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An economic evaluation of the environmental benefits from pesticide reduction

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Abstract

Previous studies on the environmental impacts of pesticide use have tended to focus either on measuring damages through changes in relative risks to various environmental categories or examining the trade-off between pesticide use levels and abatement costs. This study uses the physical risk assessment approach combined with contingent valuation survey results on consumers' willingness to reduce pesticide risk. The reduction in external costs associated with the changes in pesticide use in Ontario agriculture between 1983 and 1998 is US$ 188 per household. The environmental benefits are largely due to the reduction in the level of high and moderate-risk pesticides. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The intensive use of pesticides in agriculture has significantly increased agricultural productivity. The on-farm benefits of pesticide use are off-set to some degree by the off-farm costs imposed by these pesticides on the environment. Environmental contamination from pesticides ranges from the disruption of natural water, air and soil functions, to the alteration of the ecosystem resulting in detrimental affects on nutrient cycles, or the toxicity of non-target organisms. Concerns over these environmental impacts have led to policy efforts ranging from moral suasion to regulations to economic instruments, all designed to reduce pesticide use. Sound policy design requires an assessment of the benefits from a reduction in the amount of pesticide applied.

Approaches to assessing the economic impacts of reducing pesticide use, specifically through integrated pest management, have been reviewed recently by Swinton and Williams (1998). The environmental impacts of pesticide use are commonly proxied through variables such as pounds of active ingredient (a.i.) applied or dollars spent on pesticides. Both measures assume that environmental damage is directly correlated with the quantity of pesticide used, regardless of the specific chemical and formulation. Given the costs of monitoring and measuring the extent of damages, it is impossible to accurately determine the actual damages of pesticide use. Instead, damages have been measured through changes in the relative risks to a series of environmental and human health categories.

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An example is the work by Kovach et al. (1992) who developed the environmental impact quotient (EIQ) to determine the risk of pesticides to the environment. The EIQ assigns a number to an a.i. based on 11 characteristics of the ingredient in order to calculate the environmental components of the indices. Higley and Wintersteen (1992) followed by Mullen et al. (1997) used eight separate criteria to characterise environmental risk from insecticides, herbicides and fungicides in calculating their environmentally adjusted EIQs. Hoag and Hornsby (1992), Teague et al. (1995), and Crissman et al. (1998) included site-specific criteria in estimating environmental impacts or risks from pesticides. Hoag and Hornsby (1992) developed a trade-off frontier for pesticide costs and a ground water hazard index. The criteria included pesticide specific and site-specific criteria that could affect the likelihood of ground water contamination. Teague et al. (1995) compared the EIQ with site-specific estimates of the environmental fate of pesticides, in addition to the toxicity and leachability measures in the EIQ. Crissman et al. (1998) also included site-specific information on soil types and rainfall in their measure of pesticide leaching risk. While these studies consider the environmental impacts and farm abatement costs of reducing risks, little has been done on the economic evaluation of these impacts.

The purpose of this paper is to identify the value of environmental benefits associated with changes in the levels and types of pesticides applied in Ontario agriculture. The approach is similar to that developed by Mullen et al. (1997) who extended the physical risk assessment by incorporating a contingent valuation survey to determine consumers' willingness to pay (CWP) for reductions in pesticide risk to different components of the environment. The paper begins by describing the method for assigning levels of relative risk to the pesticidal a.i.s for eight environmental categories. The approach for valuing the changes in risk from pesticide use are then described. The changes in pesticide risk to the environment from 1983 to 1998 are then outlined for all of Ontario agriculture. The economic value of changes in risks for the eight environmental categories are then described by time period and by risk level. Factors contributing to the changes and subsequent policy implications are then discussed.

2. Methods

2.1. Identifying changes in pesticide risk to the environment

The potential for a pesticide to inflict external damage costs (risk) is measured using an approach developed by Mullen et al. (1997). Rather than assume the amount applied is an accurate proxy for risk, the approach recognises that risks vary with pesticides depending on their toxicity, mobility and persistence. Mullen et al. (1997) develop a set of criteria for assigning levels of relative risk to pesticidal a.i.s for eight environmental and human health categories; ground water, surface water, acute human health, chronic human health, aquatic species, birds, mammals, and arthropods. Each a.i. was assigned a risk level of high, moderate, or low for each environmental category. For example, atrazine is categorised as a high environmental risk to ground water, a medium risk to surface water, aquatic species, acute and chronic health, and a low-risk to birds, mammals and non-target organisms. A list of the risk levels posed by all the pesticides used in Ontario for each of the eight categories is available from the authors upon request.

The approach thus permits the measurement of the change in total kilograms of pesticide within each of the 24 risk per environmental classes (the three levels of risk for each of the eight environmental categories). For example, the 585,208 kg of atrazine a.i. applied to corn in 1993 were allocated to the appropriate risk per environmental classes as defined above. The amount of each pesticide applied was similarly allocated. The total amounts for all pesticides for each class were then summed to determine the total high, medium and low-risk per environmental category per survey year. This total within a given environmental/risk category can be expressed as

$$\mathrm{Use}_{ij} = \sum_{k=1}^{K} P_{ijk}, \quad \forall\, i = 1, 2, \ldots, 8 \text{ and } j = 1\text{–}3 \qquad (1)$$

where Use_{ij} is the amount of a.i. (kg) applied from all pesticides in environmental category i and risk level j; P_{ijk} the amount (kg) of pesticide k applied that is a risk level j to environmental category i, and K is the total number of pesticides applied. Note that, the total amount of pesticide applied in a year (total) equals the sum of the amount of a.i. across the three risk levels for each environmental category

$$\text{Total} = \sum_{j=1}^{3} \text{Use}_{ij}, \quad \forall\, i = 1, 2, 3, \ldots, 8. \tag{2}$$

Once the total level of risk is determined in kilograms of a.i. per risk category for each environmental category i and each risk level j (Use_{ij}), it is possible to determine the change in risk from year to year.

2.2. *Valuation of changes in environmental risk*

While the change in risk from pesticide use can be assessed by comparing the amount of pesticide applied within each risk level across years, this would not account for the greater benefits attached to a reduction in high versus low-risk pesticide use. One method to weight, the changes in use for alternative risk levels is to assign monetary values to these changes. Since reducing pesticide risk is not a market commodity, the value of the changes in environmental risk associated with changes in pesticide use must be estimated through a non-market valuation technique. The estimates used in this study are based on the results of a contingent valuation survey administered to a random sample of 3000 households in the United States by Mullen et al. (1997). The questionnaire began by asking for the respondent's monthly grocery bill followed by questions on the individual's willingness to pay to avoid a given level of risk to the environment and human health through an increase in that grocery bill. The respondents were asked to reveal their willingness to pay for each of the three risk levels (WTP_j, $j = 1$–3) rather than their WTP for a reduction in risk for each of the eight environmental categories with each risk level (WTP_{ij}). Thus, the obtained WTP_j for WTP_{ij} is assumed to be the sum of the WTP to reduce risk within each environmental category. However, the three WTP_j values were not split equally among the eight environmental categories since is it is assumed that reducing pesticide use that is high-risk to humans, for example, is valued more than a corresponding reduction in pesticide use that is high-risk to arthropods.

The revealed WTP_j values were used to infer the eight WTP_{ij} values for that risk level through a ranking that the individuals assigned to the environmental categories. Respondents were asked to identify how important they felt it was to avoid a given level of risk with each of the eight environmental categories through a six-point Likert scale ranking (0 = not important at all and 6 = very important). This rating was completed for each of the three risk levels. The importance of reducing risk for each category was then used to infer the respondent's WTP for a reduction in risk j for each environmental category i by taking the Likert scale rating for that category (importance_i) and dividing it by the sum of the ratings for all categories

$$\text{WTP}_{ij} = \frac{\text{importance}_i}{\sum_{i=1}^{8} \text{importance}_i} \times \text{WTP}_j, \quad \forall\, i = 1, 2, \ldots, 8 \tag{3}$$

Thus, if all environmental categories were deemed equally important, the revealed WTP for a risk level would be divided equally between the eight categories. The WTP values obtained by Mullen et al. were adjusted to reflect Ontario conditions by using Ontario average income values and converting into Canadian dollars. The resulting estimates are listed in Table 1.

With the WTP_{ij}, the value from changes in environmental pesticide risks per individual can then be assessed using the following equation:

$$\text{Value of risk change}_t = \sum_{i=1}^{8}\sum_{j=1}^{3} \text{WTP}_{ij} \left(1 - \frac{\text{Use}_{ijt}}{\text{Use}_{ijt-1}}\right) \tag{4}$$

Thus, the value of the risk reduction in period t is equal to the percentage change in the amount of

Table 1
WTP_{ij} in Ontario, 1993 (US$ per household per month)[a]

Environmental category	High-risk	Moderate-risk	Low-risk
Ground water	5.83	3.94	2.37
Surface water	6.26	4.28	2.58
Aquatic species	6.21	4.20	2.53
Acute human	6.00	3.99	2.40
Chronic human	5.96	3.93	2.39
Avian species	5.66	3.71	2.22
Mammalian species	5.63	3.69	2.25
Arthropods	5.12	3.39	2.04

[a] Source: adjusted by authors from Mullen et al. (1997), and Statistics Canada Category no. 62-001 & 11-210.

a.i. associated with each risk level j and for each environmental category I $(1-(\text{Use}_{ijt}/\text{Use}_{ijt-1}))$ multiplied by the corresponding value for the individual's WTP_{ij}. Decreases (increases) in usage for any environmental/risk category will reduce (increase) the environmental risk costs. However, savings can be generated even if there is no change in total pesticide use between periods, if there is a relative change in the level of risks posed by the same amount of a.i. For example, benefits are generated if there is a shift toward low-risk pesticides and away from high-risk ones, since the WTP values are higher for high-risk than for low-risk applications. Similarly, a reduction in the dollar value of environmental risk takes place if the relative changes occur for an environmental category for which the WTP is high. The approach does not account for the absolute level of pesticide use so that a proportionate reduction of pesticides when a large amount is applied is valued the same as when the total amount of use is small. The approach assumes a linear relationship between the percentage risk reduction and actual risk eliminated within each category since, WTP values are based on how much individuals would be willing to pay to avoid a risk while the actual changes in pesticide use result in only a fraction of the risk being eliminated.

3. Data and results

3.1. Data

The Ontario Ministry of Agriculture Food and Rural Affairs has surveyed growers every five years since 1973 to compile a record of the use of herbicides, insecticides, and fungicides in Ontario crop production. The survey collects the area of each crop grown (regardless of whether it was sprayed or not), the amount of product applied to an area, the number of times a crop is sprayed, and its PCP number that indicates the strength of the product and the multiple a.i.s in the case of mixtures. The individual grower data is then aggregated up to the county and provincial level based on production shares. This publicly available, aggregated data is used in this study to compare changes in use patterns and to document progress made in pesticide and environmental risk reduction.

3.2. Results

3.2.1. Changes in pesticide risk to the environment

The total amount of pesticides applied in Ontario has declined approximately 40% from 8.8 million kg of a.i. in 1983 to 5.2 million kg of a.i. in 1998 (Table 2). The change in the total amount of pesticide use was associated largely with a decrease in application rates. Some of the reduced rate (9%) is indirectly attributable to a government program called Food Systems 2002. This program funded research and educational activities into pesticide management with the objective of reducing pesticide use in the province of Ontario by 50% over a 15-year-period ending in 2002. However, the decrease in the total amount applied is due largely to two major changes in production practices related to pesticides during this period. The first change was a 20% reduction in the total area of land farmed, and the second was a shift in cropping patterns from corn to soybeans. Soybeans generally require less herbicide than corn and the increased use of a corn-soybean rotation reduced the need for insecticide compared with continuous corn.

The amount and share of the annual total amount applied classified by risk level are given for the eight environmental categories in Table 2. The majority of the pesticides applied are not considered high-risk for any of the environmental groupings. In 1983, high-risk pesticides represented more than one-quarter of the total amount applied for only the ground water and chronic human categories. The total amount and share of pesticides that are high-risk for these categories declined over time, particularly in terms of chronic human effects. However, there has been an increase in the relative share of total pesticides applied that represent a high-risk to aquatic species, surface water and acute human categories. The share of the total applied that is high-risk for these groupings is approximately 20%. This increase in the relative share of high-risk pesticides for these three environmental categories came as a result of a decrease in the amount of moderate-risk pesticides applied. For all categories, with the exception of arthropods, the total amount of pesticides that are moderate-risk has fallen significantly in both absolute amounts and as a share of the total. Yet around half of all pesticides applied are considered moderate-risk to surface water, aquatic species, and chronic human categories. For the last

Table 2
Total amount (kg) and share (%) of herbicide, insecticide, and fungicide a.i. applied in Ontario to all field crops, fruits and vegetables by Use_{ij}, 1983–1998

Environmental category	Risk level	1983		1988		1993		1998	
		Total amount (kg)	Share (%)	Total amount (kg)	Share (%)	Total amount (kg)	Share (%)	Total amount (kg)	Share (%)
Ground water	High	2231640	25	1867780	26	1418179	23	1150263	22
	Moderate	3193090	36	2805510	39	2139012	34	1684669	32
	Low	1023210	12	1272370	18	1590269	25	1587606	30
Surface water	High	866990	10	1106400	15	1355613	22	1449541	28
	Moderate	5223150	60	4485530	62	3181613	51	2536809	49
	Low	357800	4	353730	5	610234	10	436188	8
Aquatic species	High	785680	9	903340	13	998803	16	685498	13
	Moderate	4183620	48	3180410	44	2574754	41	2747777	53
	Low	1478640	17	1861910	26	1573903	25	989263	19
Acute human	High	833800	9	905130	13	1186354	19	1090605	21
	Moderate	3659420	42	2185040	30	1583966	25	1270393	24
	Low	1954720	22	2855490	40	2377140	38	2061540	40
Chronic human	High	2283980	26	903460	13	747554	12	535461	10
	Moderate	3293420	38	3817930	53	3053401	49	2860719	55
	Low	870540	10	1224270	17	1346505	22	1026358	20
Avian species	High	221380	3	184430	3	156564	3	85556	2
	Moderate	1302190	15	1203930	17	1056483	17	408147	8
	Low	4924370	56	4557300	63	3934413	63	3928835	75
Mammalian species	High	261330	3	202830	3	201964	3	68281	1
	Moderate	2211080	25	1192230	17	1088797	17	576365	11
	Low	3975530	45	4550600	63	3856699	62	3777892	72
Arthropods	High	624460	7	540290	8	559161	9	475995	9
	Moderate	189080	2	282410	4	594188	10	694979	13
	Low	5634400	64	5122960	71	3994111	64	3251563	62
Nematocides growth regulators and classification unknown		2329430	27	1255810	17	1098982	18	791864	15
Total for year		8777370		7201470		6246442		5214402	

Table 3
Change in the amount of pesticide applied by risk category between 1983 and 1998 in Ontario (%)

Environmental category	High-risk	Moderate-risk	Low-risk
Ground water	48	47	−55
Surface water	−67	51	−22
Aquatic species	13	34	33
Acute human	−31	65	−5
Chronic human	77	13	−18
Avian species	61	69	20
Mammalian species	74	74	5
Arthropods	24	−268	42
Average	25	11	0

three categories in Table 2, avian species, mammalian species and arthropods, the majority of pesticides applied continues to pose a low-risk.

The percentage changes in the amount of pesticide applied by risk category between 1983 and 1998 are listed in Table 3. The percentage changes are important for the valuation exercise to follow as the WTP values refer to the complete elimination of risk. The valuations multiply the WTP values (Table 1) by these percentage changes as noted in Eq. (4). There has been significant reduction in the absolute amount of pesticide that is considered high and moderate-risk for most of the environmental categories. The amount of pesticide that is high-risk for surface water and acute human categories has increased between 1983 and 1998 by 67 and 31%, respectively. While, the percentage increases are significant, the total amount still represents less than one-third of the total amount of pesticide applied by risk category. The use of moderate-risk pesticides fell for all environmental categories except arthropods. As discussed above, the majority of the pesticides applied are considered low-risk for this category. The amount that is moderate-risk for arthropods increased from 0.19 million kg of a.i. in 1983 to 0.69 million kg of a.i. in 1998 but this amount represents 13% of the total applied. In summary, most of the 40% decrease in the total amount applied between 1983 and 1998 is due to a decrease in high and moderate-risk pesticides for most of the environmental categories.

3.2.2. *Valuation of changes in environmental risk*

The values of the changes in environmental risks posed by pesticides in Ontario evaluated using Eq. (4) are listed in Table 4. The values indicate the amount an average household would be willing to pay annually to experience the percentage change in environmental risk observed for each time period. The reduction in external costs associated with the changes in pesticide use between 1983 and 1998 is US$ 188 per household annually. Since the total number of households in Ontario in 1993 was 3,781,440, the value of the environmental risk reduction for the entire province over the last 15 years was 711 million (Canadian)$.

The largest reduction occurred in the last 5-year-period with essentially no benefits associated with changes between 1988 and 1993. The value of the change in pesticide risk was greatest between 1993 and 1998 since the changes in risk were positive for all eight environmental categories. The largest benefits accrued respectively to mammalian species, avian species, chronic human, ground water and aquatic species. These results are due to the large percentage reduction in the total amount of pesticide applied

Table 4
Values of the changes in environmental risks posed by pesticides (US$ per household per year)

Environmental category	1983–1988	1988–1993	1993–1998	1983–1998
Ground water	10.22	20.97	23.31	40.55
Surface water	−13.14	−24.44	14.03	−30.84
Aquatic species	−6.94	6.42	31.27	36.85
Acute human	−0.14	−4.37	19.11	7.51
Chronic human	24.06	18.92	30.09	55.82
Avian species	16.68	19.36	58.16	77.62
Mammalian species	31.62	8.25	66.11	83.99
Arthropods	−9.58	−41.66	6.79	−83.88
Total change	52.79	3.43	248.87	187.61

Table 5
Decomposition of the value of changes in environmental risks posed by pesticides by risk category, 1983–1998 (US$ per household per year)

Environmental category	High-risk	Moderate-risk	Low-risk	Total
Ground water	33.90	22.34	−15.69	40.55
Surface water	−50.47	26.42	−6.78	−30.84
Aquatic species	9.50	17.30	10.05	36.85
Acute human	−22.18	31.26	−1.57	7.51
Chronic human	54.75	6.20	−5.13	55.82
Avian species	41.67	30.57	5.39	77.62
Mammalian species	49.91	32.74	1.34	83.99
Arthropods	14.61	−108.84	10.35	−83.88
Total change	131.69	57.96	−2.05	187.61

that is considered high-risk to these categories and the greater value placed by households on a percentage reduction in high-risk pesticides. The external costs of pesticides did increase over the whole time period for surface water and arthropods, particularly between 1988 and 1993. The negative value for the change in environmental risk for surface water was due to the increase in the amount of low and high-risk pesticide applied which more than offset the large decrease in the absolute amount of pesticide considered moderate-risk for this category. For arthropods, most of the pesticide applied is considered as low-risk. Although, this total fell significantly, a relatively large percentage increase in the amount of medium risk pesticide applied (see Table 3) accounts for the negative value change.

The values of the changes in environmental risks for the period 1983–1998 (last column of Table 4) are decomposed by risk category in Table 5. The results emphasise that the environmental benefits are due to the reduction in the level of high and moderate-risk pesticides (Table 5). Most categories experienced a reduction in the external costs from changes in the levels of pesticides that are considered high-risk for that category. Exceptions are the surface water and acute human categories for which the external costs per household increased by US$ 51 and 22, respectively. Only for the arthropod category was there an increase in the external costs due to changes in the use of pesticides considered moderate-risk as noted above. The overall external costs of low-risk pesticide use have increased since 1983 due to the increase in use of these pesticides for four environmental categories (ground water, surface water, acute human, and chronic human). However, for all these categories except surface water, the increase in cost associated with increased low-risk pesticide use is smaller than the environmental benefits that result from the reduced use of pesticides considered to be high or moderate-risk.

4. Conclusions

Designing sound policies to reduce pesticide use requires an assessment of the environmental benefits that can be compared with the abatement costs for pesticide users and the administrative costs of enforcing the policy. Previous studies of the environmental impacts of pesticide use have tended to focus either on measuring damages through changes in relative risks to various environmental categories on or examining the trade-off between pesticide use levels and abatement costs. This study uses the physical risk assessment approach combined with contingent valuation survey results on consumer's willingness to reduce pesticide risk. The method developed by Mullen et al. (1997) is used to identify the value of environmental benefits from changes in the level and types of pesticides applied in Ontario agriculture. The total amount of pesticides applied in Ontario has declined approximately 40% from 8.8 million kg of a.i. in 1983 to 5.2 million kg of a.i. in 1998. Only for the surface water category were high-risk pesticides more than one-quarter of the total amount applied in 1998. The total amount and share of pesticides that are high-risk for most environmental categories declined over time, particularly in terms of chronic human and mammalian species effects. There was a similar decrease in the amount of pesticides used that are considered moderate-risk with the exception of the arthropod environmental category. The reduction in total amount applied is due largely to the reduction in high and moderate-risk categories as the percentage change in low-risk pesticide use averaged to zero across the eight environmental groups.

The reduction in external costs associated with the changes in pesticide use between 1983 and 1998 is US$ 188 per household annually, which represents a value of US$ 711 million for the province as a whole. Once again, the environmental benefits can be attributed to the reduction in the level of high and moderate-risk pesticide use. The percentage decreases noted for the total amount applied are weighted by the willingness to pay to eliminate risks, with higher values associated with higher risks. In most cases, the categories experienced a reduction in external costs due to reductions in the use of pesticides that are considered high-risk. Over 70% of the total value associated with the reduction in environmental risk is due to the reduction of high-risk pesticide use. The overall external costs of low-risk pesticides have increased since 1983 due to the increase in use of these pesticides in the categories ground water, surface water and acute and chronic human health. However, this slight increase in cost associated with increased low-risk pesticide use is still significantly smaller than the value of the environmental benefits that results from the reduced use of pesticides considered high and moderate-risk.

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