RISK-COST-BENEFIT ANALYSIS OF ATRAZINE IN DRINKING WATER FROM AGRICULTURAL ACTIVITIES AND POLICY IMPLICATIONS

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ABSTRACT

This study provides an improved methodology for investigating the trade-offs between the health risks and economic benefits of using atrazine in the agricultural sector. Regression models are developed to predict finished water atrazine concentration in high-risk community water supplies in the US. The predicted finished water atrazine concentrations are then incorporated in a health risk assessment. The computed health risks are compared with total economic surplus in the US corn market for different atrazine application rates using estimated demand and supply functions. Analysis of different scenarios with consumer price premiums for chemical-free and reduced-chemical corn indicate that banning the use of atrazine may have adverse economic impacts. However, if the society is willing to pay a price premium, risks can be reduced without a large reduction in the total economic surplus and net benefits may be higher. The results also show that this methodology provides an improved scientific framework for future decision-making and policy evaluation in pesticide management, especially when better regional and national data become available.

Key words: Atrazine, pesticides, health risk, demand and supply, total surplus, water quality

1. INTRODUCTION

Concerns over the potential health and environmental hazards of chemicals have resulted in several investigations and research studies of commonly used pesticides (for example, see Gray and Hammit, 2000 and Paul et al., 2002). Pesticides are regulated under the Food Quality Protection Act (FQPA) as amended in 1996. The reforms of this Act have amended the Federal Food, Drug, and Cosmetic Act (FFDCA) and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). One of the important changes in the FFDCA is a clause that requires uniformity of state regulations. Important amendments under FIFRA include reviewing pesticide registration at least every 15 years, expediting registration of reduced-risk pesticides, and promoting the use of integrated pest management (http://www.pestlaw.com/x/law/HR1627.htm).

One of the most heavily used pesticides in the US is atrazine. It has considerable economic benefit. More than 85% of atrazine is applied on corn, which alone represents 1/3 share of the US crop economy according to the National Center for Food and Agricultural Policy (NCFAP, 2003). The major crops using atrazine include corn (83.8%) and sorghum (9.2%). On the other hand, atrazine is toxic to humans. Animal studies have shown that atrazine causes adverse effects to heart and lungs and changes in liver, kidney and brain functions (http://ace.orst.edu/info/extoxnet/pips/atrazine.htm).

Risks and benefits should be weighed in regulatory decision-making (Arrow et al., 1996), and it is essential that assessments be made on regulated pesticides at different application rates. On-going review of existing pesticides must also take into account the public's willingness to pay (WTP) for reduced agricultural chemical use. The public's WTP a price premium for reduced pesticide use may play an important role in pesticide management options. Risk benefit analysis provides a socially efficient solution by balancing the total societal risk and economic benefits. Under the risk-benefit balancing approach, society as a whole may benefit, but there may be individuals who nevertheless incur excessive risks. Incorporating the public's WTP for reduced pesticide use in risk-benefit assessments may provide a management insight that is helpful in reducing high risks while maintaining economic benefits. This paper examines the trade-offs between health risks and economic benefits of atrazine at different application rates, and also considers the potential role of WTP for reduced pesticide use as a measure of the benefits associated with reducing the health risks associated with atrazine. Our results indicate that banning the use of atrazine may have adverse economic impacts; however net benefits may increase when WTP higher price premium is considered.

There are several studies that discuss pesticide risk-benefits at alternating levels (Pimentel et al., 1991; Harper and Zilberman, 1992; Ribaudo and Bouzaher, 1994; Liu et al., 1995; Ribaudo and Hurley, 1997; Zilberman and Millock, 1997; Gray and Hammit, 2000; Paul et al., 2002). The human and environmental risk estimates derived in these studies are, however, gross approximations, with no details provided that explain the results. In some cases, simplified risk indices are used, while in others estimates of exposure are either compared to the Reference Dose (RfD) or Acceptable Daily Intakes (ADI) or not considered at all (Ribaudo and Bouzaher, 1994; Liu et al., 1995). To the contrary, a more comprehensive quantitative risk assessment is required to realistically evaluate the risk trade-offs. To fully evaluate the potential implications of atrazine regulation, one must formulate the corresponding economic benefits and health risk response functions. Knowledge of the expected magnitude of economic benefits and human health risks due to label-prescribed pesticide application rates alone restricts the ability to develop an effective pesticide management policy. Hence, there is a need to investigate the relationship between the different atrazine application rates into the environment and the corresponding health risks and economic benefits as well as the impact of public choices in the risk-tradeoff outcomes. This study addresses these issues.

One of the critical problems in estimating the economic benefits of atrazine at different application rates is the lack of data, especially in the area of weed management. Little is known about the yield losses and increased weed control costs associated with reduced pesticide use. To estimate the yields and the costs of production under different pesticide application alternatives, the only approach is to use results derived from experimental[1] field tests (Teasdale, 1993; Hartzler et al., 1993; Mulder and Doll, 1993; Mohler et al., 1997) and national compilations (Schroder et al., 1984; Smith et al., 1990; NCFAP, 2003). Regional- and national-scale studies of herbicide effectiveness are typically conducted by combining field observations with expert and farmer opinions collected through surveys. In order to estimate the full benefit associated with the use of a chemical in the production of corn, as well as any potential benefit for consumers as a result of preference for pesticide-free corn, we consider that farmers substitute non-chemical means to control weeds in place of atrazine.

Following previous studies of other commodities, this study estimates the cost and yield functions for different pesticide management options and uses econometric methods (Roy and Ireland, 1975; Traesupap et al., 1999) to develop the corresponding demand and supply curves for the US corn market. Our approach follows Traesupap et al. (1999), who use a Two-Stage Least Squares (2SLS) regression model to derive Japanese shrimp demand and supply functions, and Roy and Ireland (1975), who use 2SLS and 3SLS regression models to estimate major structural relationships in the US sorghum market.

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[1] Pimentel et al. (1991) indicate that field tests typically exaggerate total crop losses because assessments of insect, disease, and weed losses are carried out separately from one another.

Another problem precluding an accurate estimation of the trade-off between health risks and economic benefits at different atrazine application rates is the lack of data on pesticide residues in crops and drinking water. Regression models are therefore developed in this study to predict the stream atrazine concentrations for alterative management options, similar to the work of Battaglin and Goolsby (1997, 1998), Larson and Gilliom (2001), and Kolpin et al. (2002).

A risk-benefit analysis at a national-scale is a complex balancing process. The majority of the population may be favorably affected by a given decision while only a few may be adversely affected. Risk-benefit analysis ensures an efficient tradeoff between aggregate economic effects and societal health, but it is oblivious to risks incurred at the individual's level. Reduced pesticide management based on the public's WTP a price premium may help guide the solution to this problem. In the next section, we present the methodology of empirically developing risk and benefit functions, which are then used to investigate risk benefit tradeoffs under varying price-premium scenarios. We find that if the public is willing to pay price premium, higher net benefits are maintained at lower human health risks.

2. METHODOLOGY

2.1 Background

The methodology for this paper encompasses four main areas: **(a)** development of a regression model to predict the stream atrazine concentration in watersheds subject to watershed characteristics, climatic data, and atrazine application rate, and development of a companion model to predict finished water atrazine concentration in a given community water supply scheme knowing the corresponding stream atrazine concentration; **(b)** prediction of the health risk of atrazine in drinking water knowing the predicted distribution of finished water atrazine concentration; **(c)** development of demand and supply functions for the US corn market to predict the economic benefits of using atrazine in corn production as a function of the application rate; and **(d)** assessment of the economic benefits and risk-benefit tradeoff at different application rates, as well as the policy implications of WTP a price premium to reduce atrazine use.

The largest public health threat of atrazine is due to surface water contamination. The major route of human exposure to atrazine is through dietary means, which includes food consumption and drinking water. However, human exposure to atrazine through food consumption is extremely low, at less than 1 percent of the dietary exposure (US EPA, 2001). The exposure to atrazine through drinking water poses the greatest threat to the public in the US (US EPA, 2001).

2.2 Regression Models of Stream and Finished Water Atrazine Concentrations

First, following Battaglin and Goolsby (1997 and 1998), Larson and Gilliom (2001), and Kolpin et al. (2002), a regression model is developed using available data from various watersheds to estimate stream atrazine concentration . A second regression model is then developed to estimate finished water atrazine concentration at a given community water system (CWS) using as a key explanatory variable the predicted stream atrazine concentration of that watershed from the first regression model.[2] These two models together are used to predict the finished water atrazine concentration as a function of the atrazine application rate in that watershed. Since atrazine is primarily used in corn (more than 84%) and to a lesser degree in sorghum production, we use these two crops as the primary crops using atrazine at application

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[2] A CWS is a public water system that supplies water to the same population year-round.

rates ranging from 1 lbs ai/A-year to a maximum of 2.5 lbs ai/A-year (Mulder and Doll, 1993; US EPA, 2003). In this study, a standard application rate of 1.8 lb ai/A-year is used.

The two regression models can be represented succinctly as:

$$C_s = f_s(\mathbf{P}, \mathbf{G}, \mathbf{A}) \tag{1a}$$

$$C_f = f_f(C_s) \tag{1b}$$

where f_s and f_f are functions describing the atrazine concentrations in stream and finished water, respectively; C_s is the distribution of stream atrazine concentration in ppb; **P** is a vector of physical watershed characteristics; **G** is a vector of relevant climate variables such as precipitation, runoff, etc.; **A** is a vector of relevant agricultural practices including the actual atrazine application rate in the field (in lbs ai/A-year); and C_f is the distribution of atrazine concentration in finished water (in each CWS, in ppb). Unlike **P** and **G**, **A** represents factors that can be used as management alternatives to minimize health risks.

Data Synthesis

Nationally available datasets exist for watershed characteristics and application rates. Stream atrazine concentrations vary temporally in a given watershed as a result of timing of pesticide application, application rate, and frequency of application. Since agricultural watersheds are spatial units in the regression analysis, observed peak stream atrazine concentrations are expected to occur during high farming activity seasons. In most cases, this period corresponds to the wet season. However, high concentrations of atrazine may also be observed during other seasons due to irrigation. The regression models used in this work are applied at the 8-digit Hydrologic Unit Cataloging (HUC) level, which is the smallest hydrologic unit for which nationwide data are available.

The stream atrazine concentration data were obtained from the National Water Quality Assessment (NAWQA) program of the US Geological Survey (USGS, 2002) for 1994 to 2002. There were 52 NAWQA study units representing 417 watersheds available for this period, from which 65 watersheds with predominantly agricultural sites were selected. Each of these watersheds have data collected for at least 7 months of the year, distributed more or less uniformly throughout the year. To form an annual distribution of stream concentration percentiles, daily concentrations are first computed through interpolation of observed data. From the interpolated daily concentrations, annual percentile concentrations at successive intervals of 10% are obtained. The distribution of stream atrazine concentration of each watershed is represented by these 12 discrete percentiles, representing zero to the100th (including the 95th) percentile. Thirty-eight watersheds from the 65 watersheds were used in model training and the remaining 27 were used in model validation.

One of the most significant agricultural practice variables that can explain stream concentration is the atrazine application intensity (A_I) within the watershed. A_I represents the average atrazine usage or application across the watershed, whereas the atrazine application rate (A_R) is the actual application rate of atrazine at the farm level for a given crop, in this case corn and sorghum. On average, more than 93% of atrazine nationwide is used on corn and sorghum farms. Typical application rates on these crops range between 1 to 2.5 pounds of active ingredient per acre (NCFAP, 2001).

To estimate A_I, county-wide geographical information system (GIS) coverage of corn and sorghum data for the US was obtained from the US Department of Agriculture (USDA) for 1997, while corresponding GIS coverage of watershed boundaries of the conterminous US was obtained from the USGS. The watershed-based corn and sorghum crop areas were computed by intersecting the watershed boundary coverage and the county boundary coverage in ArcView 3.2. Corn and sorghum crop areas within each 8-digit HUC were then multiplied by the respective percent crop treated (PCT) with atrazine and A_R to obtain the actual crop areas treated with atrazine. The PCT for corn and sorghum are 73% and 70%, respectively (NCFAP, 2001; US EPA, 2003). Total atrazine applied in a watershed is then computed by adding the amount applied in each crop area within the watershed. The total applied atrazine divided by the watershed area provides our measure of A_I (in lbs ai/A-year) for that watershed.

Soil characteristics of each watershed were obtained from the BASINS database (US EPA, 2004) of the US EPA (http://www.epa.gov/waterscience/basins/b3webdwn.htm). Soil characteristics include mean area weighted percent clay, percent organic matter, percent silt, available water capacity (in/in), permeability (in/hr), bulk density (g/cc), and soil erodibility of the surface layer.[3] Precipitation and runoff characteristics were also used as explanatory variables. The spatial coverage of average annual precipitation (mm) of the conterminous US from 1961 to 1990 was obtained from the National Atlas of the US (http://www.nationalatlas.gov/prismmt.html). The coverage of average annual runoff (in/year) from 1951 to 1980 was obtained from the USGS (1999) (http://water.usgs.gov/GIS/metadata/usgswrd/runoff.html).[4]

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[3] Additional soil characteristics were also used in the regression model, but were found to be statistically insignificant and, therefore, excluded from the model.

[4] The runoff obtained from this database is a stream flow, which is the sum of groundwater baseflow and surface runoff.

Finished Water Atrazine Concentration

More than 90% of the US population receives their drinking water from CWSs (US EPA, 2001). Atrazine residues in surface and ground water sources are detected mainly in the heavy atrazine-use regions of the midwest and south. The US EPA (2001) reports that 21 states account for 92% of atrazine use nationwide. Novartis Inc., the manufacturer of atrazine in the US, has collected atrazine residue data in finished water from CWSs and the corresponding population served by each CWS. Of the 21,241 CWSs surveyed, 182 CWSs (76 CWSs of these are source CWSs) that serve over one million people had one or more annual mean atrazine concentration greater than 3 ppb from 1993 to 1998 (US EPA, 2001). These CWSs, located in 53 watersheds nationwide, are considered high-risk by the US EPA (US EPA, 2001).

A health risk assessment is normally performed using finished water. Stream atrazine residue estimated for each CWS must, therefore, be converted into the potential atrazine residue in finished water according to regression models (1a) and (1b). Among the 76 high-risk source CWSs, only six have historical data on atrazine residue in stream and the corresponding finished water. Atrazine levels were reduced after treatment in the 6 CWSs. A rather simple approach (univariate regression) was adopted to estimate finished water residue from raw water residue using the available data.

Atrazine has two major metabolites, *hydroxyl and chlorinated metabolites*. Chlorinated metabolites are generally considered to have similar toxicity endpoints as atrazine itself. It is, therefore, important to determine the amount of metabolites in finished water to find the total chlorotriazine residue, which is the sum of the residues of atrazine and its chlorinated metabolites. An annual regression model developed by the US EPA (2001) to relate the sum of atrazine and chlorotriazine metabolites to finished-water atrazine concentration in a CWS is given as

$$C_{total} = 0.24 + 1.42C_f \tag{2}$$

where C_{total} is the sum of atrazine and chlorotriazine metabolite residues in finished water (ppb).

Health Risk Assessment

This section demonstrates how finished-water atrazine concentration is converted to exposure in the population. Drinking water exposure to atrazine is a function of the water consumption rate and pesticide residue in finished drinking water. In its simplest form, exposure, E [mg/Kg-body weight-day], is expressed as

$$E = W \times C_{f\text{-}avg} \tag{3}$$

where W is the rate of drinking water consumption (μg/L-kg body weight), and $C_{f\text{-}avg}$ is the population-weighted total distribution of atrazine concentration in finished water (across all CWSs, in ppb) computed by (i) combining the distribution of C_{total} of all CWSs and (ii) by taking into consideration the corresponding population served by each CWS. Therefore, E is the exposure distribution of all high risk CWSs put together. Exposure assessment given by (3) was performed using the risk assessment software, LifeLine^{TM} Ver. 2.0 (LifeLine Group, Inc., 2000). The drinking water consumption rate W is available in the LifeLine software and is based on

USDA data from 1989 to 1992 and 1994 to 1998. For this study, we use the data from 1994 to 1998.

Atrazine is associated with developmental effects (US EPA, 2002), such as birth defects, structural anomalies, and adverse hormone changes. The risk for non-cancer endpoint pesticides is expressed as a percentage of the Population Adjusted Dose (PAD) (US EPA, 1992) and can be given as

$$\text{Risk} = \%\text{PAD} = (E/\text{PAD}) \times 100 \qquad (4)$$

PAD is obtained by dividing the reference dose (RfD) by a safety factor. An RfD is the safe average daily intake, which over a predefined span of time causes no significant adverse effects in humans. If the calculated %PAD is less than 100, the risk is generally considered to be acceptable. For example, both the intermediate and chronic PADs of atrazine are the same at 0.0018 mg/Kg-day (US EPA, 2001). A person ingesting 0.0018 mg/Kg-day or more of atrazine over a long period of time is, therefore, above the allowable daily intake and may be exposed to a significant risk from the pesticide.

We use the intermediate exposure and compute the 99.9% exposure values for infants 0-2 years old, children 2-10 years old, and the general population 0-75 years old. The 99.9 percentile is computed here since the US EPA considers this value as the upper-bound threshold of concern (US EPA, 1995). Intermediate risk is defined as the average dosage received in 90 days. It is computed by taking the maximum of the 90-day rolling average exposure.

2.3 Economic Analysis

Farmers currently depend heavily on atrazine to control wide-leaf weeds common in corn fields. Approximately 74% of corn acreage is treated with atrazine annually, which accounts for approximately 84% of the total atrazine, usage. The impacts of regulatory actions, ranging from a reduced application rate to a total withdrawal of atrazine are therefore best investigated by focusing on the US corn market. A policy change would likely affect the demand and supply dynamics of corn. Demand and supply functions are thus estimated from available explanatory variables using the 2SLS model.[5] These functions are then used to estimate the total surplus and the change in the total surplus accruing to consumers and producers due to possible pesticide policy changes.

Data Synthesis

Time-series data of annual US corn consumption, exports, imports, production, yield, stock at the beginning of the year, price of corn, and price of substitutes received by farmers from 1984 to 2002 were obtained from different sources including the National Agricultural Statistical Service (NASS) of the USDA. Per capita personal disposable real income (I), real per capita food expenditure (I_f), Consumer Price Index (CPI), and Producer's Price Index (PPI) for corn were obtained from the Bureau of Labor Statistics of the US Department of Labor.

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[5] We also used a 3SLS model, which gave quantitatively similar results. The results are available from the authors upon request.

Demand and Supply Functions

The corn market is composed of structural equations for demand and supply. Supply is defined as the sum of corn produced, imports, and the stock at the beginning of that year, all defined per year. The supply equation can be expressed as

$$Q_s = f_{sp}(P, PPI_c, Y) \tag{5}$$

where Q_s is the supply of corn (bushels), P is the price of corn ($/bushel), PPI_c is the producer-price index for corn (dimensionless), and Y is corn yield (bushels per acre).[6] P is deflated by the CPI to obtain real prices. The supply function may shift with time because of technological changes, climate change, and natural disasters (e.g., fire, flood, and pests). A linear time trend may, therefore, be used in place of Y, but this assumes a smooth technological or nature-induced change from year to year. We therefore use Y to proxy for these changes, as the yield is able to capture the natural variability due to technological changes, climatic changes, and natural disasters. The remaining shifter variable in the supply function is PPI_c. This is an index of annual inputs measuring labor, material, and capital costs of producing a unit of corn.[7] We also included additional explanatory variables in the supply function such as per-capita meat consumption. However, these variables were found to be highly correlated with the price of corn and were neglected for reasons of colinearity. Further, the solution to this type of system of equations becomes stable and reliable as the number of explanatory variables become fewer (Levine et Al., 2001).

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[6] We assume that farmers base their current production decisions on current price levels, rather than lagged prices, due to the availability of up-to-date price information.

[7] For additional information on how PPI_c is calculated, see USDA National Agricultural Statistics Service annual publications and Tomek and Kenneth (1990).

Demand is defined as the sum of domestic consumption and exports. Following Traesupap et al. (1999), a demand function may be written as,

$$Q_d = f_d(P, P_s, I_f) \tag{6}$$

where Q_d is the quantity of corn demanded (bushels), P_s is the average price of a substitute commodity (e.g., average price of soybean, wheat, oats, and hay), and I_f is real per capita food expenditure ($/year).[8]

At market equilibrium, $Q = Q_s = Q_d$. As commonly assumed in the literature, this condition holds at any given point in time. Thus, Q and P are determined simultaneously within the system. This simultaneous system is used to jointly determine the demand and supply functions corresponding to the reduced atrazine application rate scenarios. We hypothesize that the withdrawal or reduced use of atrazine may cause a decrease in yield, an increase in the cost of weed control, and an increase in the demand for corn. For each reduced application rate scenario, we assume that farmers substitute non-chemical means to control weeds in place of atrazine and reconstruct the PPI_c and Y variables accordingly. This approach helps to estimate the benefit associated with the use of atrazine in the production of corn, as well as any potential benefit for consumers as a result of preference for pesticide-free corn.

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[8] Additional explanatory variables, such as the real prices of meat, time, and livestock populations, were considered at the initial stage of developing the demand function. However, these variables were found to be highly correlated with some of the independent variables and were, therefore, dropped from the model.

Reduced Atrazine Use

Yield is directly affected by reduced atrazine use. The two major pesticides used on corn are atrazine and metolachlor. Most studies have documented the effect on corn yield of withdrawing all pesticides. For example, NCFAP (2003) estimated a 20% yield loss without the use of herbicides. NCFAP assumes that farmers substitute pesticides with mechanical weed removal methods (e.g., cultivation and hand weeding). NCFAP has also estimated that it may be possible to achieve the same yield without herbicides, but only by incurring untenable labor costs. The average yield loss without herbicides ranges from 20% to 32% (Smith et al., 1990; NCFAP, 2003). USDA (1994) has similarly estimated the sorghum yield loss without atrazine as 12%. The average yield loss without the application of atrazine is, therefore, assumed to be a conservative 10% in this study. Since there are no studies that have estimated yield losses as a function of a reduced atrazine application rate, we extrapolate between a 10% yield loss with no atrazine application and no yield loss with a normal atrazine application rate of 1.8 lbs ai/A-year (Mulder and Doll, 1993; US EPA, 2003).

At a reduced application rate, the supply of corn will decrease due to lower yields. The cultivated area will be assumed to remain constant; and, therefore, the new quantity of corn supplied each year will be the product of the reduced yield and acreage planted. The percent area of land treated in the U.S. with atrazine from 1990 to 2002 varied from 50% to 75% (NCFAP, 2003). Since the data for years 1984 to 1989 are unavailable, the required data are obtained through extrapolation. PPI_c is used as a measure of the total production costs. If atrazine application rates are reduced, weed control costs will increase. Atrazine accounts for approximately 20% of the total corn herbicide cost, while the herbicide cost is over 8% of the total corn production cost per acre (Smith et al., 1990). Thus, we estimate that atrazine accounts for approximately 2% of the total corn production costs per acre. This percentage is used to estimate the percentage change in PPI_c as a result of a change in the atrazine application rate. Different sets of demand and supply curves corresponding to different reduced application rates from 1.8 lbs ai/A-year to zero are estimated, and the corresponding total surplus in each scenario is determined.

Price Premiums

Recent studies show that the public may have a preference for pesticide-free and non-genetically modified (GM) foods (Boccaletti and Morro, 2000; Moon and Balasubramaniam, 2001; Chern et al., 2002; Tegene et al., 2003). The implication of these studies is that consumers may be willing to pay more for chemical-free or non-GM foods. USDA (2001) reports that US producers receive premiums of 5 to 10 cents/bushel for non-GM corn. Tegene et al. (2003) similarly find that WTP is lower for biotechnologically engineered food. It has been suggested that consumers discount food items labeled “Genetically Modified” by 14% (Tegene et al., 2003). Similar to adjustments made to the PPI_c to account for potential changes in the atrazine application rates, the estimated price premiums are applied to the existing prices to estimate the change in Q_d for a given price P as a result of consumer preferences for atrazine-free corn.

Data sets were reconstructed as discussed previously for each reduced atrazine application rate from which the demand and supply functions were obtained using the 2SLS method. The difference in the total surplus between zero and other application rates, therefore represents an estimate of the net economic benefit of using atrazine at that application rate. A plot of atrazine application rate versus the expected changes in the total surplus may, therefore, be established for both scenarios, i.e, when the public is willing or unwilling to pay a price premium to reduce atrazine use.

Efficient Solution

The total surplus (S) is defined as the sum of consumer surplus and producer surplus which is a function of the demand and supply functions for a given atrazine application rate. Since the demand and supply functions depend on several variables, S may be expressed as:

$$S = f_{SP}(P, P_s, I_f, PPI_{c,} Y, A_R) \qquad (7)$$

Similarly, the human health risk (R), as derived in (4), can be used to measure the expected number of people exposed above the average allowable dosage and can be expressed as

$$R = f_R(\mathbf{P}, \mathbf{C}, \mathbf{T}, \mathbf{W}, A_R, N, H) \qquad (8)$$

where **T** is a vector of drinking water treatment practices and N is the exposed population. CWSs use different drinking water treatment practices with varying efficiency of removing pesticides, often based on the size of the population served (US EPA, 1999a, 1999b).

The damage, D, (in monetary terms) is considered to be the *average cost of illness ($ per person per year)* for people at risk, CI_{av}, multiplied by the risk, R, and given as

$$D = CI_{av} \times R = CI_{av} \text{ x } f_R(\mathbf{P}, \mathbf{C}, \mathbf{T}, \mathbf{W}, A_R; N, H) \qquad (9)$$

The net benefit to the society (B) is therefore expressed as:

$$B = S - D = f_{SP}(P, P_s, I_f, PPI_{c,} Y, A_R) - CI_{av}\ f_R(\mathbf{P}, \mathbf{C}, \mathbf{T}, \mathbf{W}, A_R, N, H) \tag{10}$$

Assuming the corn market is competitive and thus the market has obtained the optimal application rate, this application rate solves:

$$\frac{\partial \mathbf{B}}{\partial \mathbf{A_R}} = \frac{\partial \mathbf{f_{SP}}}{\partial \mathbf{A_R}} - \mathbf{CI_{av}} \frac{\partial \mathbf{f_R}}{\partial \mathbf{A_R}} = \mathbf{0} \tag{11}$$

yielding

$$\mathbf{CI_{av}} = \mathbf{CI_{IM}} = \frac{\partial \mathbf{f_{SP}} / \partial \mathbf{A_R}}{\partial \mathbf{f_R} / \partial \mathbf{A_R}} \tag{12}$$

where CI_{IM} is the *implied cost of illness ($ per person per year)*. Now, (12) can be used to estimate the CI_{IM} at a given atrazine application rate. Conversely, if the average cost of illness is known, Equation (12) may be used to find the associated application rate.

3. RESULTS AND DISCUSSIONS

3.1 Regression Analysis of Stream and Finished Water Atrazine Concentrations

The results of the regression model given by (1) are shown in Table 1 as percentiles.[9] Explanatory variables with p-values less than or equal to 0.1 are considered statistically significant. Note that atrazine application intensity (A_I) and the clay content of the soil (Clay) are statistically significant explanatory variables in each percentile. It is also worth noting that A_I is the strongest predictor, usually accounting for 50% to 65% of the variability of stream atrazine concentration. Validation of the regression model is performed by examining the distribution of residuals. A residual is defined as the log of the ratio between the observed and predicted finished water concentrations of atrazine (Larson and Gilliom, 2001).

The watersheds used in the development and validation were selected on the basis of a uniform spatial distribution throughout the US. The distribution of residuals in model development and validation are shown in Figure 1. The box plots in Figure 1a indicate that the predicted residues are within a factor of 10 of the observed residue more than 99% of the time, and within a factor of 5 more than 95% of the time in model development sites. The distribution of residuals for the validation sites (from 28 sites) is shown in Figure 1b. The model performs well in validation sites predicting atrazine concentrations 96% of the time within a factor of 10, and 87% of the time within a factor of 5. These results are similar in accuracy to the results obtained from other studies (Larson and Gilliom, 2001). Additionally, the model performance in development and validation sites was analyzed using linear fit; for example R^2 of the 50th percentile regression was 0.774 in development sites and 0.504 in validation sites

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[9] Explanatory variables that have been used but not shown in Table 1 include runoff and precipitation, which were found to be consistently insignificant in all percentiles. This observation is in agreement with other studies on atrazine and other pesticides (Battaglin and Goolsby, 1998; Larson and Gilliom, 2001).

3.2 Exposure Assessment

The regression models described in Table 1 were used to simulate the stream atrazine residue percentiles of high-risk watersheds identified by the US EPA. It should be noted that each of the explanatory factors except A_I shown in Table 1 are constants for a given watershed. A_I is the application intensity defined as the total atrazine applied divided by the watershed area. It is, therefore, a function of the actual application rate at the farm level, A_R. Thus, the cumulative distribution of stream atrazine concentration as a function of A_I can be estimated and this distribution is a function of the application rate as indicated in Table 1.

According to the US EPA (2001), there are 76 CWSs located in 53 watersheds serving over one million individuals. These CWSs use surface water from their watersheds as the only source of water. For each CWS, the percentiles of finished water atrazine concentrations were computed using the regression models (1) and (2)[10] and then the corresponding exposure assessment was conducted using the residue distribution thus created. For each application rate, we computed the exposure distribution (Equation 3). The exposure corresponding to the 99.9 percentile is taken from each cumulative distribution obtained and the resulting plot of exposure versus application rate is shown in Figure 2. The figure shows that 1.1% of infants, 0.091% of children or 0.041% of the general population are exposed above the PAD of $1.8\text{x}10^{-3}$ mg/Kg-day indicating that infants and children are highly exposed segments of the population.

The expected number of individuals at risk is computed for the exposed population above the PAD. The summary results of the population at risk versus the application rate are shown in Figure 3 for the general population age 0-75 years. Note the typical characteristic of a non-linear response of toxicity is expressed by the abrupt change in the slope beyond an application rate of

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[10] Univariate regression models for 11 percentiles (0^{th}, 10^{th}, 20^{th},…100^{th}) were developed using data from 6 CWSs. R^2 ranges from 0.54 to 0.76. No model validation was performed due to a paucity of data.

0.875 lb ai/A-year. Atrazine is toxic to humans only beyond the RfD, or more technically, the PAD level. For concentrations below this level, the risk is zero.

3.3 Economic Analysis

In the event of banning or reducing the application of atrazine, the major economic change is due to increased hand weeding. At an optimal atrazine application rate of 1.8 lbs ai/A-year and metolachlor application rate of 2.5 lbs ai/A-year, weed control costs are estimated to be \$29.90/acre. Atrazine contributes about 21% of the total herbicide cost and it is estimated that farmers require four hours of tillage at a rate of \$4.50/acre, and five hours of hand labor at a rate of \$8.75/acre to replace both metolachlor and atrazine (NCFAP, 2003). It is assumed here that half of this cost is attributed to the replacement of atrazine only. At a zero atrazine application rate, weed control costs are predicted to rise to \$54.80/acre. Weed control costs at other application rates are estimated by interpolating exponentially between these estimates due to the nonlinear variation between the costs and the application rate (see Figure 4). Weed control costs rise as the atrazine application rate decreases because hand weeding and cultivation to the same level of weed control is markedly more expensive.

Two scenarios were considered for the derivation of demand and supply functions for corn and the corresponding estimation of the welfare impact of reduced application of atrazine. Scenario I assumes that consumers are willing to pay a 3% price premium for atrazine-free corn.[11] Scenario II assumes that consumers are unwilling to pay a price premium. The 2SLS model was used in each scenario to simultaneously solve for the demand and supply functions.

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[11] USDA (2001) reported that US producers receive premiums of 5 to 10 cents/bushel or 2 to 6% for non-GM corn.

Scenario I - The explanatory variables of the supply and demand functions of Scenario I are shown in Table 2. The parameters[12] of demand and supply functions obtained from the regression model are shown in Table 3. Using these parameters, the estimated demand and supply functions for the most recent year of 2002 are given as

$$Q_d = 6.5363 - 4.1015P + 0.1299I_f + 2.9720P_s \tag{13a}$$

$$Q_s = 2.5065 + 1.5291P - 0.0408PPI_c + 0.0764Y \tag{13b}$$

from which the equilibrium quantity and the real price for the year 2002 are computed as 10.6 billion bushels and \$1.15/bushel, respectively. Note that all the prices are deflated to a base year of 1982 (the conversion factor for 2002 is 1.937). The demand and supply curves (which assume an atrazine application rate of 1.8 lbs ai/A-year) are shown in Figure 5. The total surplus is estimated to be \$24.7 billion of which the consumer surplus is \$13.6 billion and the producer surplus is \$11.1 billion.

To determine the change in the total surplus due to a change in atrazine use policy, the total surplus is estimated assuming atrazine is banned and farmers substitute mechanical weed control methods. For this purpose, the atrazine application rate is assumed zero and the original explanatory variables in Table 2 are accordingly adjusted. The adjusted values are shown in Table 4. The estimates of weed control costs with zero atrazine are obtained from Figure 4 and converted directly into a percentage increment in the total corn production cost per acre via the PPI_c of 1.67%. It is assumed that yield decreases linearly by 10% from a standard atrazine application rate of 1.8 lbs ai/A-year to zero. Further, a 3% increment is applied to the price

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[12] As a check on the short-run global stability, the Cobweb model of Nerlove (1958) was also estimated. The prices and quantities are interrelated recursively in this model, i.e., last year's price is used by producers to determine the current year's production level. We find that our structural model of the U.S Corn market is stable.

column in Table 2 for each year. Using the updated values reported in Table 4, the demand and supply functions are solved jointly and the computed parameter values are shown in Table 5. The demand and supply functions corresponding to the zero atrazine application case are determined as,

$$Q_d = 6.53723 - 3.9736P + 0.1300I_f + 2.9639P_s \qquad (14a)$$

$$Q_s = 2.0151 + 1.4971P - 0.0386PPI_c + 0.0787Y \qquad (14b)$$

Solving Equations (14a) and (14b) simultaneously for the year 2002 produce an equilibrium quantity of 9.97 billion bushels of corn per year and an equilibrium real price of $1.33/bushel. Thus, under a total ban of atrazine, the supply decreases slightly while the price rises (see Figure 5). As a result of the expected increase in weed control costs, the supply curve has shifted leftward while the demand curve has shifted slightly to the right (as a result of expected consumer WTP the price premium). The total surplus now reduces to $24.5 billion (of which the consumer surplus is $12.5 billion and the producer surplus is $11.97 billion), implying that the estimated benefit of using atrazine at the standard application rate of 1.8 lb ai/A-year is $268.6 million ($24.7 billion - $24.5 billion). This is equivalent to a loss of $520 million in 2002 currency. In other words, banning atrazine would cause a total surplus loss of $3.88 per acre ($7.52 per acre in 2002 currency). The move from the standard to zero application rate resulted in a consumer surplus loss of $1.1 billions ($13.6 billion - $12.5 billion).

A similar procedure was followed for other application rates between zero to 1.8 lbs ai/A-year under this scenario. The resulting plot of total surplus versus atrazine application rate is shown in Figure 6a. For reduced application rates, WTP is assumed to vary linearly from zero to

3% with the corresponding reduction in the application rate from 1.8 lbs ai/A-year to zero. A plot of the change in total surplus is also shown in Figure 6b. The change in the total surplus at a given atrazine application rate is defined as the total surplus at that application rate minus the total surplus at zero application.

Scenario II - Since it is assumed that consumers are unwilling to pay a price premium, the demand for corn is unaffected by the changes in the application rate. Figures 6a and 6b show that the total surplus and the change in the total surplus increase at higher atrazine application rates for both scenarios. Additionally, the total surplus at a price premium of 3% is higher than at zero premium, while the change in the total surplus at a price premium of 3% is lower than at zero premium for a given application rate, as shown in Figure 6b. For example, the total surplus loss of banning atrazine would be approximately $520 million per year with a 3% price premium for atrazine-free corn and $1.84 billion with 0% price premium (in 2002 currency). This implies that if WTP a price premium is much higher than 3%, then the change in the total surplus under that scenario would be lower. In other words, there may be no appreciable benefit in using atrazine at all if WTP a price premium for atrazine-free corn is sufficiently high. This result has far-reaching implications. For instance, European consumers have demonstrated more negative attitudes toward pesticides and biotechnology, and are therefore willing to pay a higher price premium than their US counterparts for chemical-free food (Boccaletti and Morro, 2000). This implies that US consumers exhibit more confidence in their policy-makers and are less willing to pay a price premium for chemical-free foods, thereby justifying the use of atrazine.

Policy Implications

Under which scenario is society better off? The relationship between total surplus and risk for scenarios I and II is shown in Figure 7. The results show that for a given number of individuals at risk, the total surplus with a 3% price premium exceeds the total surplus with 0% price premium. Moreover, the rate of change of the total surplus with a 3% price premium is less than that with a 0% price premium. Thus, if the society is willing to pay a price premium, risks can be reduced without a large reduction in total surplus.

Figure 8 shows the risk-benefit ratio and the implied cost of illness in relation to the atrazine application rate. However, not much information can be gleaned from the risk benefit ration curves in terms of the merits of the two scenarios. The problem with risk-benefit ratios is that they camouflage the actual number of risks. On the other hand, our implied cost of illness measure (CI_{IM}) provides a potentially more accurate depiction of societal risk tradeoffs. As shown in Figure 8, the implied cost of illness decreases at higher application rates for both scenarios. It is lower for the scenario II, implying that for a given implied cost of illness the optimum application rate is lower.

Equation (12) can be used to estimate the optimum application rate if the cost of illness is fixed at a given level. The corresponding net benefit as a function of the application rate is shown in Figure 9. The optimum application rate for a given cost of illness corresponds to the maximum net benefit, which is at the crest of the curves. For example for an average cost of illness of 10,000 per patient, it is interesting to note that the optimum application rate for the first scenario (1.0 lb ai/A-year) is less than that of the second scenario (1.7 lb ai/A-year), while the net benefit is greater under the first scenario ($47.55 billion) than under the second scenario ($47.16 billion). Both scenarios have been assessed using tradeoff analysis. One of the problems with tradeoff analyses is that they are not protective of individual risks. Under the second scenario while tradeoff ensures that all the sick are covered from the total surplus, the risk borne by individuals is very high because the optimum application rate is high. This may not be tolerated by society in spite of the tradeoff feasibility. Under the first scenario however, we have similar tradeoff feasibility (in fact the net benefit here is slightly higher) but now this occurs under an optimum pesticide application rate which is lower. A lower atrazine application rate means less excessive risks to individuals. Note that totally banning atrazine is not beneficial to society because atrazine does not cause risk below application rate of 0.875 lb ai/A-year. From these findings it appears that risk benefit analysis needs to consider public WTP price premium for reduced pesticide use. As has been found in this study, the public may be better-off reducing atrazine use and paying higher price premiums. Society's WTP a price premium plays a key role in the pesticide reduction or banning policy decision.

In closing, it is important to bear in mind that these results are only numerical estimates. The study is primarily designed to discuss risk-benefit issues in a policy setting using available data. Besides presenting an improved theoretical framework, this study has highlighted areas that are in critical need of better data; for example, the relationship between weed control costs and application rates. With this improved framework in place, however, and with better local, regional and national data, this approach may be used in risk-benefit analyses of any pesticide and corresponding policy analysis.

4. SUMMARY AND CONCLUSIONS

This study provides an improved methodology for investigating the trade-offs between the health risks and economic benefits of using atrazine in the agricultural sector by incorporating potential public WTP a price premium for reduced atrazine use. The proposed framework has developed regression models to predict the stream atrazine concentration based on watershed characteristics and agricultural practices, specifically based on the atrazine application rate. These models are then used to estimate the finished water atrazine concentration using an additional regression model. The concentration distributions of atrazine in finished water are extended to compute the intermediate health risk as a function of the atrazine application rate. Finally, data from various national databases for economic indicators are used to develop demand and supply functions for the US corn market with atrazine application rate as a primary variable. Deriving the total economic surplus based on different assumptions about consumer WTP for atrazine-free corn and the associated changes in health risk as functions of the application rate, enables us to assess the consequences of different policy decisions of reducing or banning atrazine from agricultural practices.

The results show that the optimum atrazine application rate may be reduced if WTP is increased. This is potentially important information for decision makers, in that a more preferable trade off between gains in total economic surplus and the associated health risks may be obtained.

Although this is an improved study incorporating both health risks and economic benefits through the development of demand and supply functions computed as a function of the atrazine application rate, the study still has limitations. Due to the limited data of watershed characteristics, observed stream atrazine concentrations, and application rates, the predicted stream concentrations from the regression models are subject to uncertainty and still need refinement. The uncertainty of the predictions caused by data limitations may affect the eventual net benefit estimates and, therefore, more field monitoring and data collection are needed to improve the analysis within the proposed framework. A similar uncertainty exists in the prediction of finished water concentration from stream concentrations due to the lack of detailed and sufficient data. For example, only 2-6 years of data from six CWSs exist. Due to these reasons, additional future studies are needed.

Despite these limitations, however, we believe that this study provides a significant contribution in its framework to assess and compare the trade-offs between human health risk and economic net benefit at different atrazine application rates by incorporating WTP measures for reduced pesticide use. With the framework for comparing risks and benefits in place, it is now a task of obtaining better resolution data to more accurately estimate the trade-offs at different atrazine application rates. Often, it is the risk to humans and the environment which acts as a limiting factor in relevant policy decisions. If regional and local data can be generated, a GIS-based risk assessment decision support system can be easily implemented and such a system can be used to develop permissible application rates on a regional basis.

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List of Tables

Table 1. Results of the linear regression model parameters to predict the percentiles of stream atrazine concentration using data from 38 watersheds of NAWQA study units; p-values are given in parentheses. Note A_I is the application intensity, A is the area, AWC is the available water content, OM is the organic matter, BD is the bulk density, and K is the soil erodibility factor.

Table 2. Time-series data used in the development of the demand and supply model for the US corn market with an atrazine application rate of 1.8 lbs ai/A-year.

Table 3. Parameters describing the demand and Supply functions for an application rate of 1.8 lbs ai/A-year.

Table 4. Adjusted time-series data used in the prediction of demand and supply functions of the US corn market at zero atrazine application

Table 5. Parameters describing the demand and Supply functions for zero application rate of atrazine.

Table 1. Results of the linear regression model parameters to predict the percentiles of stream atrazine concentration using data from 38 watersheds of NAWQA study units; p-values are given in parentheses. Note, A_I is the application intensity, A is the area, AWC is the available water content, OM is the organic matter, BD is the bulk density, and K is the soil erodibility factor.

Percentile	**Constant**	**ln(AI) (lb/A-year)**	**ln(A) (acre)**	**AWC (in/in)**	**Clay (%)**	**OM (%)**	**BD (g/cc)**	**K**	**Adj. R^2**
0	-5.320 (0.000)	0.518 (0.000)		16.200 (0.001)	4.570 (0.009)	-0.284 (0.000)			0.742
10	-4.418 (0.000)	0.518 (0.000)		12.686 (0.006)	4.777 (0.005)	-0.265 (0.000)			0.730
20	-3.964 (0.001)	0.512 (0.000)		10.741 (0.022)	4.695 (0.007)	-0.219 (0.001)			0.685
30	5.568 (0.205)	0.429 (0.001)	-0.735 (0.029)	12.651 (0.007)	5.213 (0.002)	-0.196 (0.001)			0.689
40	8.042 (0.073)	0.393 (0.003)	-0.934 (0.007)	14.910 (0.002)	5.247 (0.002)	-0.188 (0.002)			0.694
50	9.574 (0.020)	0.389 (0.001)	-1.019 (0.001)	15.699 (0.000)	4.507 (0.004)	-0.204 (0.000)			0.736
60	10.223 (0.014)	0.454 (0.000)	-1.020 (0.002)	14.484 (0.001)	5.054 (0.001)	-0.201 (0.000)			0.753
70	9.166 (0.052)	0.680 (0.000)	-0.900 (0.012)		5.258 (0.005)			7.943 (0.000)	0.734
80	-8.153 (0.002)	0.733 (0.000)			5.207 (0.007)		4.216 (0.017)	7.896 (0.000)	0.762
90	-6.827 (0.004)	0.896 (0.000)			5.603 (0.002)		4.008 (0.015)	8.129 (0.000)	0.826
95	-6.558 (0.003)	0.960 (0.000)			5.933 (0.001)		4.229 (0.006)	8.082 (0.000)	0.863
100	-5.172 (0.030)	1.034 (0.000)			6.277 (0.001)		4.084 (0.016)	6.462 (0.002)	0.838

Table 2. Time-series data used in the development of the demand and supply model for the US corn market with an atrazine application rate of 1.8 lbs ai/A-year.

Year	**Q_s (billion bushels)**	**Q_d (billion bushels)**	**P ($ per bushel)**	**I_f ($/year)**	**PPI_c**	**Y (bushels per acre)**	**P_s ($ per bushel)**
1984	8.68	7.03	2.531	12.186	129.46	106.7	2.785
1985	10.53	6.49	2.072	12.908	105.78	118.0	2.447
1986	12.27	7.39	1.369	13.528	83.11	119.4	1.940
1987	12.02	7.76	1.708	14.213	67.67	119.8	1.999
1988	9.19	7.26	2.147	15.282	97.51	84.6	2.714
1989	9.46	8.12	1.903	16.207	102.50	116.3	2.590
1990	9.28	7.76	1.744	17.135	100.83	118.5	1.860
1991	9.02	7.92	1.740	17.615	97.25	108.6	1.916
1992	10.58	8.47	1.475	18.486	95.81	131.5	1.993
1993	8.47	7.62	1.730	18.947	93.27	100.7	2.006
1994	10.96	9.41	1.525	19.598	99.85	138.6	2.053
1995	8.97	8.55	2.126	20.335	109.02	113.5	2.453
1996	9.67	8.79	1.727	21.045	157.65	127.1	2.350
1997	10.10	8.30	1.514	21.863	110.24	126.7	1.938
1998	11.09	9.30	1.190	23.016	91.49	134.4	1.529
1999	11.23	9.52	1.092	23.73	78.05	133.8	1.388
2000	11.64	9.74	1.074	25.206	76.05	136.9	1.435
2001	11.42	9.82	1.112	25.889	78.57	138.2	1.513
2002	10.62	9.69	1.306	27.083	89.24	130.0	1.759

Table 3. Parameters describing the demand and supply functions for an application rate of 1.8 lbs ai/A-year.

Variable	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Demand Function (R^2=0.755)				
Intercept	6.5363	1.8415	3.55	0.0029
p	-4.1015	2.2604	-1.81	0.0897
I_f	0.1299	0.0555	2.34	0.0335
P_s	2.972	1.8164	1.64	0.1226
Supply Function (R^2=0.646)				
Intercept	2.5065	4.2258	0.59	0.5619
P	1.5291	1.1803	1.3	0.2147
PPI_c	-0.0408	0.0138	-2.96	0.0097
Y	0.0764	0.0263	2.91	0.0108

Table 4. Adjusted time-series data used in the prediction of demand and supply functions of the US corn market at zero atrazine application.

Year	**Q_s (billion bushels)**	**Q_d (billion bushels)**	**P ($ per bushel)**	**I_f ($/year)**	**PPI_c**	**Y (bushels per acre)**	**P_s ($ per bushel)**
1984	8.203	7.03	2.607	12.186	132	100.83	2.785
1985	9.934	6.49	2.135	12.908	108	111.27	2.447
1986	11.543	7.39	1.410	13.528	84	112.36	1.940
1987	11.283	7.76	1.759	14.213	69	112.49	1.999
1988	8.612	7.26	2.211	15.282	99	79.27	2.714
1989	8.849	8.12	1.960	16.207	104	108.74	2.590
1990	8.660	7.76	1.797	17.135	103	110.56	1.860
1991	8.394	7.92	1.792	17.615	99	101.11	1.916
1992	9.822	8.47	1.520	18.486	97	122.03	1.993
1993	7.877	7.62	1.782	18.947	95	93.65	2.006
1994	10.228	9.41	1.571	19.598	102	129.31	2.053
1995	8.364	8.55	2.190	20.335	111	105.78	2.453
1996	8.937	8.79	1.779	21.045	160	117.44	2.350
1997	9.402	8.30	1.559	21.863	112	117.96	1.938
1998	10.287	9.30	1.226	23.016	93	124.72	1.529
1999	10.446	9.52	1.125	23.73	79	124.43	1.388
2000	10.848	9.74	1.107	25.206	77	127.59	1.435
2001	10.571	9.82	1.146	25.889	80	127.97	1.513
2002	9.823	9.69	1.345	27.083	91	120.25	1.759

Table 5. Parameters describing the demand and Supply functions for zero application rate of atrazine.

Variable	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Demand Function (R^2=0.755)				
Intercept	6.5372	1.8437	3.55	0.0029
p	-3.9736	2.2157	-1.79	0.0931
I_f	0.13	0.0557	2.34	0.0338
P_s	2.96	1.8317	1.62	0.1265
Supply Function (R^2=0.642)				
Intercept	2.0151	3.8352	0.53	0.607
P	1.4971	1.0237	1.46	0.1643
PPI_c	-0.0385	0.0124	-3.09	0.0074
Y	0.0786	0.0256	3.06	0.00079

List of Figures

Figure 1. A box plot showing the distribution of ratio of observed to predicted stream atrazine concentration from the regression model during a. development b. validation.

Figure 2. The 99.9% exposure values for different age-based population groups and the general population**.**

Figure 3. Expected number of individuals at risk from intermediate exposure in the US at different atrazine application rates**.**

Figure 4. Estimated weed-control costs with varying atrazine application rates**.**

Figure 5. Demand and supply curves for corn at two atrazine application rates with a 3% price premium for atrazine-free corn**.**

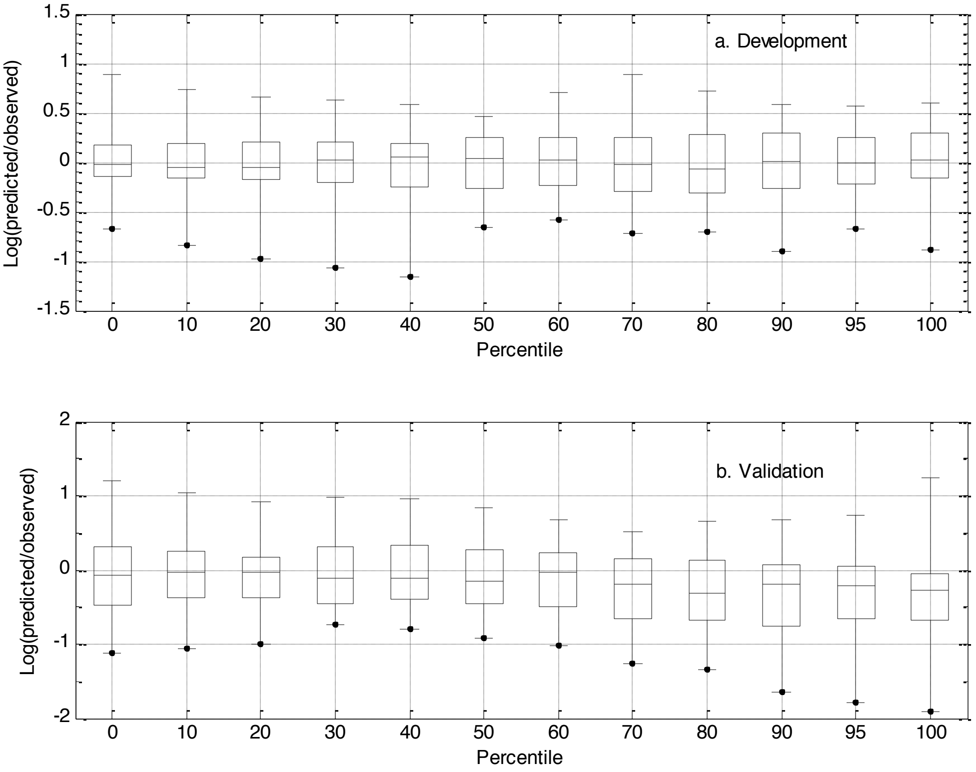
Figure 6. Total surplus and change in total surplus from the corn market in the US for different atrazine application rates with and without a price premium**.**

Figure 7. Expected number of individuals at risk versus the total surplus due to the atrazine use with and without a price premium**.**

Figure 8. Risk-benefit ratio and *implied cost of illness* (CI_{IM}) at different atrazine application

rates with and without a price premium**.**

Figure 9. Net benefit under different costs of illness as function of the atrazine application rate without price premium**.**



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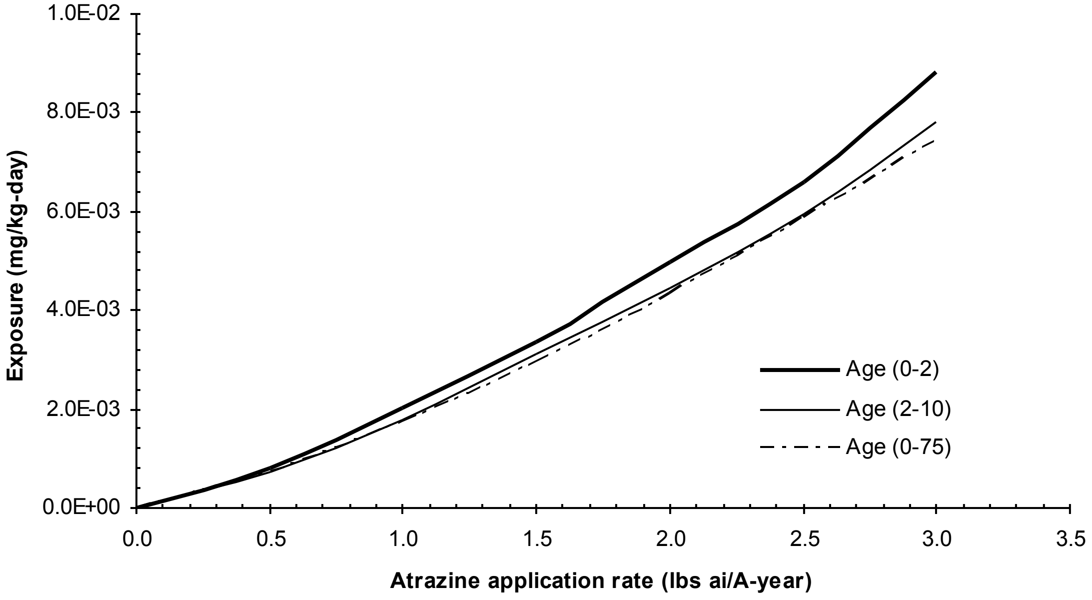
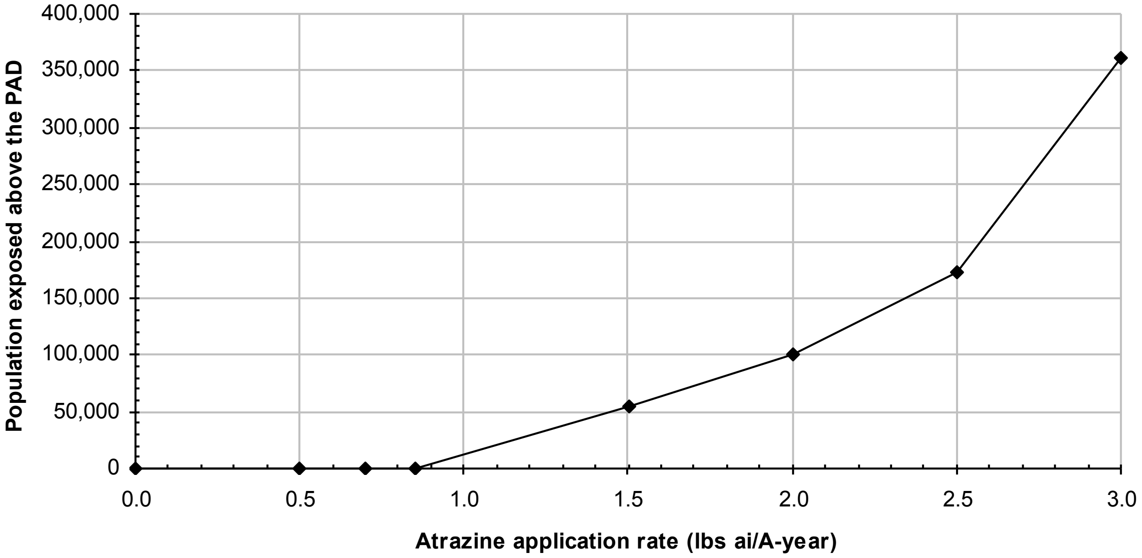


Figure 2. The 99.9% exposure values for different age-based population groups and the general population.



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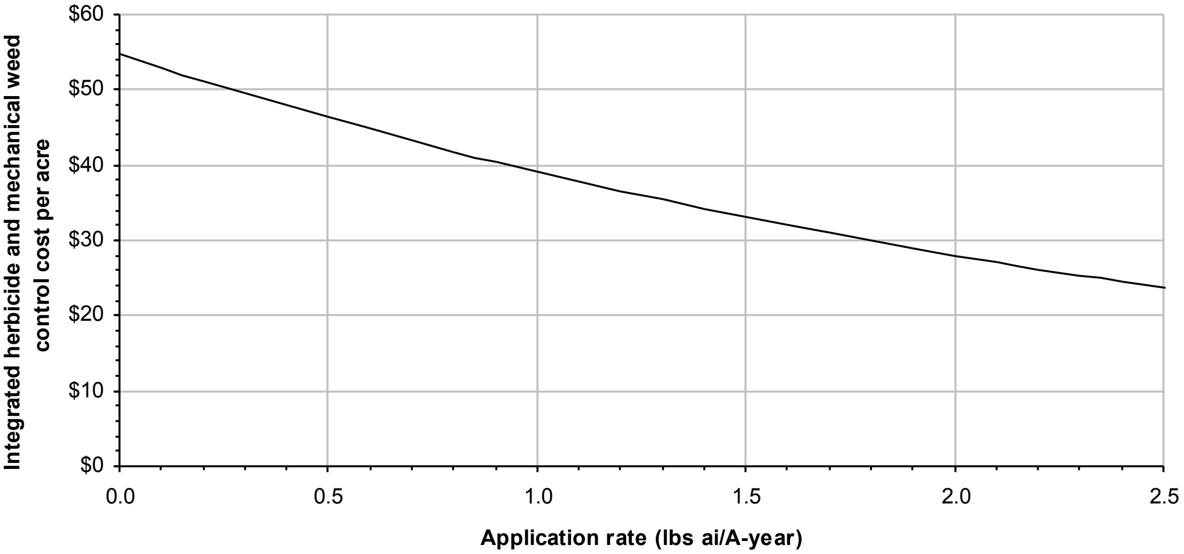

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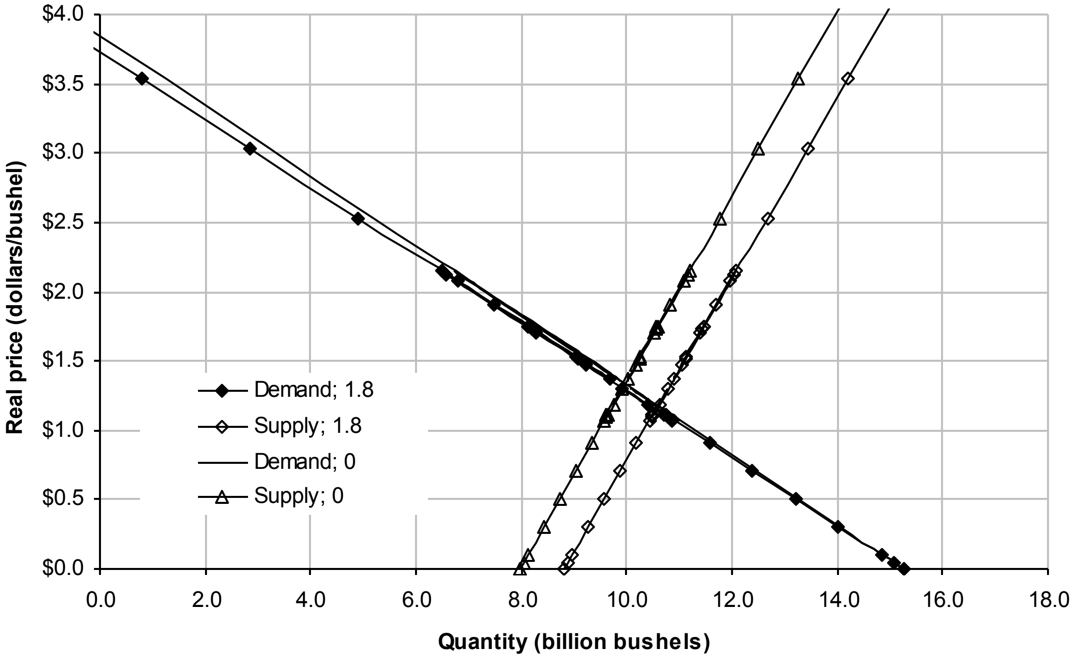

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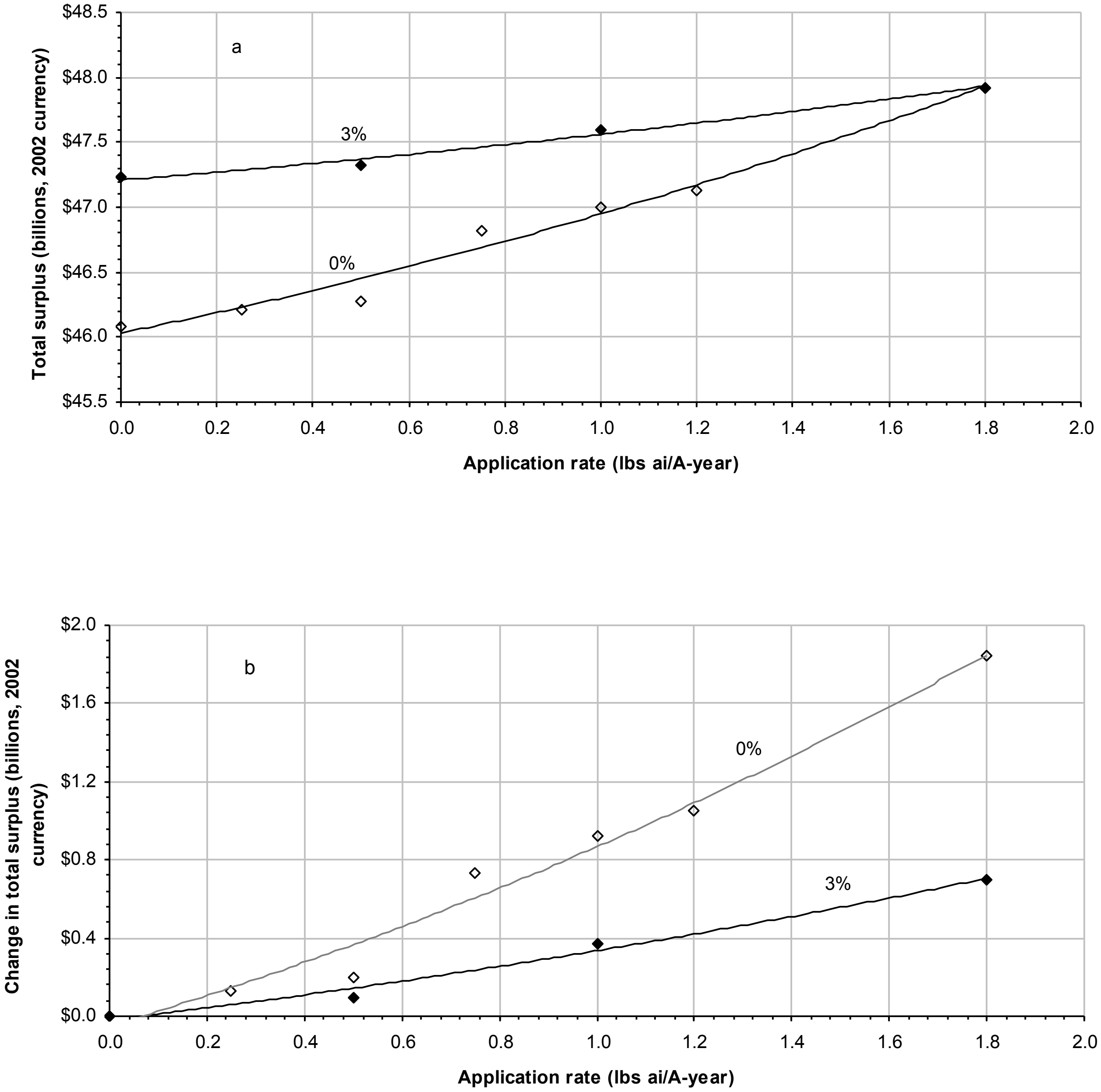

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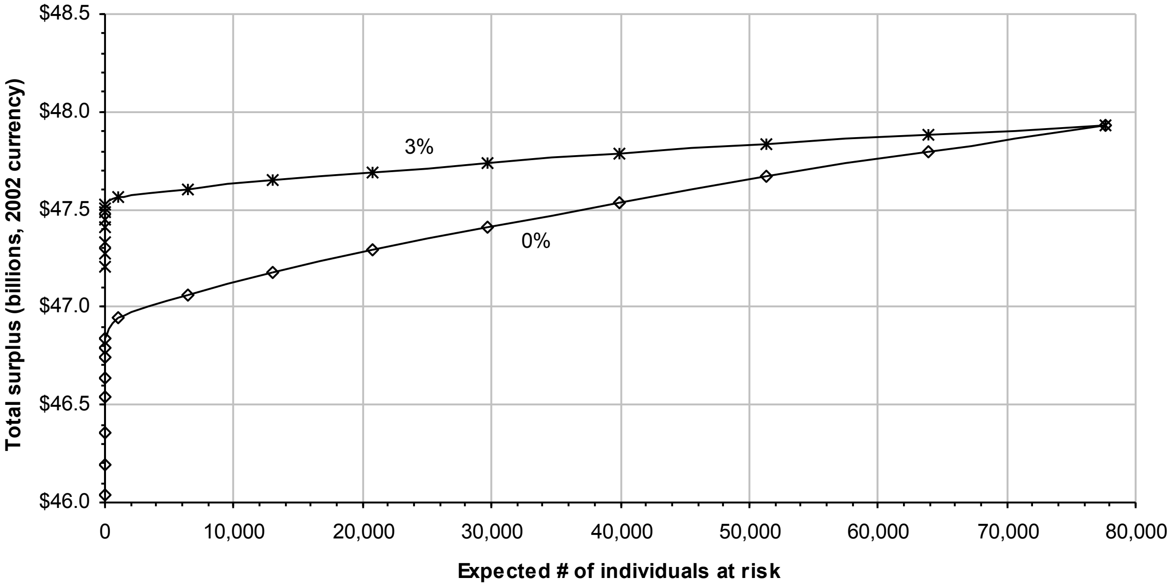

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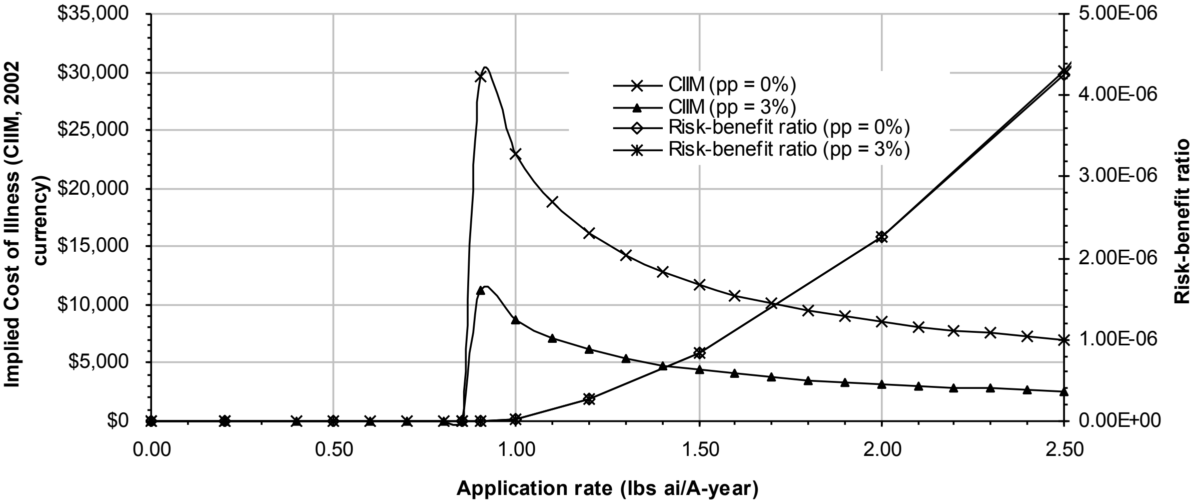

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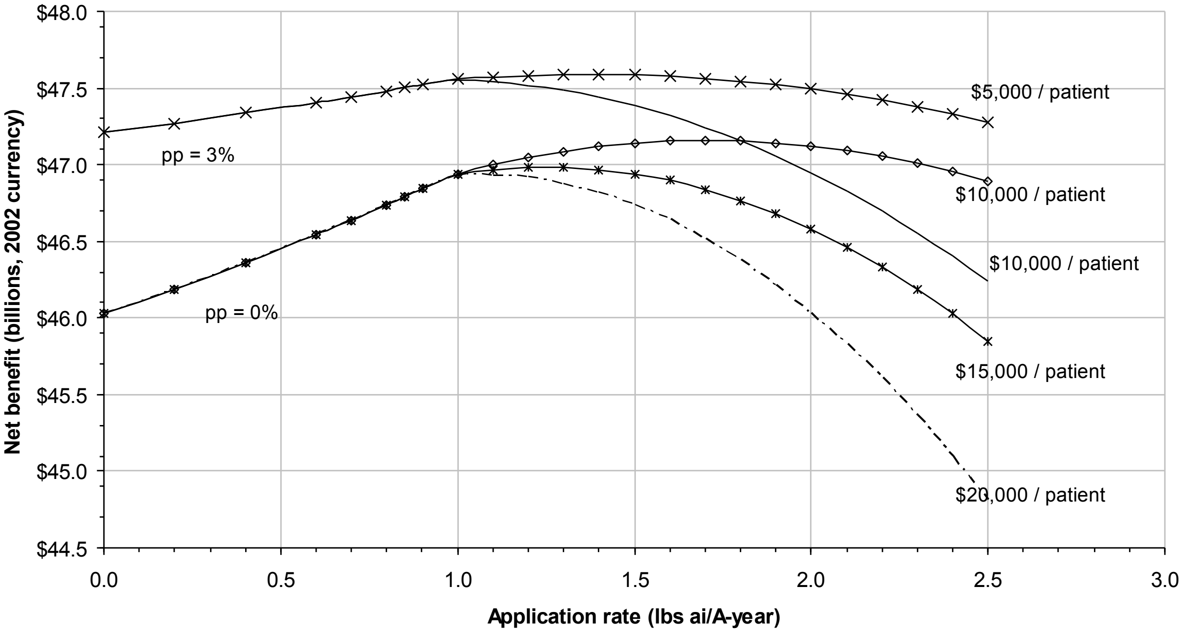

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