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Pesticide externalities from the US agricultural sector – The impact of internalization, reduced pesticide application rates, and climate change

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Abstract

This study uses mathematical programming to examine alternative assumptions about regulations of external costs from pesticide applications in US agriculture. We find that, without external cost regulation, climate change benefits from increased agricultural production in the US may be more than offset by increased environmental costs. The internalization of the pesticide externalities increase farmers' production costs but increase farmers' income because of price adjustments and associated welfare shifts from consumers to producers. Our results also show that full internalizations of external pesticide costs substantially reduces preferred pesticide applications rates for corn and soybeans as climate change.

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Keywords: climate change impacts; pesticide externalities; farm management adaptation; agricultural sector model; welfare maximization, environmental policy analysis; United States

1. Introduction

Agricultural pesticides have been increasingly recognized for their adverse effects on the environment and human health. These impacts are sensitive to climate change because pest pressure and optimal pesticide application rates vary with weather and climate conditions. In the current situation, with about 500 million kilograms of pesticide applied to about 170 million hectares (NASS, [1]), Koleva and Schneider [2] calculate that pesticide external costs are about 12.5 billion dollars annually: 9.5 billion due

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to human health impact and the remaining 3 billion due to environmental damages. Using the projection on pesticide application due to climate change, they estimate human health and environmental costs to reach 14.5 billion dollars and 5.3 billion dollars respectively in 2100. However, these estimations neglect possible agricultural adaptations regarding alternative pest management, major technological improvements in cropping systems or changes in planting crops.

This study analyzes a hypothetical regulation of the pesticide externality in the US under current climate conditions and for different projections of climate change. Two major questions will be addressed both of which are relevant to researchers, policymakers, and the general public. First, we want to quantify the net impacts of pesticide regulations on the US agricultural sector including likely consequences for agricultural producers, consumers, and the environment. Second, we want to estimate if and how these impacts differ under projected changes in weather and climate. We hope that the answers to these questions will provide more insight into the ongoing debate about the scope, degree, and justification of environmental policies. To simultaneously portray the diverse spectrum of agricultural production options, feedback from national and international commodity markets, climate change impacts, and external effects of pesticides, we integrate the results from Koleva et al.[3], Koleva and Schneider [2], and Knutson et al. [4] in the Agricultural Sector and Mitigation of Greenhouse Gas (ASMGHG) model (Schneider et al. [5]).

The paper proceeds as follows. Section 2 describes the data and basic structure of the ASMGHG model. The monetary estimates of agricultural surplus, market shifts, and land use changes associated with climate change are analyzed in section 3. Finally, section 4 concludes.

2. Data and Methods

The basic methodology of this study involves five major components. First, we use the estimates from Koleva et al. [3] on the effects climate change has on pesticide use. Second, we use the estimates from Pretty et al. [6] on how pesticide use causes external costs. Third, we use estimates of the effects of climate change on yields, and water use that are derived from Alig et al. [7]. Fourth, we use results from Knutson et al. [4] to depict the impact of reduced pesticide application rates on crop yields and costs. Fifth, we integrate all of these into an agricultural sector model to estimate the welfare costs and influence of considering pest related differences. Each of these steps is reviewed in more detail below.

2.1. Pesticide intensities and climate change

To estimate the effects of weather and climate on conventional pesticide application rates, Koleva et al. (2009) investigate crop and chemical class specific panel data across 14 years and 32 US states. They regress pesticide application rates on marginal revenue, total crop area, and climate and weather variables related to temperature and precipitation. The authors then combine the regression coefficients with downscaled climate projections developed at the Canadian Centre for Climate and the Hadley Centre in the United Kingdom based on the IPCC's A2 scenario (IPCC data distribution center, [8]). Their study explicitly considers three time periods: 2033, 2066 and 2099. For each time period, a 33-year average over the relevant weather and climate variables is used to estimate changes in pesticide application rates. They find that the application of most pesticides increases under both scenarios. The projection results vary by crop, region and pesticide.

2.2. External costs of pesticides

The external cost calculations for pesticide applications in the US are based on Koleva and Schneider [2]. These authors update the cost component estimates by Pretty et al. [6] on and integrate them with the Pesticide Environmental Accounting (PEA) tool developed by Leach and Mumford [9].

Koleva and Schneider [2] use the year 2000 as base period and project external costs of individual pesticides to three future dates including 2033, 2066 and 2100. For the base period, their cost estimates use observed data on individual pesticide applications from NASS [1]. The impact of climate change on external costs is based on the above described projections of pesticide applications by Koleva et al. [3]. The current average external cost of pesticide use in US agriculture they calculated at US$42 per hectare. Under projected climate change this cost could increase to $72 per hectare by 2100.

2.3. Crop impacts of climate change

Reilly et al. [10] examine the impacts on US agriculture of transient climate change as simulated by 2 global general circulation models focusing on the decades of the 2030s and 2090s. They use site-specific crop models to project biophysical impacts and linked economic models to simulate commodity trade and market effects. The final results of this national assessment indicate substantial regional differences. Particularly, under the Canadian scenario, the authors find agricultural production to increase between 40 and 80% in the Corn Belt and the Lake States but to decrease by as much as 60% in the Southeast. For the Hadley scenario, all regions show increased crop production with a more than 100% increase in the Lake States. The Canadian model based scenario leads to a much warmer and much drier climate, particularly in the 2030 period, thus projecting less positive effects on overall crop production and more negative effects in the Southern and Plains areas of the US. For this study, we use the climate, region, and crop specific data on yields, irrigation water requirements, and production costs from Reilly et al. [10].

2.4. Pest management

We also introduce alternative pest management options: conventional pesticide application rates, 50% reduction of overall pesticide rates, and pesticide free crop management. The data on associated cost and yield changes are based on Hall et al. [11] and Knutson et al. [4]. Both studies investigate empirically the potential effect of reduction or elimination of various pesticides in US agriculture and find that the broader the group of pesticides eliminated, the greater are the yield impacts. Their results also show that fruits and vegetables are more adversely affected by a broad-based reduction in pesticides than are field crops. Note that the 50% reduction scenario does not refer to a 50% reduction of all individual pesticides applied to a specific crop but rather an elimination of one or several individual pesticides which account for approximately 50% of the total application of active ingredients. Additionally, the authors observe that alternative pest control options to compensate the lack of chemicals are hardly sensible because the percentage increase in alternative treatment cost is generally larger than the percentage increase in revenue from avoided yield losses.

2.5. Integrating agricultural sector model

The above described impact estimates of climate on the pesticide externality did not depict possible agricultural adaptation regarding crop acreage, livestock numbers, and management intensity. To include these impacts, we use the model ASMGHG (Schneider et al., [5]). ASMGHG is designed to emulate US agricultural decision making along with the impacts of agricultural decisions on agricultural production factors, international agricultural commodity markets, and the environment. The model has been used for the analysis of technological developments and policy scenarios including environmental, agricultural, and energy regulations. ASMGHG is an extended version of Agricultural sector model of McCarl and associates (McCarl et al. [12]; Chang et al. [13]). Schneider [14] modified and expanded ASM to include a comprehensive GHG emission accounting module along with emission mitigation possibilities. ASMGHG portrays the following key components: natural and human resource endowments, agricultural production factor markets, agricultural technologies, primary and processed commodity markets, and agricultural policies. The model depicts representative crop and livestock enterprises in 63 aggregated US production regions. International markets and trade relationships are portrayed through 27 international regions for 8 major crops and through one rest-of-the-world region for 32 other commodities including various crop, livestock and processed products.

The objective function of the model maximizes total agricultural economic surplus subject to a set of constraining equations, which include resource limits, supply and demand balances, trade balances, policy restrictions, and crop mix constraints. The economic surplus equals the sum of consumers' surplus, producers' surplus, and governmental net payments to the agricultural sector minus the total cost of production, transportation, and processing. Based on economic theory, the optimal variable levels can be interpreted as equilibrium levels for agricultural activities after adjustment to given economic, political, and technological conditions. The shadow prices on supply demand balance equations identify market clearing prices.

Model solutions provide projection on land use and commodity production within the 63 US regions, commodity production in the rest of the world, international trade, crop and livestock commodity prices, processed commodity prices, agricultural commodity consumption, producer income effects consumer welfare effects, and various environmental impacts.

To do this study we integrate pest costs and yield changes under the SRES based A2 climate change scenario following the procedures used in the US National assessment. When we add the external costs we run the model with and without the externality internalized.

3. Results

The objective of this study is to find out how pesticide externalities are affected by climate change and by the internalization of the pesticide externality that would hold farmers accountable for the environmental damages of pesticides. Furthermore, we want to analyze the role of alternative pest management regimes. To accomplish these objectives, we consider a total of 24 scenarios which result from combinations of four time steps (2000, 2030, 2060, 2090), two climate projections (Canadian and Hadley), and three the internalization of the pesticide externalities (internalization of external environmental costs at 0, 50, and 100%). We use different internalization rates to address the uncertainty of the estimated external costs. For each scenario, we solve a scenario specific version of the ASMGHG model. Here the results from both climate change models are averaged.

3.1. Agricultural market and welfare impacts

Table 1 summarizes the individual and combined effects of climate change and the degree of internalization of the pesticide externality on agricultural market and welfare indicators. Climate and pesticide policy impacts affect agricultural markets in opposite directions. Under climate change projections, we find substantial increases in US crop production. A 50% internalization of external environmental costs of pesticides more than offsets the positive impacts of climate change. If stronger regulations of external costs are used, i.e. 100%, the negative impacts on production amplify. Agricultural crop prices and exports mirror the impacts on crop production. Climate change alone decreases prices and increases pesticide use. Note, however, that we kept the international crop supply functions constant. If crop production outside the US decreased substantially due to climate change, the downward pressure on crop prices from increases US crop production could have been mitigated. The combination of climate change and pesticide policy projections yields more complex price effects because the external costs are sensitive to climate change affects. Under climate change projections, a full (100%) internalization of external costs decreases US production by 18% and this almost doubles crop prices in the last simulation period.

Agricultural welfare impacts are displayed in the last four columns of Table 1. In absence of pesticide externality internalization, total agricultural sector surplus increases monotonically for both climate projections. With the combined impact of climate change and the assumed pesticide policies, total agricultural sector surplus decreases. The decreases are the consequence of increasing market prices and reduced supply. It is important to note that the combined impacts do not equal the sum of individual impacts. For example, the climate change projection for 2060 increases total agricultural surplus by US$10.8 billion. On the other hand, the 50 and 100% externality regulation scenarios decrease total agricultural surplus by US$24 and 34.8 billion, respectively. However, the combined effect of climate change and the internalization of the pesticide externality decrease total surplus by US$18.1 and 30.7 billion for the 50 and 100% internalization scenarios, respectively. The non-additionality of climate change and the internalization of the pesticide externality impacts arises for two reasons. First, downward sloped demand and upward sloped supply cause non-linear responses with non-constant rates of welfare changes. Second, climate change affects pesticide applications and thus the magnitude of external costs from agricultural pesticides. The increased benefits under climate change from positive supply shifts are partially or completely offset by the increased external costs from the additional use of pesticides.

Table 1 Economic surplus and market effects in US agriculture in response to pesticide policy and climate change

Internalization of External Pesticide Impacts	Climate Projection	*US Agricultural market impacts (Fisher Index)*				*Change in agricultural surplus (Billion $)*				
		Production	Prices	Exports	Imports	US Producers	US Consumers	Foreign Producers	Foreign Consumers	Total Surplus
None	2000	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0
	2030	108.5	83.7	124.4	85.7	-2.0	7.5	-0.7	3.6	8.4
	2060	112	80.2	137.5	87.9	-2.5	8.6	-0.9	5.6	10.8
	2090	115.5	80.7	158.0	93.9	0.4	7.0	-1.0	6.8	13.2
50%	2000	84.9	131.8	53.7	132.8	-3.1	-18.6	3.2	-5.5	-24.0
	2030	90.1	122.5	70.1	107.2	-4.0	-14.2	2.4	-3.0	-18.7
	2060	90.9	124.9	77.5	114.6	-2.0	-16.6	2.3	-1.9	-18.1
	2090	92.8	124.4	87.8	120.9	-1.1	-17.2	2.0	-0.6	-16.8
100%	2000	77.1	170.2	34.6	168.3	6.5	-38.4	5.6	-8.5	-34.8
	2030	80.7	169.4	49.3	144.3	9.7	-38.8	5.3	-7.1	-31.0
	2060	81.1	178.3	54	156.5	14.6	-44.3	5.3	-6.3	-30.7
	2090	81.9	182.9	59.3	148.7	16.8	-46.6	4.7	-5.0	-30.1

Table 1 also reveals the distribution of agricultural surplus between US producers, US consumers, and foreign countries. The direction of changes in consumers' surplus reflects price changes. The more prices increase, the higher are losses to US consumers. The impact on producers is more diverse because price and supply impacts work in opposite directions. Particular, supply increases lead to higher sales at lower prices and vice versa. Our simulation results show that the supply enhancing impact of climate change projections do not benefit producers. A 50% internalization of pesticide externalities worsens producer surplus. However, if the external costs are fully internalized, producers gain because the beneficial producer surplus effects of increased prices outpace the negative effects of reduced supply. If 100% internalization is applied, this effect becomes much stronger. Foreign countries' surplus aggregates foreign producer and consumer surplus changes. The net effects are moderately positive for climate change in absence of US pesticide policies and, with few exceptions, moderately negative under the combined impact of climate change and pesticide policies

Details on pesticide externality impacts in US agriculture in response to the internalization of the pesticide externality and climate change are displayed in Table2. In absence of internalization, climate change leads to relatively minor changes in US total agricultural revenue (TAR) but substantial increases in total environmental and human health costs (TEHH) this was not introduced above. Particularly, the latter costs increase relative to total US agricultural revenue from about one third in 2000 to about one half in 2090.

Table 2 Pesticide externality impacts in US agriculture in response to pesticide policy and climate change

Internalization rate of external pesticide impacts	Climate Projection	Average internalized pesticide costs ($/kg/ha)	Total Environmental and Human Health Costs in US (TEHH)	Total Internalized Costs in the US	Total Agricultural Revenues in the US (TAR)	Absolute Change in TEHH	Absolute Change in TAR	TAR Levels Relative to Base	TEHH Levels Relative to Base
			-------- in Billion US dollars --------					--- in % ---	
None	2000	0.0	125.2	0.0	357.1	0.0	0.0	100.0	100.0
	2030	0.0	155.9	0.0	352.6	30.7	-4.6	98.8	124.6
	2060	0.0	173.7	0.0	353.6	48.6	-3.6	99.0	138.8
	2090	0.0	182.4	0.0	354.4	57.2	-2.7	99.3	145.7
50%	2000	21.5	27.5	13.7	367.7	-97.7	10.6	103.0	21.9
	2030	25.5	32.8	16.4	365.7	-92.4	8.6	102.4	26.2
	2060	31.7	33.2	16.6	366.4	-92.0	9.6	102.6	26.5
	2090	34.7	35.3	17.6	367.8	-90.0	10.7	103	28.1
100%	2000	43.0	18.1	18.1	380.3	-107.1	23.2	106.5	14.5
	2030	51.0	18.8	18.8	378.5	-106.5	21.4	106	15.0
	2060	63.6	19.0	19.0	382.8	-106.2	25.7	107.2	15.2
	2090	69.4	20.8	20.8	386.0	-104.4	28.9	108.1	16.6

An internalization of the external costs of pesticides increases moderately total US agricultural revenues but decrease substantially the total environmental and human health costs. The increase in total revenue implies that supply reductions are more than compensated for by associated price changes. At a

100% internalization rate, agricultural revenues change by no more than 10% but pesticide externalities decrease by 80% and more across all climate scenarios. If stronger or weaker regulations of external costs are used, the magnitude of effects changes accordingly.

3.2. Pesticide Application Intensities

Climate change and pesticide externality internalization affect agricultural decisions in multiple ways. Farmers may grow different crops, use different rotations, and change the intensity of management related to irrigation, tillage, fertilization, and pesticide use. These adjustments are represented in ASMGHG. The simulated combined effects of climate projections and internalization on pest management strategy are provided in Table 3. The simulation results from Table 3, represent weighted averages over major crop groups.

Table 3 Effect of climate projections and the internalization of the pesticide externalities on pesticide application rates

Pesticide Application Rate	Climate Projection	Internalization Rate of External Environmental Costs of Agricultural Pesticides					
		None (Base)		50%		100%	
		in million acres (in percent relative to base)					
All Pesticide Management	2000 (Base)	330	(100.0)	299	(90.5)	280	(84.7)
	2030	321	(97.2)	274	(83.0)	270	(81.9)
	2060	303	(91.9)	284	(85.9)	279	(84.6)
	2090	313	(94.9)	286	(86.7)	267	(80.8)
				in million acres (share of total acreage)			
Conventional (100%)	2000 (Base)	330	(100.0)	194	(58.7)	165	(50.1)
	2030	321	(100.0)	172	(52.1)	154	(46.8)
	2060	303	(100.0)	180	(54.3)	162	(49.2)
	2090	313	(100.0)	171	(51.9)	150	(45.3)
Reduced (50%)	2000 (Base)	0	(0.0)	73	(22.1)	60	(18.2)
	2030	0	(0.0)	64	(19.4)	56	(17.0)
	2060	0	(0.0)	56	(17.0)	45	(13.8)
	2090	0	(0.0)	65	(19.6)	35	(10.7)
Minimum (0%)	2000 (Base)	0	(0.0)	32	(9.7)	54	(16.4)
	2030	0	(0.0)	38	(11.5)	60	(18.2)
	2060	0	(0.0)	48	(14.7)	71	(21.6)
	2090	0	(0.0)	50	(15.2)	82	(24.8)

The first table section shows the change in total crop area summed over all pesticide application intensities. Total area decreases both in responses to climate change and regulations of external costs from pesticides. Note, however, that the impacts of the two drivers do not add up. For example, a full internalization of external pesticide cost under climate 2000 conditions would reduce the cropped area by almost 14%. Equivalently, climate 2060 projections without internalization of external cost would reduce cropping areas by 14%. The combined impact of climate change and pesticide impact internalization on cropping is only slightly stronger than the individual effects and amounts to 15% reduction.

The following table sections show the area allocated to different pesticide application intensities. In absence of pesticide externality internalization, agricultural producers fare best with conventional pesticide intensities under all climate projections. As the regulation of external costs increases, the planted area fully treated with pesticides decreases and reduced or zero pesticide application intensities become more frequent. Particularly, if 50% of the external environmental costs of pesticides are internalized (columns 3 and 4 of Table 3), the land share under conventional pesticide application intensity decreases by about 35% and goes to reduced and zero application intensities. For stronger regulations of external costs, the land shares under conventional application rates decrease further and the area with zero pesticide application rates reaches about one third of the entire crop area.

Our simulation results indicate that, climate change coupled with internalization of the externality mostly decreases conventional and reduced pesticide application intensity, but increases the share of pesticide-free crop management. The changes in area shares of different pesticide application intensities due to climate are relatively small and do not exceed 10% across the entire simulation period.

4. Conclusions

This study examines alternative assumptions about regulations of external costs from pesticide applications in US agriculture under different climate conditions. The impacts of the internalization of the pesticide externality and climate change are assessed both independently and jointly. Without external cost regulation, climate change benefits from increased agricultural production in the US may be more than offset by increased environmental costs. While the internalization of the pesticide externalities may increase farmers' production costs, they are likely to increase farm income because of price adjustments and associated welfare shifts from consumers to producers. Our study also illustrates that full consideration of pesticides' external costs motivate farmers to choose substantially reduce pesticide applications

Our results have important research and policy implications. First, this analysis quantifies the tradeoff between agricultural market surplus and external pesticide costs under different climate conditions. Our estimated benefits from internalization may be contrasted with policy transaction costs, to judge whether externality regulation is desirable. The examined pesticide policy could be interpreted as a pesticide tax, where the tax level corresponds to the environmental and human health damage. Such a policy is different from most existing regulations, which only prohibit pesticides but impose no charge on admitted ones. Second, if climate change leads to higher pesticide applications, the socially optimal response to climate change moves away from adaptation towards mitigation. Third, our results could affect agricultural research programs because the expected social returns to research on alternative pest control strategies depend also on the expected external cost change. Fourth, our study can help to improve the mathematical representation of agricultural externalities in integrated assessment models. These models are increasingly used for the design and justification of climate and other environmental policies.

Several important limitations and uncertainties to this research should be noted. First, the findings presented here reflect agricultural management options for which data were available to us. Alternative pesticide management options are limited to three levels of application rates. In reality, farmers could adopt any application rate and could consider many other pest control adaptations which are not considered here. Second, the data for pesticide treatment costs, yield impacts, irrigation water requirements, and external costs involve regression analyses and mathematical simulation models. Thus, the certainty of the estimates presented here depends on the quality of these models and the certainty of all associated input data. Third, not monetized in this analysis were costs or benefits from reduced levels of other agricultural externalities, and costs or benefits of changed income distribution in the agricultural sector. Fourth, we operate with 32 crops mainly grains and not many fruits and vegetables which have higher contribution to the external cost of pesticide use. Fifth, the reductions in external costs due to regulation may be overstated because of leakage of pesticide intensive crops to other countries. Finally, all simulated results are derived from the optimal solution of the mathematical program and as such constitute point estimates without probability distribution.

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