Country-Specific Market Impacts of Climate Change

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Abstract: We have developed an intermediate climate-impact model, the Global Impact Model (GIM), which is more comprehensive than the "Top-down" approach and less computationally demanding than the "Bottom-up" approach. GIM consists of individual modules for climate, sectoral features, and climate response functions for each sector. GIM uses detailed spatial simulations by general circulation models (GCMs) to generate country-specific climates. The climate simulations are used to project country-specific market impacts, given the characteristics of the affected economic sectors and a response function for each sector. Two types of empirical response function, reduced-form and Ricardian, are used to assess the uncertainty of the climate impacts. The response functions for all sectors except tourism are currently based on analyses for the United States. Country-specific results indicate that the 2°C global-mean warming projected for 2060 will result in net market benefits for most OECD countries and net market damages for most non-OECD countries. The possibility that impacts may systematically differ among the countries is likely to be important to international agreements on climate-change policy. This demonstrates the importance of developing country-specific response functions to improve the science and inform the policy debate.

1. INTRODUCTION

The most recent IPCC reports (Bruce et al. 1996; Watson et al. 1996) highlight the state of the art of estimating the impacts of global warming. Although there is a vast amount of information about the direct effects of warming on a host of resources (Watson et al. 1996), only a handful of studies have linked these direct effects to damages. The most comprehensive national damage estimates were done by the U. S. Environmental Protection Agency (USEPA) (Smith and Tirpak 1989). Using the USEPA and other studies, together with their expert opinion, several authors (Cline 1992; Fankhauser 1995; Nordhaus 1991; Tol 1995) have estimated the damages from the equilibrium climate change induced by a doubling of the pre-industrial CO_2 concentration. These authors estimate that U.S. damages would range from 1% to 1.5% of the U.S. Gross Domestic Product (GDP), with 0.3% to 0.8% coming from market impacts (Bruce et al. 1996). Extrapolation of these results to other countries using physical impact measures (for example, miles of vulnerable coast line, Holdridge Life Zones, area of wetlands) and judgment suggests total losses in non-OECD countries of 1-3% of their GDP (Fankhauser 1995; Tol 1995).

Integrated assessment (IA) models have taken two approaches to calculating climate impacts: "Top-down" and "Bottom-up". "Top-down" models rely on aggregate damage functions, the simplest of which calculate global damages as a function of only the global-mean temperature change (e.g., Hope et al. 1993; Nordhaus 1991; Peck and Teisberg 1992). More recent regional models have constructed damage functions based on regional temperatures (Manne et al. 1993; Nordhaus 1994). Thus, IA models using the "Top-down" approach lack spatial and structural detail. In contrast, "Bottom-up" IA models have sought to capture the individual direct effects of climate change across the landscape (e.g., Alcamo 1994; Edmonds et al. 1994; Watson et al. 1996). While these models have done a good job of capturing the spatial detail given by climate models, they have not yet developed sound damage estimates because they do not seek to estimate welfare effects and because they fail to account for adaptation. Moreover, because "Bottom-up" models include an overwhelming amount of detail (Watson et al. 1996), they are computationally demanding.

In this study we develop a climate-impact model that is intermediate between the "Top-down" and "Bottom-up" models. We have constructed a Global Impacts Model (GIM) that combines: (1) the geographically detailed climate simulations of a general circulation model (GCM), (2) sectoral data for different countries, and (3) climate-response functions to estimate climate impacts in every country around the world.

2. METHODOLOGY

In this section we describe the three components of GIM.

2.1. Climate

GIM determines the change in annual surface-air temperature and precipitation for 184 countries using the geographical distributions simulated by a version of the University of Illinois at Urbana-Champaign (UIUC) atmospheric general circulation/mixed-layer-ocean model (Schlesinger and Verbitsky 1996) for control (326 ppmv, 1xCO_2), doubled (2xCO_2) and quadrupled (4xCO_2) CO_2 concentrations. The distributions of surface-air temperature and precipitation changes for the CO_2 doubling (2xCO_2-1xCO_2) and quadrupling (4xCO_2-1xCO_2) were divided by their respective simulated global-mean surface-air temperature changes and the resulting normalized distributions averaged to yield normalized values for each 4° latitude x 5° longitude GCM grid cell (Schlesinger and Andronova 1995). Country-specific normalized surface-air temperature and precipitation changes were then calculated by averaging grid-cell values within national borders. Climate changes above 65° latitude were omitted in estimating national averages because economic activities there are limited.

GIM multiplies the country-specific normalized surface-air temperature and precipitation changes by any given global-mean surface-air temperature change to determine the corresponding country-specific changes in annual surface-air temperature and precipitation. Country-specific present-day surface-air temperature and precipitation were obtained by averaging observed surface-air temperature and precipitation across the 4°x5° latitude-longitude grid cells within national borders (Schlesinger and Andronova 1995). Country-specific future surface-air temperature and precipitation levels were calculated by summing observed current values with the predicted changes.

2.2. Sectoral Data

GIM incorporates country-specific information including GDP, population, cropland, forest land and coastline. The size of each economic sector is measured for each country. We project growth in each sector so that we can measure future sensitivity. For example, given the historic reduction of agriculture as a fraction of GDP, we project that future agriculture sectors will grow only one half as fast as GDP. GDP projections suggest that developing countries will grow more rapidly than OECD countries (Houghton et al. 1994).

2.3. Response Functions

It is not yet possible to derive individual response functions to climate change for each country of the world. Consequently, except for tourism, which is based on an international comparison, we apply the response functions for the United States to the entire world. Clearly this approximation is unsatisfactory; it is taken here only to demonstrate the GIM approach to impact assessment. The response functions to climate change in GIM are based on empirical studies that have been carefully designed to include adaptation by firms and people to climate change. Separate response functions are estimated for agriculture, forestry, coastal resources, commercial energy, residential energy, tourism and water. We use two alternative response functions for most sectors to demonstrate the sensitivity of our results to the type of response function used.

The first set of response functions is based on a collection of sectoral studies for the United States completed by a team of leading impact experts (Mendelsohn and Neumann 1998). These studies use a variety of empirical approaches to build consistent, comprehensive estimates of damages in each sector. Using the net results from each sector, we have constructed a reduced-form model which links climate scenarios and welfare impacts for each sector to temperature and precipitation (Table 1).

We also use a Ricardian approach that relies on cross-sectional comparisons to reveal how each sector would respond to climate change. The agricultural Ricardian model (Mendelsohn et al. 1994) measures how long-term farm profitability varies with local climate, controlling for other factors. The forestry model is based on a similar cross sectional analysis of the effect of climate on the present value of timber grown in the United States (Mendelsohn and Sohngen 1996). To measure the sensitivity of energy use to climate, we adopted an expenditure analysis of the commercial and residential sectors (Morrison and Mendelsohn 1998) wherein energy expenditures across firms or households were regressed on climate and other control variables. The coastal results are predicted by a sea-level-rise model, assuming imperfect foresight (Yohe et al. 1996). The impact of climate on tourism was calculated by examining international tourism expenditures (Morrison and Mendelsohn 1996).

Most of the response functions imply that the net productivity of sensitive economic sectors is a quadratic function of temperature (Mendelsohn et al. 1997). Ceterus paribus, starting from cool temperatures, each economic activity increases in value as temperature increases to some maximum value and then decreases as temperature increases beyond that point. This is consistent with what we know about global economic productivity, where the most profitable sites for most climate-sensitive activities lie in the temperate or subtropical zones.

To extrapolate from one economy to another, we assumed that: (1) agricultural and forestry responses will be proportional to cropland and forestland, respectively; (2) coastal damages from sea-level rise would be proportional to the amount of coastline and the average value of land, the latter approximated using GDP divided by area; (3) energy impacts were proportional to GDP; and (4) water impacts will be proportional to area. These assumptions can be relaxed when systematic country-specific impact studies are completed.

3. RESULTS

GIM is designed to evaluate any time trajectory of temperature change. However, we illustrate how the model works by exploring the impacts resulting from a 2°C increase in global-mean temperature in 2060. This climate-change scenario falls well within the range predicted in the most recent IPCC scientific assessment (Houghton et al. 1996). We assume that CO_2 has doubled from its preindustrial levels at this time and that sea level will rise by 0.5 meter by 2100. The economies of each country are assumed to grow according to current projections so that by 2060 the world economy has grown to \$95 trillion from \$21 trillion today (Houghton et al. 1994).

Table 3 presents the regional market results using the reduced-form response functions. Africa, Asia, Latin America and Oceania are damaged by the warming, whereas Europe and North America benefit. The net effect for the world is a \$278 billion loss, which is about 0.3% of GDP. Most of these damages come from agriculture which suffers a \$215 billion loss. Water and energy contribute losses of \$60 and \$26 billion, respectively. Coastal damage from sea-level rise contributes another \$5 billion of damages, and forests contribute a \$27 billion gain. Dividing the world into the OECD and other countries reveals that the OECD economy will gain about \$69 billion from the warming, while the economy of the rest of the world will lose about \$348 billion. This result depends largely on the fact that the OECD currently has cool climates, whereas the rest of the world currently has warmer temperatures. Thus according to the US reduced-form response function, the warm (non-OECD) countries will be damaged by additional warming and the cool (OECD) countries will benefit.

Table 4 presents the results using the Ricardian response functions. The results are similar to those using the reduced-form model in that Africa, Asia, Latin America and Oceania are damaged by the warming, while Europe and North America benefit. However, the Ricardian model predicts much smaller losses and gains than the reduced-form model. According to the Ricardian model there will be a small gain in agriculture worldwide. The damages in the energy sector and the gains to forestry are also found to be smaller. The net result is that warming is found to result in a $41 billion gain for the world (equal to 0.04% of world GDP in 2060). Given the uncertainty, this is virtually equivalent to no discernible effect.

One result, however, is quite similar in both models, namely, the OECD will gain $69-$82 billion from the 2°C global warming. The striking difference between the two models concerns the non-OECD for which the Ricardian model predicts a $40 billion loss while the reduced-form model predicts a $348 billion loss. This nine-fold difference is largely due to the different predictions about agriculture made by the two impact models.

Given these regional results, it is no surprise that some countries are winners and others are losers. Table 5 presents net market results for selected countries around the world. The former Soviet Union, Canada, China and the United States receive the largest net annual benefits. Their cool climates turn warming into gains, their large economies lead to large energy effects, and their large land masses suggest more coast line, agriculture, forestry, and water impacts. India, Brazil, Nigeria and Mexico are the largest losers because of their present warm climates and large land masses. Although the aggregate impacts in the above countries are large, they are only a small fraction of GDP for most of these countries.

The countries that have the largest damages from global warming as a fraction of GDP are in Africa according to the reduced-form model, while they are island countries according to the Ricardian model. The reduced-form model predicts that agriculture will virtually disappear from most of Africa and Southern Asia, thereby causing large losses in agriculturally dependent countries. This relative damage is large in 2060, even with the expected economic development in these countries. However, given that the reduced-form model predicts that agriculture would not exist in these countries given today's climate, one must be cautious about giving these results too much credence. The Ricardian model confirms that warming will be bad in this region, but it does not predict such dire results. Instead, the Ricardian model highlights the island countries as the most vulnerable because of their extensive coastlines, limited development and dependence on tourism.

The net impacts are mapped in Figure 1 for the Ricardian response functions. Countries near the Arctic Circle and in the temperate zone benefit. The Ricardian model predicts that countries in the tropics are only mildly affected, while the reduced-form model (not shown) predicts these countries will be severely affected. Note that individual countries do not always follow continental averages. Although Asia loses from global warming, China gains. Although Europe and North America gain from global warming, Spain, Portugal and Mexico suffer net damages.

4. CONCLUSION

This study has several limitations including: (1) the response functions were calibrated only for the United States; (2) the non-climate information about each country is not as extensive as it should be; (3) non-market effects are not included; (4) the resolution of the GCM is coarse relative to the size of small countries; (5) the transient response of the climate system is not considered; and (6) the simulated climate changes are due only to increased CO2 and not to the partially compensating effects of anthropogenic sulfate aerosols. Nevertheless, the results of this study show that the impacts of climate change will likely not be uniform from country to country and suggest, therefore, that establishment of successful international agreements to control greenhouse gases must take these country-specific responses into consideration.

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Table 1. Reduced-form climate response functions.

Agriculture

$$R_{a,k} = \left(-751 + 123.2T_k - 4.52T_k^2 + 49.627P_k\right)\left(\frac{L_{a,k}}{L_{a,US}}\right)$$

Forestry

$$R_{f,k} = \left(-26.7 + 0.84T_k + 6.61P_k\right)\left(\frac{L_{f,k}}{L_{f,US}}\right)$$

Coast Resource (Sea Level Rise)

$$R_{s,k} = \left(-65.9 + 365.7M\right)\left(\frac{Coast_k}{Coast_{US}}\right)\left(\frac{GNP_k}{Area_k}\right)\left(\frac{GNP_{US}}{Area_{US}}\right)$$

Energy

$$R_{e,k} = \left(-36.7 + 7.4T_k - 0.37T_k^2\right)\left(\frac{GNP_k}{GNP_{US}}\right)$$

Water

$$R_{w,k} = \left(3.2 - 4.1T_k + 0.067T_k^2 + 12.7P_k\right)\left(\frac{Area_k}{Area_{US}}\right)$$

$R_{a,k}$, $R_{f,k}$, $R_{s,k}$, $R_{e,k}$ and $R_{w,k}$ are the values ($) of agriculture, forestry, coastal resource, energy and water in country k. $L_{a,k}$ and $L_{f,k}$ are the areas of farmland and forest in country k (acres); T_k and P_k are annual temperature (°C) and precipitation (mm) in country k; Coast, GDP and Area are the length of coastline (km), gross domestic product ($), and area ($km^2$)

of country k; and M is sea-level rise in 2100 (m). The reduced forms are deduced from (Mendelsohn and Neumann 1998).

Table 2. Ricardian climate response functions.

Agriculture (Mendelsohn et al. 1996)

$$R_{a,k} = rL_{a,k}\left(1639 + 171.9T_k - 23.7T_k^{2} + 91.7P_k - 75.7P_k^{2}\right) + 0.177\ln(CO_2)$$

Forestry (Mendelsohn and Sohngen 1996)

$$R_{f,k} = rL_{f,k}\left(-725.8 + 118T_k - 3.97T_k^{2} + 69.9P_k\right) + 0.177\ln(CO_2)$$

Coast Resource (Sea Level Rise) (Yohe et al. 1996)

$$R_{s,k} = 2.94x10^{8}\left(\frac{Coast_k}{Coast_{us}}\right)\left(\frac{GDP_k / Area_k}{GDP_{US} / Area_{US}}\right)M^{1.9}t^{-2.8}$$

Commercial Energy (Morrison and Mendelsohn 1998)

$$R_{c,k} = GDP_k\left[0.0212t^{-0.32}\exp\left(-0.066T_k + 0.0023T_k^{2}\right)\right]$$

Residential Energy (Morrison and Mendelsohn 1998)

$$R_{r,k} = GDP_k\left[0.022t^{0.172}\exp\left(-0.0187T_k + 0.00098T_k^{2}\right)\right]$$

Tourism (Morrison and Mendelsohn 1996)

$$R_{t,k} = \exp\left[\left(\frac{POP_k(t)}{POP_k(t_o)}\right)\left(a_k + 0.31T_k - 0.0101T_k^{2}\right)\right]$$

$R_{a,k}$, $R_{f,k}$, $R_{s,k}$, $R_{c,k}$, $R_{r,k}$ and $R_{t,k}$are the values ($) of agricultural land, forest land, coastal land, commercial energy, residential energy and tourism in country k. $POP_k(t)$ is population in country k; a_k is a constant term for each country; r is the interest rate (5%); $L_{a,k}$ and $L_{f,k}$ are the areas of farmland and forest in country k (acres); T_k and P_k are annual temperature (°C) and precipitation (mm) in country k; Coast, GDP and Area are the length of coastline (km), gross domestic product ($), and area ($km^2$) of country k; M is sea-level rise (m); and CO_2 is the ambient carbon dioxide concentrations (ppmv).

Table 3. Regional market impacts (billions of dollars) from the reduced-form model for a 2°C global-mean warming.

Region	Sector						
	Agric	Forest	Coast	Energy	Water	Total	%GDP
Africa	-132	4	-0	-3	-2	-133	-4.7
Asia	-220	4	-2	-13	-11	-242	-0.8
Latin America	-78	7	-0	-5	0	-76	-1.3
Europe	148	6	-2	-2	-26	124	0.4
North America	86	5	-0	-4	-20	67	0.3
Oceania	-19	1	-0	-1	-1	-20	-1.9
Total	-215	27	-5	-26	-60	-278	-0.3
OECD	99	7	-3	-8	-26	69	0.1
Non-OECD	-314	20	-2	-18	-34	-348	-0.8

Table 4. Regional market impacts (billions of dollars) from the Ricardian model for a 2°C global-mean warming.

Region	Sector						
	Agric	Forest	Coast	Energy	Tourism	Total	%GDP
Africa	-11	-6	-0	-2	-3	-22	-0.8
Asia	-14	-1	-5	-9	-8	-37	-0.1
Latin America	-7	-5	-0	-4	-5	-22	-0.4
Europe	34	16	-4	4	31	82	0.2
North America	21	14	-0	0	13	47	0.2
Oceania	-3	-1	-0	-1	-1	- 7	-0.6
Total	20	17	-10	-13	27	41	0.04

OECD	26	16	-7	2	45	82	0.15
Non-OECD	-6	1	-3	-14	-18	-40	-0.10

Table 5. Selected country-specific net market impacts (billions of dollars) for a 2°C global-mean warming in year 2060.

Country	Model			
	Reduced-form		Ricardian	
	Welfare	%GDP	Welfare	%GDP
Australia	-19	-2.2	-8	-0.9
Brazil	-37	-1.1	-14	-0.4
Canada	70	3.9	31	1.7
China	21	0.4	10	0.2
Ethiopia	-9	-17.7	-1	-2.7
Germany	4	0.1	5	0.1
India	-135	-5.5	-22	-0.9
Mexico	-23	-1.6	-8	-0.5
Mozambique	-2	-19.0	-0	-3.8
Nigeria	-27	-11.2	-5	-1.9
Thailand	-20	-3.5	-6	-1.1
United States	21	0.1	22	0.1
USSR, Former	107	1.1	39	0.4

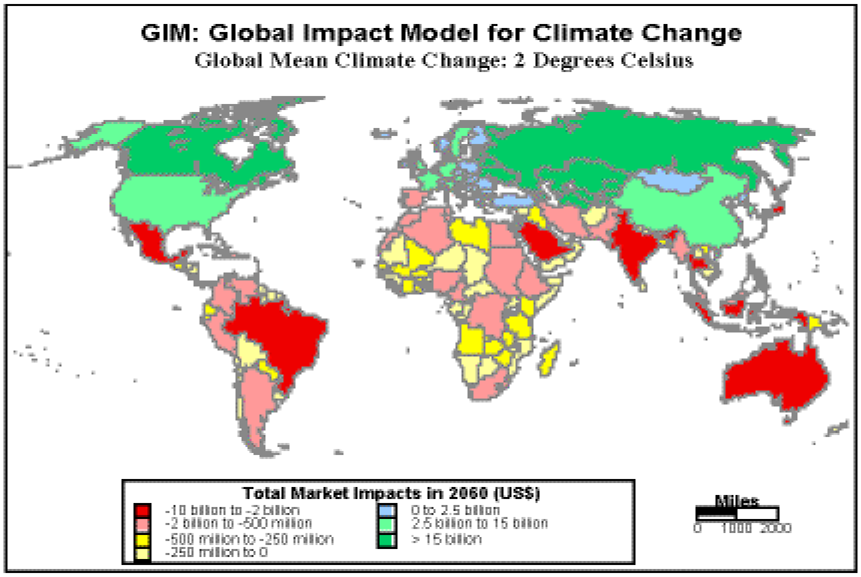

Figure 1. Total market impacts in US$ of a 2°C global warming in 2060.