y^*A$),
m and k are coefficients related to marginal cost of production, and
$R(A)$ is a fixed cost such as land rent.

Taking the derivative of Equation 1 with respect to Q yields the first-order condition: marginal cost (MC) is equal to marginal benefit (MB)

$$\begin{aligned} MB &= P = MC_0 \\ &= k{\cdot}Q + m \\ &= k{\cdot}(A{\cdot}Y) + m\,. \end{aligned} \tag{2}$$

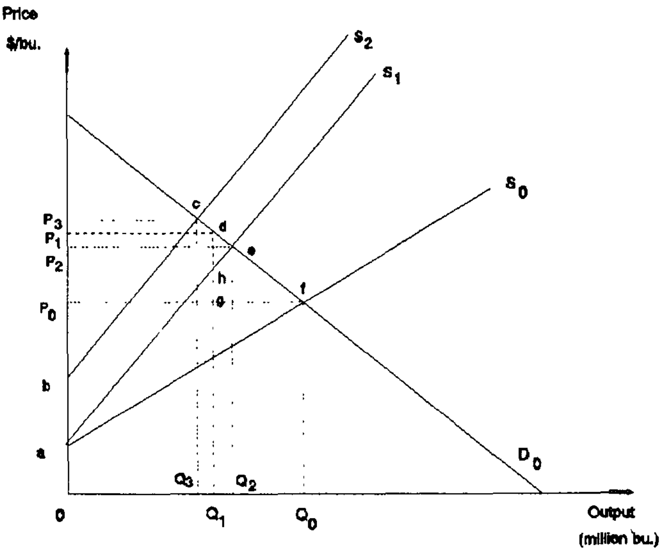
This MC_0 equation can be used to represent the initial short-run supply curve (S_0) in Figure 1; k is the slope of initial supply curve S_0 and m is the intercept. The demand function represented by D_0 in Figure 1 can be expressed as

$$Q = \alpha - \beta{\cdot}P\,, \tag{3}$$

where
α and β are the intercept and slope of the demand curve.

The effects of a herbicide cancellation are separated into two parts: average control cost change and yield loss. Considering yield loss first, marginal cost would increase and the supply curve shift left (represented as S_1 in Figure 1) with the loss of a herbicide. The ratio of k_1 (slope of curve S_1) to k is equal to Y_0 (the average yield per acre before a regulation) over Y_1 (the average yield per

Figure 1. A Simple Model for Measuring Welfare Loss in a Given Agricultural Product Market from a Herbicide Cancellation.



acre after regulation). The new equilibrium corresponding to this special case will be (P_2, Q_2) in Figure 1.

If weed control cost for herbicide materials and application costs also increase, the supply curve would shift even further to the left, to S_2. This curve can be determined by S_1 and the herbicide cost change. The vertical distance between S_1 and S_2 will equal the change in herbicide cost (ab in Figure 1); given linearity, it can be represented with a change in the intercept. If the change in average material cost per output unit (bushel) is Δc, then the new supply curve S_2 can be expressed as

$$S_2 = MC_2 = k_1 \cdot Q + m + \Delta c$$
$$= k \cdot \left(\frac{Y_0}{Y_1} \right) \cdot Q + m + \Delta c \qquad (4)$$

Δc can be positive or negative. Material costs will increase if a producer substitutes more expensive herbicides to maintain weed control, however, costs will fall if the grower reduces weed control objectives in response to the ban.

The demand and supply equations can be set equal and solved for two unknowns—new equilibrium price (P_3) and quantity (Q_3). Comparing Q_3 with $Q_1(Y_1{*}A_0)$, it is possible to determine whether or not more land would be used for producing the agricultural crop under study. If Q_3 is greater than Q_1, then more land should be used for production because the price increase was sufficient to offset the yield loss and control cost increase. Otherwise, some land used for the production of, say, corn, would be shifted to production of another commodity, say, soybeans, if land and other input prices do not change because of a herbicide cancellation (Taylor and Howitt in Carlson, Zilberman, Miranowski, p. 149-150, 1993).

Yield Loss

Average percentage reduction in yield ($\%\Delta Y$) can be estimated with

$$\%\Delta Y = \frac{\Delta Y}{Y_b} = \frac{Y_b - Y_a}{Y_b} = \frac{\sum_{i=1}^{i=I}\sum_{j=1}^{j=J}(S_{ij}^b - S_{ij}^a)\cdot[1 - D_{ij}/100]}{\sum_{i=1}^{i=I}\sum_{j=1}^{j=J} S_{ij}^b\cdot[1 - D_{ij}/100]}, \tag{5}$$

where

ΔY is the average change in yield following a herbicide cancellation,

Y_b is the average yield per acre before the herbicide cancellation,[4]

Y_0 is the expected weed-free yield (Taylor et al. 1979),

Y_a is the average yield per acre after the herbicide cancellation,[5]

S_{ij}^a is the share of post-regulation acre treatments of pesticide i for weed j,

S_{ij}^b is the share of pre-regulation acre treatments of pesticide i for weed j, and

D_{ij} is the percent damage (yield reduction) after the treatment.

S_{ij}^b, S_{ij}^a, and D_{ij} can be estimated from study area data. The values of S_{ij}^b were obtained for all major herbicides and all major weeds from the Maritz survey information. If a herbicide is to be canceled, its post-regulation share is zero. If a herbicide is a potential substitute for the herbicide to be canceled, its post-regulation share is unknown. The shares of potential substitute herbicides for a given cancellation can be estimated by

$$S_{ij}^a = S_{ij}^b + SH_i \cdot S_{Aj}^b, \tag{6}$$

where

S_{ij}^a is the share of post-regulation acre treatments of pesticide i for weed j,

S_{ij}^b is the share of pre-regulation acre treatments of pesticide i for weed j,

SH_i is the substitute percentages of herbicide i for the one to be canceled, which was estimated with the index method (Liu 1993),[6] and

S_{Aj}^b is the share of pre-regulation acre treatments of pesticide A (to be canceled) for weed j.

In equation 6 we assume that the substitutability of herbicide i for A is the same across all weed species. It is also assumed that the total area treated by the herbicide to be canceled would remain as treated area with various substitute herbicides. Mechanical control and cultivation are considered in this study, but they are not stand alone replacements. This is accomplished by allowing cultivation to be part of each herbicide option i, and effecting efficacy and costs.

Yield loss due to weeds can be estimated by a competitive load index (Modena et al. 1991; Coble and Mortensen 1992). The competitive load of weed specie j after treatment with pesticide i (TCL_{ij}) can be estimated by

$$TCL_{ij} = [1.0 - K_{ij}(X)]\cdot N_{jt}\cdot CI_j, \tag{7}$$

where

$K_{ij}(X)$ indicates the proportion of weed species j killed by herbicide i with dosage X, referred to as efficacy,

N_{jt} is the amount of weed j present per unit of area at time t, and

CI_j is the competitive index for each weed species, it is estimated based on experimental data by weed scientists Coble and Mortenson, 1992).

The herbicide efficacy of specific weed species treated at different times in the season was obtained from weed control manuals prepared by weed scientists in each state. The target weed species in North Carolina (about 40 species) were obtained from the Maritz farmer survey. Frequencies for low, medium and high weed densities in North Carolina were estimated for each weed species by weed scientists at North Carolina State University. The scientists were asked to think of low densities as a good year (one in 20 years) and high densities as the worse case (one in 20 years).

Using TCL_{ij} in Equation 7, the percent of yield loss after use of herbicide i against weeds j for corn can be calculated as (Modena et al., 1991):

$$D_{ij} = \begin{cases} 0.14 \cdot TCL_{ij} & \text{if } TCL_{ij} \le 1 \\ 0.14 + \dfrac{0.14 \cdot (TCL_{ij} - 1)}{[1 + 0.002333 \cdot (TCL_{ij} - 1)]} & \text{if } TCL_{ij} > 1 \end{cases} \tag{8}$$

The percent of yield loss after use of herbicide i for soybeans can be calculated as :

$$D_{ij} = \begin{cases} 0.5 \cdot TCL_{ij} & \text{if } TCL_{ij} \le 50 \\ 25 + \dfrac{55 \cdot (TCL_{ij} - 50)}{(TCL_{ij} + 60)} & \text{if } TCL_{ij} > 50 \end{cases} \tag{9}$$

Yield losses for each cancellation and each weed density (high, medium and low) were based on the 12-year (1979-1990) average corn yield (76.25 bushels/acre) and the weed competition index. In addition to weed pressure, average yield loss depends on the efficacy of the herbicide to be banned relative to its substitutes and the percentage of fields treated with the herbicide to be canceled. Average yield losses across North Carolina ranged from 0.00 (0.00 percent) bushels per acre for a Banvel ban with low weed pressure to 2.16 (2.84 percent) bushels per acre for an Atrazine, Banvel and Dual ban with high weed pressure (table 1).[7] The largest average yield loss for a single herbicide ban was for Atrazine (1.56 bushels/acre or 2.05 percent). The index method accounts for the weeds being treated by the banned herbicide and the efficacy of the substitute herbicides on those weeds. Multiple year or weed dynamic effects are not considered because of frequent crop rotation in the study area.

The same procedure is used for the three soybean bans. Using 12-year (1979-1990) soybean average yield (23.92 bushels/acre) as the yield before the cancellations, average yield losses across North Carolina ranged from 0.01 bushel per acre (0.04 percent) for the Dual ban with low weed pressure to 1.22 bushels per acre (5.11 percent) for both Lasso plus Dual ban with high weed pressure (table 2). The largest average yield losses for a single herbicide ban are for Lasso. The average yield loss per acre is 0.78 bushel with high weed pressure. This is about 3.26 percent of the pre-regulation average yield.

Control Cost Changes

Another component in estimating supply shifts for proposed pesticide bans is cost changes in pesticide materials. Average material cost change per acre ($\Delta C = \Delta C$ * average yield per acre) can be calculated by

$$\Delta C = \sum_{i=1}^{i=I} \sum_{j=1}^{j=J} C_{ij} \cdot [S_{ij}^{b} - S_{ij}^{a}] \ , \tag{10}$$

where

C_{ij} is the average cost per acre treatment with herbicide i for weed j,

S_{ij}^{a} is the post-cancellation acreage shares for pesticide i with weed j, and

S_{ij}^{b} is the pre-cancellation acreage shares for pesticide i with weed j.

The C_{ij} material costs were obtained from the Maritz farm survey; it measured expenditure per acre treatment for each herbicide applied at a given time used to control each specific weed species.

Estimated cost changes corresponding to the seven corn herbicide cancellations are given in table

Table 1. Average Yield Loss, Herbicide Material Cost Increase and Benefit Loss per Acre for the Seven Corn Herbicide Cancellations in North Carolina

		Atrazine Ban	Banvel Ban	Dual Ban	A&B Ban	A&D Ban	B&D Ban	A,B&D[a] Ban
Weed Density		Percent Reduction in Yield						
Low		0.46	0.00	0.02	0.61	0.47	0.09	0.62
Medium		0.82	0.01	0.09	1.12	0.86	0.24	1.16
High		2.05	0.02	0.11	2.78	2.09	0.47	2.84
	Initial	Post-ban Herbicide Material Cost ($/Acre)						
Cost	6.75	7.87	6.68	6.63	7.84	7.81	6.61	7.80
Cost Increase		1.12	-0.07	-0.12	1.09	1.06	-0.14	1.05
Weed Density		Benefit Loss in Corn Market ($/Acre)						
Low		1.99	-0.06	-0.08	2.24	1.96	0.04	2.22
Medium		2.67	-0.05	0.04	3.22	2.69	0.31	3.25
High		5.03	-0.03	0.09	6 47	5.06	0.75	6.50

a A = Atrazine
B = Banvel
D = Dual
A&B = Atrazine and Banvel
A&D = Atrazine and Dual
B&D = Banvel and Dual
A, B&D = Atrazine, Banvel, and Dual

Table 2. Average Yield Loss, Herbicide Material Cost Increase , and Benefit Loss per Acre for the Three Soybean Herbicide Cancellations in North Carolina

		Lasso Ban	Dual Ban	Lasso and Dual Ban
Weed Density		Percent Reduction in Yield		
Low		0.36	0.04	0.10
Medium		1.27	0.22	1.42
High		3.26	0.74	5.11
	Initial	Post-ban Herbicide Material Cost ($/Acre)		
Cost	9.59	9.35	9.46	9.14
Cost Increase		-0.24	-0.13	-0.45
Weed Density		Benefit Loss in Corn Market ($/Acre)		
Low		0.29	-0.08	-0.30
Medium		1.64	0.19	1.65
High		4.63	0.96	7.24

1. Both average herbicide material cost per treatment acre and average cost reduction per acre are given.[8] The net change depends on the prices of substitute herbicides and the level of control the grower strives to achieve. Changes in average herbicide material costs range from −$0.12 per acre for the Dual ban to $1.12 per acre for the Atrazine ban. Average material costs are lower after Dual bans because Dual is a relatively expensive ($11.42 per acre), and its substitutes are relatively cheaper ($3.62 for Atrazine, $9.58 for Lasso, and $3.89 for Princep) (Liu 1993). A ban on Atrazine yields the opposite result as the Dual ban. The changes in absolute value also depend on the initial shares of two herbicides to be canceled. For example, the relatively high percentage change in average control material costs for the Atrazine ban is due in part to a big initial share of Atrazine (31.17%). The relatively small percentage change in average control material costs for the Dual ban is because of a small initial share of Dual (2.97%).

Results for material cost reductions per acre on soybeans in North Carolina range from a −$0.45 to −0.13 (table 2). Herbicide material costs decrease for either of the two single bans or the ban of both together because Lasso and Dual are relatively expensive herbicides compared to their substitutes.

Economic Assessment of Benefit Losses

Knowing changes in price and quantity of output, it is possible to estimate the social welfare losses from a regional herbicide cancellation on corn and soybean consumption and production. The loss can be approximately estimated by (Griliches, 1957; Danielson et al., 1993)[9]:

$$\Delta[CS+PS] = \Delta Q \cdot (1+0.5 \cdot \Delta P) \cdot P_0 \ , \qquad (11)$$

where

$\Delta[CS+PS]$ is the local changes in consumer plus producer surplus per acre,

ΔQ is the change in yield per acre plus changes in control costs in bushel equivalents,

P_0 is the base corn price, which for the 12-year period (1979-1990) was $2.45 per bushel,[10] and

ΔP is the regional output price change from the particular herbicide cancellation in percent.[11]

All variables can be estimated from the changes in control cost and yield outlined in previous sections except for the change in output price (ΔP). To estimate the change in price, it is assumed that the changes in both price and quantity before and after each cancellation are limited. Therefore, both linear function and constant elasticity can be assumed.[12] With these assumptions, the solution for P_3 is[13]

$$P_3 = P_0 + \left[1 - \frac{1+\frac{\eta}{E}-\Delta c \cdot \frac{\eta}{E}}{1+\frac{\eta}{E} \cdot \frac{Y_0}{Y_1}} \right] \left[\frac{P_0}{\eta} \right] \qquad (12)$$

where

E is the regional supply elasticity of corn or soybeans,

η is the absolute value of the regional demand elasticity of the commodity, and

all other variables are defined as in previous equations.

Once P_3 is estimated, the total percentage change in price can be estimated. We use information about average yield loss (ΔC) in North Carolina and assume that the percentage change in yield from each of the cancellations for a given crop is the same at every location in the four state region. The same assumption is made for the changes in herbicide material costs. With these assumptions, Equation 12 can be used to calculate the price of output after cancellations and to compute the consumer and producer loss in benefits for North Carolina.[14]

The estimated losses in consumer plus producer surplus in North Carolina for the seven corn herbicide bans, under low, medium and high weed density, are given in the lower part of table 1. The producer plus consumer surplus losses computed by this method reflect local herbicide use patterns and weeds to give local yield and control cost changes rather than national changes for each of the ten hypothetical cancellations. For corn production, these total cost changes range from less than −$0.06 per acre for a Banvel ban with low weed density to $6.50 per acre for the Atrazine, Banvel and Dual ban with high weed density. We used a demand elasticity of −.21 and a supply elasticity of .48 based on Gardiner et al. (1989), but found that our total surplus changes were not sensitive to demand and supply elasticity changes.[15] All losses are expected to be positive. Negative values in table 1 were not significantly different (statistically) from zero. Only primary weed species in fields are considered in this study due to limited density information. This omission explains the small negative values in table 1.

From table 1, it is clear that $\Delta(CS + PS)$ is increased as weed density increases. This is expected because herbicide efficacy is more important when there are high weed densities than for low weed densities. The largest single benefit loss was for Atrazine. However, multiple cancellations had stronger impacts than canceling all related herbicides independently. For example the Atrazine and Banvel bans alone result in losses of $5.03 and −.03, or a sum of $5.00, but the A&B column shows a loss of $6.47 per acre.

Similar computations were made for the three soybean herbicide cancellations and are given in table 2. The basic findings are similar to those for corn herbicide cancellations; production loss increases as weed density increases. The effects of banning Lasso and Dual together is stronger than banning both of them independently with high weed density. The elasticities used in the soybean weed calculation are based on Gardiner et al.'s (1989) estimates for soybeans of −0.42 for demand and 0.60 for supply. Again, changing these values to reflect regional demand and supply elasticities does not significantly alter results.

As discussed in the previous section, whether a cancellation makes society better or worse off depends on both risk reductions and losses to consumers and producers. The results estimated in this section are just the losses in benefits in the agricultural commodity markets. Potential groundwater quality improvement from a herbicide cancellation is another benefit that could enter into assessments of whether a herbicide should be canceled.

Changes in Groundwater Quality

One of the primary purposes of herbicide cancellations has been to improve groundwater quality. As discussed in previous sections, however, a herbicide cancellation does not necessarily guarantee groundwater quality improvement. This depends on the groundwater pollution potential of the herbicide to be canceled and those of its substitutes. Given an estimate of potential substitutes for several potential cancellations, the changes in groundwater quality can also be estimated. One way to estimate the groundwater quality improvement due to herbicide cancellations is to estimate changes in pesticide leaching potential, especially for large-scale estimates (state, regional or national levels) when it is almost impossible to include soil information into the calculations. Changes in pesticide leaching potential at the state level were estimated by using (Weber 1990; Danielson et al. 1993; Weber and Warren 1993):

$$\Delta PLP\% = \Delta\frac{PLP}{PLP}\cdot 100 = \frac{\sum_{i=1}^{i=I} S_i^b \cdot PLP_i - \sum_{i=1}^{i=I} S_i^a \cdot PLP_i}{\sum_{i=1}^{i=I} S_i^b \cdot PLP_i}\cdot 100, \qquad (13)$$

where

PLP_i is pesticide leaching potential score for herbicide i,

S_i^b is herbicide i's treatment share before the cancellation, and

S_i^a is herbicide i's treatment share after the cancellation.

The pesticide leaching potential (PLP) was calculated as:

$$PLP = T_{1/2} \cdot R \cdot F/Koc, \qquad (14)$$

where

PLP is herbicide leaching potential,

Koc is pesticide retention by soil index,

$T_{1/2}$ is the half-life of pesticide in the field for the region,

R is the rate of pesticide applied for the region, and

F is the fraction of pesticide hitting the soil, which depends on crop canopy size (Weber and Warren 1993; Danielson et al. 1993).

One of the advantages of this type of index is that it is very simple and can be understood easily by farmers. Also, it can be used easily to estimate potential change in leaching for large geographical areas for potential cancellations (Danielson et al., 1993). The fraction of pesticide hitting the soil and the application rate give a precise estimate of the amount of pesticide hitting the soil. One of the disadvantages of this model is that it still does not give an absolute estimate of the amount or the percent of a pesticide that will reach groundwater. This is a relative measure of leaching across herbicides.

The reductions in *PLP* corresponding to the seven corn and three soybean herbicide cancellations are estimated for four states and given in tables 3 and 4.[16] The percentage reductions in *PLP* are quite different among different cancellations in each state and among different states for a given cancellation. The changes in *PLP* are different within each state because initial shares, substitutability of other herbicides, and leaching potentials are different for each herbicide. The percent changes in *PLP* vary for different states because initial shares and substitute herbicides are different for different states. For example, the percentage changes in *PLP* are much larger for the cancellation of Atrazine than those for the cancellation of Banvel for each state. This is because the initial share of Atrazine for each state is much larger than that of Banvel. For the cancellation of Atrazine, the percentage change in Georgia is much larger than that in Virginia because the share of Atrazine in Georgia is 53.06 percent compared to 30.38 percent in Virginia (Liu, 1993). In addition, there are different substitute herbicides for the same cancellation in each of the states. The high percentages of substitution of Princep for Atrazine in Virginia leads to very limited changes in *PLP* because Princep's *PLP* is almost as high as Atrazine's.

The range of reduction in *PLP* among all states for the seven corn herbicide bans is from −2.29 to 75.61 percent and from −9.20 to 60.63 for the three soybean bans, depending on the assumptions used for estimating the shares of substitute herbicides. The largest *PLP* reduction from a single herbicide cancellation is for bans of Atrazine. The smallest *PLP* reduction is for bans of Dual. The *PLP* even increases in three of four states for the ban of Dual. This change is not statistically significant but it is in the direction of illustrating the National Research Council's conclusion that: "Cancellations sometimes lead to increased human risk, as replacement pesticides are used at high rates." Whether a cancellation will increase or decrease groundwater pollution potential (or *PLP*) depends on the initial shares of the product to be canceled and its substitutes as well as on the relative pesticide leaching potential of each related pesticide.

From tables 3 and 4, it is clear that the both cost and *PLP* effects of the ban of several herbicides at the same time are not equal to the sum of the effects of each herbicide ban considered independently. The major reason for this is that potential substitute herbicides are different across herbicide products. If two products are canceled they can no longer act as replacements, and total effects are larger with multiple cancellations.

Trade-offs of Costs and Benefits of Potential Herbicide Cancellations

Knowing the potential benefit losses in agricultural markets and the potential benefits gained from environmental quality improvement because of the possible ban of a herbicide is important in making decisions to cancel herbicides. However, studying these effects separately, as do many studies, does not allow comparisons of cost and benefit changes including herbicide substitutions, and thus may not accurately reflect economic or environmental impacts (Ferguson et al. 1992). According to FIFRA, decision makers must formulate policies regarding the use of agricultural pesticides so as to balance the benefits against environmental risks. Therefore, both Δ $(PS + CS)$ and changes in *PLP* must be analyzed together.

Of primary interest to policymakers is the extent to which the costs of pesticide cancellations translate into a reduction in groundwater contamination potential or pesticide leaching potential. Changes in the *PLP* are not easily converted into changes in monetary values and therefore cannot be directly integrated into cost/benefit analysis. However, the change in *PLP* can be directly compared to changes in costs and benefits from a cancellation. The results for North Carolina are expressed graphically in Figures 2 and 3, which show the relationship between average losses of benefits per acre and the estimated percentage reductions in pesticide leaching potential for the seven corn herbicide cancellation and the three soybean herbicide cancellations.

Table 3. Corn Herbicide Leaching Potential (x100) and Percentage Changes

State	Initial	Ban A	Ban B	Ban D	Ban A&B	Ban A&D	Ban B&D	Ban A,B&D[a]
	Herbicide Leaching Potential Before and After Cancellations							
GA	73.70	25.30	72.75	74.96	22.73	20.71	74.01	17.97
NC	63.88	36.38	62.68	63.74	34.59	32.52	62.54	31.29
SC	71.87	41.60	71.35	72.34	40.94	39.31	71.83	38.80
VA	78.84	59.32	77.12	80.65	57.10	57.26	78.93	55.23
	Percent Reduction of Herbicide Leaching Potentials							
GA		65.67	1.29	-1.70	69.16	71.90	-0.41	75.61
NC		43.06	1.89	0.22	45.85	49.09	2.11	51.02
SC		42.11	0.71	-0.66	43.03	45.30	0.05	46.01
VA		24.76	2.19	-2.29	27.57	27.37	-0.11	29.95

a A = Atrazine
B = Banvel
D = Dual
A&B = Atrazine and Banvel
A&D = Atrazine and Dual
B&D = Banvel and Dual
A. B&D = Atrazine, Banvel, and Dual

Table 4. Soybean Herbicide Leaching Potential (X100) and Percentage Changes

State	Initial	Lasso Ban	Dual Ban	Lasso and Dual Ban
	Herbicide Leaching Potential Before and After Cancellations			
GA	12.29	10.55	10.85	8.72
NC	16.61	13.43	15.43	9.09
SC	13.57	11.39	11.57	8.74
VA	23.24	12.67	25.37	9.15
	Percent Reduction of Herbicide Leaching Potentials			
GA		14.16	11.72	29.11
NC		19.14	7.12	45.26
SC		16.06	14.71	35.58
VA		45.46	-9.20	60.63

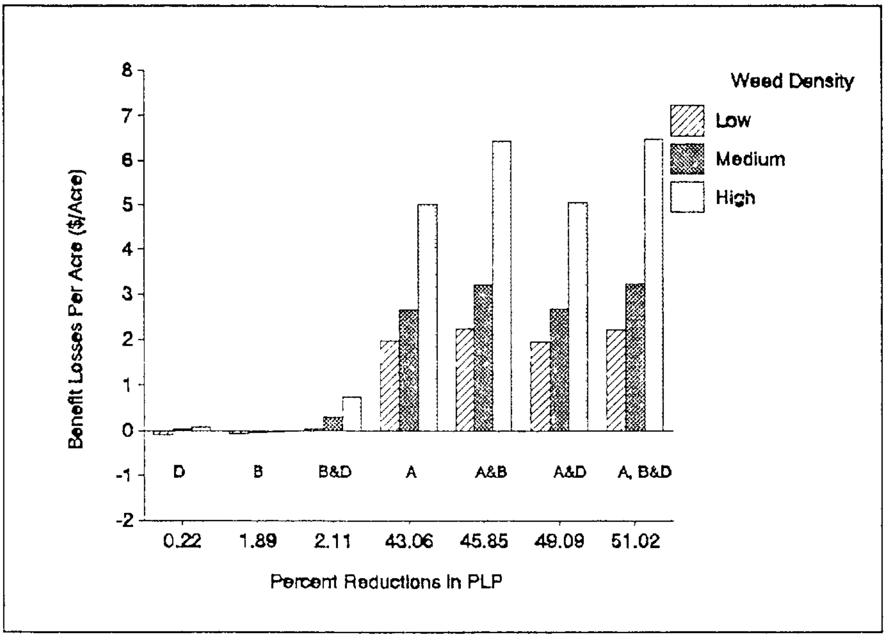
Losses in benefits per acre increase as weed density increases for each herbicide cancellation. The basic tendency is an increase in the reductions in *PLP* associated with an increase in benefit losses, but there are some notable exceptions. As shown in Figures 2 and 3, Atrazine and Dual bans lead to larger reductions in groundwater contamination potential than do Atrazine and Banvel bans, but the benefit losses for Atrazine and Dual bans are less than those for Atrazine and Banvel bans.

Summary and Conclusions

Ten hypothetical herbicide bans, seven for corn and three for soybeans, were evaluated utilizing herbicide and weed data in North Carolina. Both the impact on producer and consumer surplus and the environmental impact on groundwater contamination potential were examined. For the seven corn herbicide cancellations, producer and consumer benefit losses per acre ranged from −\$0.08 to \$6.50 per acre in North Carolina, depending on weed density and replacement herbicides. For the three soybean herbicide cancellations, producer and consumer benefit losses per acre ranged from −\$0.30 to \$7.24. For the seven corn herbicide cancellations, pesticide leaching potential (*PLP*) reductions (used as measurements of groundwater quality improvement) in North Carolina ranged from 0.22 to 51.02 percent. Reductions in *PLP* for the three soybean herbicide cancellations ranged from 7.12 to 45.26 percent. At the state level, the reductions *PLP* among four states (Georgia, North Carolina, South Carolina and Virginia) ranged from −2.29 to 75.61 percent for the seven corn herbicide cancellations and ranged from −9.20 to 60.63 for the three soybean herbicide cancellations.

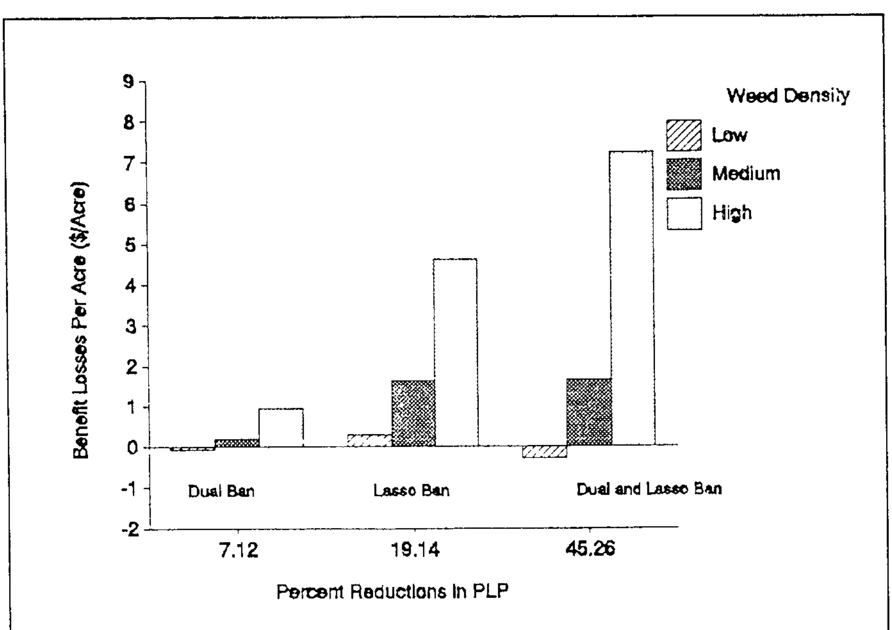
The effects of herbicide cancellations on groundwater quality can be very significant, but a cancellation does not guarantee groundwater quality

Figure 2. Relative Changes in PLP and per Acre Consumer Plus Producer Losses in Benefits for Seven Hypothetical Corn Herbicide Cancellations in North Carolina.



A = Atrazine Ban
B = Banvel Ban
D = Dual Ban
A&B = Atrazine and Banvel Ban
A&D = Atrazine and Dual Ban
B&D = Banvel and Dual Ban
A, B&D = Atrazine, Banvel, and Dual Ban

Figure 3. Relative Changes in PLP and per Acre Consumer Plus Producer Losses in Benefits for Three Hypothetical Soybean Herbicide Cancellations in North Carolina.



improvement, and the effects of a multiple cancellation are different from the summation of the effects of independent cancellations. Therefore, if there are several herbicides under consideration for cancellation, effects of both single and multiple cancellations can be studied as illustrated in this study. Weed density has very strong affects on benefit losses, but agricultural output demand and supply elasticities do not in the Southeast. To improve the precision of welfare loss estimates in agricultural commodity markets due to herbicide cancellations, it is necessary to study the yield and cost effects in each state because of the heterogeneity of weed conditions across states. The tradeoff methodology developed and applied to the Southeast could be applied to other regions and crops.

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Endnotes

1. For feed grains, there are price support programs that operate to hold producer prices to about 20 percent above world equilibrium prices (Gardner 1987). This distortion together with set-aside requirements can alter the changes in producer and consumer surplus from an herbicide cancellation. Explicit accounting for the independent impacts of price supports for corn are beyond the scope of this study. See Lichtenberg and Zilberman (1986) for methods.

2. If a pesticide withdrawal results in a quality improvement of the product---for example, pesticide residuals in food are decreased with cancellation---then demand for the product could increase and it is possible that consumers could gain from a pesticide cancellation. Therefore, there could be consumer gains in the agricultural commodity market from a pesticide cancellation (Liu and Carlson 1992).

3. This is a geographically stratified, random sample of farmers chosen to give accurate estimates of pesticide use at the crop reporting district level of aggregation. For our four states and four years (1985-1988), on average there are about 770 farmers for corn and 994 farmers for soybeans sampled per year. Since data from this survey is annually sold to most pesticide companies, it is judged to be reliable survey.

4. Y_b can be estimated as

$$Y_b = \sum_{i=1}^{i=I} \sum_{j=1}^{j=J} Y_{ij} \cdot S_{ij}^{b} = Y_0 \cdot \sum_{i=1}^{i=I} \sum_{j=1}^{j=J} S_{ij}^{b} \cdot [1 - D_{ij}/100] \ .$$

5. Y_a can be estimated as

$$Y_a = \sum_{i=1}^{i=I} \sum_{j=1}^{j=J} Y_{ij} \cdot S_{ij}^{a} = Y_0 \cdot \sum_{i=1}^{i=I} \sum_{j=1}^{j=J} S_{ij}^{a} \cdot [1 - D_{ij}/100] \ .$$

6. The relative substitution index that reflects the ability of one herbicide (i) to substitute for another to be canceled (b) is:

$$IND_i = \sum_{w=1}^{w} \sum_{w=1}^{T} A_{iwt} \cdot \frac{EFF_{iwt}}{Cost_{iwt}} \cdot \frac{A_{bwt}}{A_b} \ ,$$

where, Eff_{iwt} is the weed control efficacy of herbicide i used to treat weed specie w at application time t; $Cost_{iwt}$ is the herbicide material cost per acre treatment for the same herbicide i, weed species w and time t; A_{iwt} are the acre treatments of herbicide i and A_{bwt} are the treatment acres for herbicide b against these same weeds at time t; and A_b is the sum of all treatments of herbicide b across all times and weeds for this crop. Treatment shares (SH_i) for any combination of herbicides can then be formed by:

$$SH_i = IND_i \Big/ \sum_{i=1}^{k} IND_i \ ,$$

where k is the total available set of substitute herbicides (Liu, 1993).

7. Probably only medium and high weed densities make sense because only primary weed species are considered in the calculation. Potential damage from secondary weeds is ignored because of information limitation.

8. A positive value indicates that control cost will increase if a herbicide is canceled and a negative value indicates that herbicide material cost will decrease.

9. The losses to society due to "disappearance" of hybrid were estimated by Griliches (1957) with both long-run and short-run supplies of corn (horizontal and vertical supply curves). The ratio of two estimates is 1.07. Therefore, the difference between these two extreme assumptions is very limited. The loss due to a herbicide cancellation is approximately calculated by the case with a vertical supply curve.

10. The Southeast has a regional market for corn and soybeans which is influenced by many regional factors, and is for convenience in this study assumed to be separate from that of the remainder of the United States (Strobel et al., 1992).

11. A regional cancellation might have minor affects on national commodity prices since these are small shares of national and international markets. However, for regional cancellations in the regional corn market there can be larger affects.

12. Linear demand and supply functions are not constant elasticity demand and supply functions. However, if the changes in price and quantity are very limited, the elasticities of demand and supply can be considered approximately constant within a limited range for the linear functions.

13. With these assumptions and using difference to replace differential, the following two equations can be derived

$$K\cdot(Q_0-Q_3) = \left[\frac{Q_0-Q_3}{Q_0}\right]\left[\frac{P_0}{E}\right],$$

and

$$P_3-P_0=\left[\frac{Q_0-Q_3}{Q_0}\right]\left[\frac{P_0}{\eta}\right],$$

These two equations are derived based on the geometry in Figure 1 and the definitions of the demand and supply elasticities. Solving these two equations and equations 3 and 4 simultaneously, four unknowns, K, M, P_3 and Q_3, can be expressed as functions of η, E, P_0, Q_0, Y_0, Y_1, and Δc.

14. Supply and demand elasticities, base yields, weed types and herbicide use patterns are similar over the study region, however, there are some differences. Sensitivity of $\Delta[CS + PS]$ results to weed density as shown below led us to present yield, material cost and benefit loss figures specific to North Carolina since we did not have starting weed density figures for the three other states.

15. For sensitivity analysis purposes, three elasticities of demand and supply are used in the analysis. The demand elasticities for corn used in calculation are −0.21, −1.21, and −2.21. Three supply elasticities used in analysis are 0.28, 0.48, and 0.68. Based on this analysis, elasticity effects are limited relative to total effects. The largest difference due to elasticities of demand and supply is only $0.16 per acre. (Detailed results are available from authors.)

16. Separate estimates by state only require starting herbicide use and substitution patterns. Therefore, state level estimates for the four separate states are presented.