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Modeling of Economic Effects of Air Pollution

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ABSTRACT

Background: Economic impacts of projected 2000–2050 changes in ozone pollution using the MIT Emissions Prediction and Policy Analysis (EPPA) model, in combination with results from the GEOS-Chem global tropospheric chemistry model of climate and chemistry effects of projected future emission have been assumed in our research. **Objective:** We compare the costs of ozone pollution under scenarios with 2000 and 2050 ozone precursor and greenhouse gas emissions (using the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A1B scenario. **Results:** We find that previous methodologies underestimate costs of air pollution by more than a third because they do not take into account the long-term, compounding effects of health costs**. Conclusion:** The economic effects of emissions changes far exceed the influence of climate alone.

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INTRODUCTION

Poor air quality affects public health in a variety of far-reaching ways, from our physical health, to our environment, to our economy (Kampa, & Castanas, 2008). The impacts of air pollution on the economy include direct economic impacts as well as indirect economic impacts stemming from the human health and environmental effects of air pollution. Reducing air pollution would lead to significant benefits to the socio-economic well-being of human being. Reductions in illness and mortality have direct social benefits and also improve the productivity of industry and decrease health care costs. Air pollution reductions have the potential to directly increase the productivity of agriculture, fishing, and tourism industries by decreasing environmental damages suffered by these industries, especially during Pilgrimage and visits (Haj and Umrah).

There are also costs to reducing air pollution though reducing emissions by cutting production, switching fuels or installing scrubbers can cost producers money. Developing and enforcing instruments such as regulation also costs governments money. To a varying degree, costs to producers and governments are ultimately paid for by people through higher taxes and prices.

Although a number of physical activities (volcanoes, fire, etc.) may release different pollutants in the environment, anthropogenic activities are the major cause of environmental air pollution. Hazardous chemicals can escape to the environment by accident, but a number of air pollutants are released from industrial facilities and other activities and may cause adverse effects on human health and the environment (Walkowiak *et al*., 2001). By definition, an air pollutant is any substance which may harm humans, animals, vegetation or material. As far as human are concerned an air pollutant may cause or contribute to an increase in mortality or serious illness or may pose a present or potential hazard to human health. The determination of whether or not a substance poses a health risk to humans is based on clinical, epidemiological, and/or animal studies which demonstrate that exposure to a substance is associated with health effects. In the context of human health, ‘‘risk’’ is the probability that a noxious health effects may occur (Vermylen *et al*., 2005).

Tropospheric ozone is an air pollutant that causes adverse human health impacts. Increasing industrialization without emissions controls will increase releases of chemical precursors to ozone, such as nitrogen oxides (NO*x*) and volatile organic compounds (VOCs). Changes in climate, including increasing temperature and other changing meteorological variables, have a complex effect on ozone concentrations Mickley 2007). Previous studies have explored the impacts of future emissions and climate on surface ozone concentrations using climate and chemical transport models. We apply these results to an economic model to assess the potential future health and economic damages of ozone due to changing emissions and climate in 2050.

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Previous research has projected the influence of both climatic change and future emissions under a variety of scenarios on surface ozone levels in the United States and elsewhere (Wu *et al* 2008a, 2008b, Hogrefe *et al* 2004, Racherla and Adams 2006, Murazaki and Hess 2006, Royal Society 2008, Racherla and Adams 2009). While there is substantial variability among models of the climate impact of ozone, most models predict a decrease in surface ozone background due to the effect of water vapour, and surface ozone increases of 1–10 ppb driven primarily by temperature in polluted mid-latitude regions (Jacob and Winner 2009). For example, Racherla and Adams (2006) used a global climate model to project a 5% decrease in the global Tropospheric ozone burden under the Intergovernmental Panel on Climate Change (IPCC) SRES A2 scenario, but an increase of 1–5 ppb in some polluted regions including the eastern United States. The Royal Society (2008) assessed projected trends in tropospheric ozone due to emissions and climate changes and implications for human health and vegetation. They found that mean O_3 concentrations will likely increase over polluted land regions due to climatic changes, but would decline where strong precursor emissions controls are put into place.

There is paucity and scarcity on data for O_3 concentrations as well as other pollutants are in KSA. The methodological approach presented herein addresses this limitation through the combination of air quality and GIS-based modeling techniques. Within the framework of the present study, a methodology is presented in order to assess spatial impacts and economic damages of photochemical air pollution to crops (Ashmore 1991, Vlachokostas *et al*., 2010).

The importance of this paper lies in the demonstration of a flexible and reliable methodological approach presented herein, which can support local or national authorities' planning schemes in order to analyse relevant benefits of policy interventions, focusing on the agricultural production. The results are very useful for highlighting the magnitude of the total economic impacts of photochemical air pollution to the area's agricultural sector and can possibly be used for comparison with relevant studies worldwide. Furthermore, spatial analysis of the economic damage could be of prime importance for governmental authorities and decision makers since they provide an indicative insight, especially if the economic instruments such as financial incentives or state subsidies to farmers are considered. Last but not least, incorporating O_3 impact in crop production forecasts can potentially improve the results of agricultural forecast by capturing the fluctuation in yield losses due to air pollution.

Methodology:

Over the last two decades, there have been many studies of the economic effects of reduced agricultural production due to O_3 air pollution. The first studies were undertaken in the USA in the mid- 1980s (Heck *et al*., 1987). Two main methodological approaches have been employed; the first approach simply uses market prices to estimate the monetary value of crop losses due to exposure to O_3. The second approach uses a model of supply and demand to estimate changes in producers' and consumers' surpluses. In theory, an approach that does not incorporate changes in prices with variation in yield will provide a less accurate estimate than a more comprehensive economic model, provided that the economic model is adequately parameterised. In general, the welfare effect of air pollution is a function of the value of crop production, the O3 sensitivity of the crops, the exposure to O3, the elasticity of demand for the crops and the constrained ability of producers to reallocate resources to less sensitive crops (Murphy *et al*., 1999).

Policy makers are able to use the logical flow presented in Fig. 1. For the formulation of an efficient policymaking scheme, the compilation of an accurate air pollutant emission inventory is crucial. It provides the input data for air quality simulations and therefore affects the reliability of concentrations fields and consequently accumulative exposure estimations to the cultivations under consideration. In order to enhance the reliability of an emission inventory it is important that all existing information is taken properly into account. The respective economic damages for the reference year reproduce a clear picture for the spatial relative yield losses in the area of interest.

Input Data:

In the GEOS-Chem future climate simulation used here (Wu *et al* 2008a, 2008b), both climate and ozone precursor emissions are based on the IPCC A1B scenario (IPCC 2001). Climate changes are simulated by the NASA/GISS GCM 3 (Rind *et al* 2007) and are used to drive GEOS-Chem as described by Wu *et al* (2007). In the A1B scenario, emissions of fossil fuel NO*x* decrease in developed countries (−40% in the United States) but increase by 90% globally. Detailed emissions for other ozone precursors from both anthropogenic and natural sources are given in Wu *et al* (2008a).

Model Simulation:

Four cases are used, following Wu *et al* (2008b): (1) year 2000 ozone precursor emissions and climate; (2) 2000 precursor emissions and 2050 climate; (3) 2050 precursor emissions and 2000 climate; and (4) 2050 precursor emissions and 2050 climate. This scenario design allows diagnosis of ozone cha as the difference between these simulations. nges due to only precursor emission changes, only climate change, and combined changes (Selin *et al*., 2009).

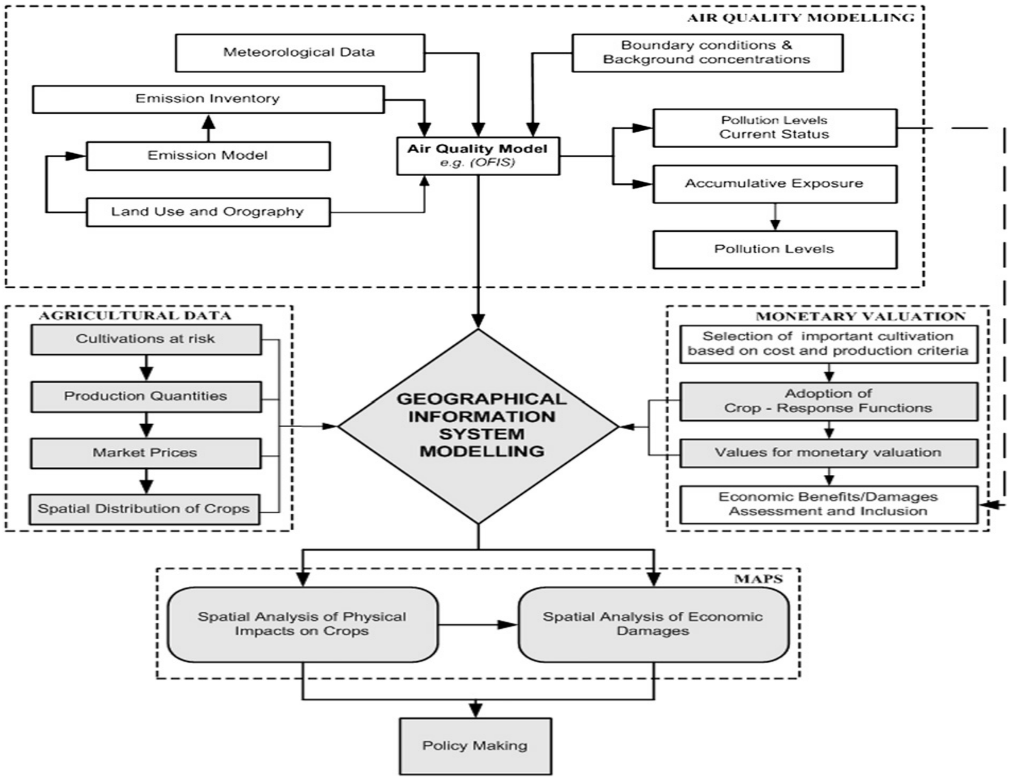

Fig. 1: Economic evaluation of damages to agricultural crops attributed to air pollution.

Model Simulation And Uncertainty Analysis:

Economic impacts from ozone was calculated using the EPPA reference scenario, which is consistent with an economy that produces global greenhouse gas emissions within 15% of A1B emissions to 2050. Moreover, the economic impacts of ozone pollution was also assessed by calculating the change in economic welfare (defined as macroeconomic consumption plus the value of leisure time) between simulations with varying levels of ozone.

We assessed the uncertainties in calculated mortalities and costs resulting from both the uncertainties in concentration– response functions and economic valuation of health endpoints, using a probabilistic approach with Monte Carlo sampling. We conduct our uncertainty analysis similarly to the methodology used by Webster *et al* (2008). We constructed probability distributions of concentration–response functions and associated costs, based on probabilistic ranges from Bickel and Friedrich (2005) and Holland *et al* (2005) (table 1). We assume that concentration–response functions are correlated (details in supporting information table S.1, available at stacks.iop.org/ERL/4/044014/mmedia) and that costs are correlated at $r = 0.9$. Using Latin Hypercube sampling, we select 400 sets of inputs for each case, with concentration–response functions and associated costs varying, and simulate resulting welfare change for each case using EPPA-HE.

Table 1: Concentration–response functions and costs for Europe region. Sources: Bickel and Friedrich (2005), Holland *et al* (1999, 2005), Matus (2005).

Outcome	Concentration–response functions	95% confidence interval	Cost EUc ($2000)	SE of costs	Cost China ($2000)
Mortality from acute exposure	0.03%	(0.01 -0.04%)	23 000	3100	690
Respiratory hospital admission (adults >65 years)	1.25×10^{-5}	$(-5.0 \times 10^{-6}, 3.0 \times 10^{-5})$	1800	570	290
Respiratory symptom day	3.3×10^{-2}	$(5.7 \times 10^{-3}, 6.3 \times 10^{-2})$	35	11	<1
Minor restricted activity day	1.15×10^{-2}	$(4.4 \times 10^{-3}, 1.9 \times 10^{-2})$	35	11	<1
Asthma attack	4.29×10^{-3}	$(3.3 \times 10-4, 8.3 \times 10-3)$	49	16	4.6
Bronchodilator usage	7.30×10^{-2}	$(-2.6 \times 10^{-2}, 1.6 \times 10^{-1})$	0.92	0.29	<1

Human Health And Economic Model Description:

The model calculates health impacts and related costs to the economy (lost labour, services, and leisure time) for a given mean concentration of pollutant in each of sixteen world regions. The regional structure of the model is shown in figure 2. The model takes as input the population weighted concentration in each region, and calculates cases and associated costs using a five-year time step. Resources devoted to health care become unavailable to the rest of the economy, and labour and leisure time lost as a result of illness or death is valued at prevailing wage rates. A full description of the economic assumptions of the EPPA-HE model is presented by Matus *et al* (2008).

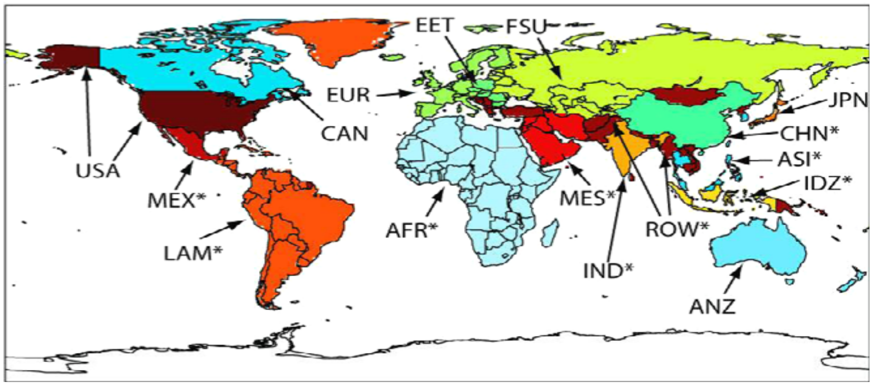

Fig. 2: EPPA-HE Regions. Asterisks represent regions referred to in text as developing

RESULTS AND DISCUSSION

Population-Weighted Ozone Concentrations:

Table 2 presents population-weighted average regional ozone concentrations for each EPPA region for both the year 2000 and projected 2050 concentrations with changed precursor emissions and climate. Also shown are changes in ozone due to climate alone, diagnosed from a model simulation with 2050 climate and 2000 precursor emissions, and due to emissions alone, from a simulation with 2050 precursor emissions and 2000 climate. (details in supporting information available at stacks.iop.org/ERL/4/044014/mmedia)

Table 2: Population-weighted ozone concentrations by EPPA region, and change in ozone due to climate, emissions, and net change 2000–2050, from GEOS-Chem.

Region	2000 [O_3]	2050 [O_3]	ΔO_3, climate	ΔO_3, emissions	ΔO_3 (2050–2000)
AFR	33.2	43.2	−0.2	10.3	10.1
ANZ	31.3	30.4	0.0	−0.9	−0.9
EUR	43.5	45.2	0.2	1.5	1.7
IND	61.0	85.4	0.4	24.0	24.4
ASI	41.4	53.4	0.1	11.9	12.0
JPN	50.9	48.4	0.9	−3.4	−2.5
MES	48.4	58.8	−0.5	10.9	10.4
USA	50.1	45.2	0.2	−5.1	−4.9

The net 2000–2050 ozone change is equal to the sum of these two contributions, indicating they are independent of each other in these simulations. Figure 3 shows population-weighted ozone concentration for Asia. Panel (a) shows O3 concentrations in Asia in 2050 climate, with constant (year 2000) ozone precursor emissions, while panel (b) shows the changes in O_3 due to climate change from present-day conditions (year 2000 climate and precursor emissions). Panels (c) and (d) show the total population in areas where O_3 decreases and increases, respectively, due to climatic changes.

As shown in figure 3 for Asia, the total population is roughly equal (1.5 × 109 people) in areas where ozone is increasing and decreasing. Areas of high population where ozone is projected to increase due to climate include northern India and eastern China, where ozone levels (panel (a) are particularly high. The population-weighted totals thus indicate a 0.1 ppb decrease due to climate change in China, and a 0.4 ppb climate-driven increase in India. This suggests a strong subregional variation in the effects of climate on ozone in urban areas, which could be further explored with regional atmospheric and economic modeling

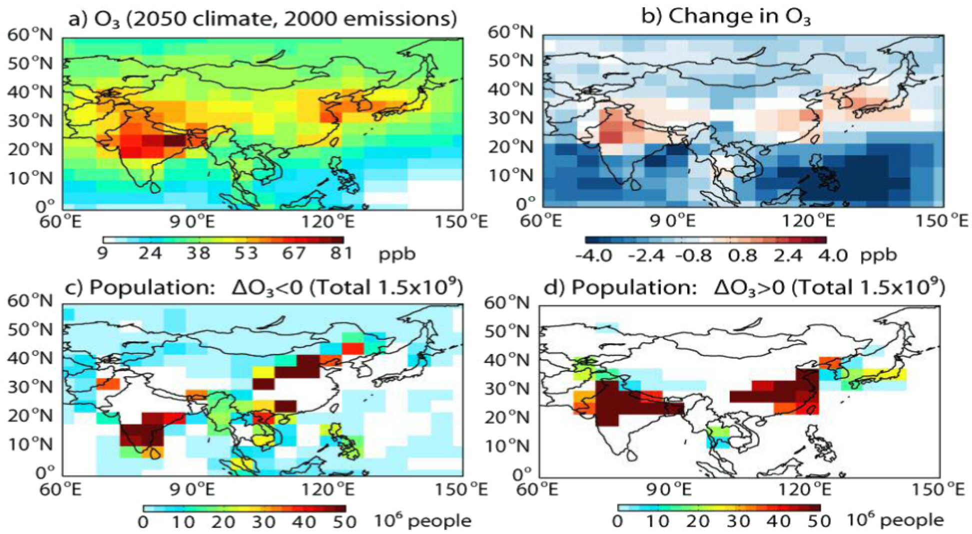

Fig. 3: Model simulated O3 change in Asia relative to population. Panel (a) shows O3 concentrations for 2050 climate and 2000 emissions. Panel (b) shows the overall projected change in ozone due to climate. Panel (c) shows total population in areas where ozone decreases due to climate, and panel (d) shows total population in areas where ozone increases due to climate

Monte Carlo analysis shows the influence of both concentration–response and economic uncertainty on our welfare results. Figure 4 shows the difference in welfare between the scenario with climate and emission changes to 2050 and 2000 ozone levels (first row), and between 2050 and the pre-industrial background (second row). We calculate a 95% probability interval of \$13 billion–\$190 billion for the annual welfare loss due to climate and emissions changes from 2000–2050. For the total cost of ozone pollution above pre-industrial background, the 95% probability interval is \$101 billion–\$1.53 trillion. These uncertainties only take into account the uncertainties in the concentration–response factors and the economic valuation of impacts, and do not take into account additional uncertainties in future emissions and climate.

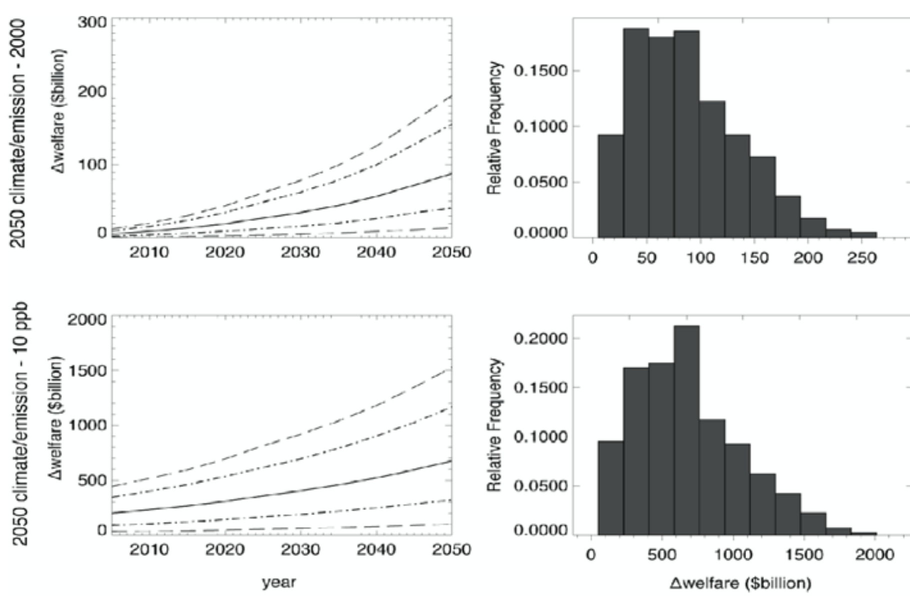

Fig. 4: Uncertainty in total global loss in economic welfare (consumption+leisure) from ozone-related health impacts due to (first row) climate and emission changes in 2050 relative to 2000, and (second row) ozone enhancements in 2050 above pre-industrial exposure (10 ppb), based on a 400 sample Monte Carlo simulation. Left column shows median (solid), 67% (dash–dot) and 95% (dashed) probability intervals. Right column shows frequency distribution of welfare loss for year 2050. All values are in year 2000\$. Note that the median welfare change for the ensemble is not equivalent to the welfare change calculated with mean inputs.

In contrast to previous findings of an increased trend of ozone with climate change in urban, high-ozone areas (Jacob and Winner 2009), we find that average population-weighted ozone changes due to climate are very small. Consistent with previous studies, ozone increases on the order of a few ppb are present in many urban regions in the model simulation of Wu *et al* (2008a), but in most cases they are offset by decreases in other highly populated regions, leading to a net change near zero.

Similar to the results for mortalities alone, the change in welfare due to emissions changes in the A1B scenario far exceeds the difference due to climate change alone. Using EPPA-HE, we can calculate the compounding effect of ozone pollution between 2000 and 2049 on the 2050 economy.

Economic effects in earlier years reduce the overall level of the economy and savings and investment in those years that then lead to a lower stock of capital in succeeding years. We

calculate this effect in EPPA-HE by the difference between our simulation in 2050, and a simulation with pre-industrial ozone.

Though ozone concentration changes due to climate change vary in sign and magnitude in different regions, we nevertheless calculate a net global welfare loss due to climate related ozone changes under the A1B scenario. The magnitude of changes due to emissions trajectories, however, far exceeds the climate signal, suggesting that future analyses could consider the effects of different emissions projections. Our analysis suggests that potential reductions in ozone emissions precursors such as NO*x* and VOCs could have substantial economic benefits due to human health improvements.

Conclusion:

This study provides information about ozone control benefits on crops and human morbidity and an approximation of control costs of NOx and ROG reductions to meet ozone standards ranging from 0.16 to 0.10 ppm in the San Joaquin Valley. With the information presented here, an ozone standard between 0.14 and 0.12 ppm appears to be the most efficient; this estimate needs to be qualified by uncertainties and omitted information. Even if it is not the optimal level of ozone control, attaining the current federal ozone standard of 0.12 ppm appears beneficial to the San Joaquin Valley. Use of incentive approaches, by lowering the costs of attaining any standard, makes a tighter ozone standard more efficient than if command-and-control is used.

The benefit and cost estimates in this study are subject to a margin of variability and uncertainties for several reasons. The agricultural benefit estimates could have large variances due to uncertainties in yield responses to ozone and elasticities of demand for crops. The health response function used in this study relates ozone concentration only to acute respiratory symptoms, although ozone also is known to affect human mortality and chronic respiratory conditions. These effects have not been documented sufficiently to be included here, leading to likely underestimation of the health benefits of ozone control. Large uncertainties surround both the health effects and the values of those effects. The cost estimates are likely to be overstated, due to lack of information on technology choices for businesses and omission of controls of some major mobile sources of pollution. Also, in the long run, new technologies are likely to reduce these costs further. Although reducing waste emissions from stationary and mobile sources in the San Joaquin Valley will likely reduce other air pollutants (such as particulates and carbon monoxide), these effects are omitted here. Finally, the analysis omits consideration of other benefits of ozone reduction, such as effects on visibility and structures. These factors will affect the efficiency of the ozone standards considered in this study.

Further research is required to provide a more complete cost-benefit assessment of regional ozone controls.

Efficiency is not the only criterion for deciding ambient air quality levels; indeed, under the Clean Air Act, consideration of costs is not permitted as a criterion. Even if efficiency were the generally accepted criterion, this analysis does not include all benefits of ozone regulation, and the costs provided are only estimates. Still, information on the benefits and costs of regulating ozone provides useful inputs into the public policy debates.

Undoubtedly, the current state of knowledge has still gaps and uncertainties. The purpose of ongoing research is to reduce gaps and in addition refine the methodology to reduce uncertainties, especially those regarding the CRFs. Clarity in defining these issues is a prerequisite for proper interpretation of the results in the policy arena. It is the authors' strong belief that the considerable figures of damage costs estimated in the present study would justify instant implementation of measures to reduce O3 in a regional scale, while increase public awareness to enhance environmental protection. There is still much to learn about subtle, chronic, low-level-pollution yield effects. Until some of all the above aforementioned areas of uncertainty are investigated further, the vegetation loss estimate can only be used with an understanding of its many deficiencies.

Despite these limitations, this study presents useful information on the benefits and costs associated with an environmental regulation. Through its incorporation of effects on both agriculture and health, its presentation of marginal as well as total effects, its assessment of different regulatory approaches, and its regional disaggregation of impacts, this analysis provides additional information to policy makers often absent from benefit-cost analyses of single options. As policy makers are likely to have a range of options in choosing how to control an environmental problem, this expanded information can contribute to better informed decisions. Furthermore, spatial analysis of the economic damage could be of importance for governmental authorities and decision makers since it provides an indicative insight, especially if the economic instruments such as financial incentives or state subsidies to farmers are considered.

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