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Thinking Ahead on International Trade (TAIT) – 2nd Conference
Climate Change, Trade and Competitiveness: Issues for the WTO

Climate, Trade and Development[1]

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Thinking Ahead on International Trade (TAIT)
The Thinking Ahead on International Trade (TAIT) programme, run by the Centre for Trade and Economic Integration (CTEI) at the Graduate Institute, Geneva, is a 4-year research programme devoted to the analyses of medium-term challenges facing the international trade system in general and the WTO in particular. www.graduateinstitute.ch/ctei

1 This is a background paper written for Round Table 1 on **The Impact of Climate Change on Trade Patterns**, at the business-government-academic conference **Climate Change, Trade and Competitiveness: Issues for the WTO**. The conference is organised by organised by the (CTEI) as part of its TAIT programme, in collaboration with the Economic Research and Statistics Division of the Secretariat of the World Trade Organization and The World Bank, and held at the headquarters of the World Trade Organization on 16th, 17th and 18th June, 2010.

2 Respectively with the Development Prospects Group (DECPG) at the World Bank and Ca' Foscari University, Venice, IEFE and CMCC. Correspondonce: The World Bank, 1818 H Street, NW, Washington, DC 20433, email: dvandermensbrugg@worldbank.org. The authors would like to thank Jianwu He and Martina Sartori for excellent assistance and Hans Timmer for many helpful discussions and suggestions, as well as participants at several seminars held at the World Bank in the preparation of this paper. The views and conclusions reported in this paper should not be attributed to the World Bank, its Executive Board or member countries.

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Introduction

Climate change has the potential to be the major social and economic challenge over the next century—with the aggregate economic impacts largely overshadowing other major global economic issues such as trade policies and international migration. To put the magnitudes in perspective, a report issued in 2006[1] compiled results from 18 models of the global economy that had average carbon emissions at around 10 gigatons in 2025 in the baseline or business-as-usual scenario. The average carbon tax in 2025 to achieve an overall limit on temperature change from these models is $100 per ton of carbon. Thus the revenues from carbon taxes, on a global level, would be around $1 trillion in 2025 and rising over time. Estimates of damages from climate change, though varying widely across studies, range up to 20 percent of GDP, with the mode at around 1-2 percent of GDP.

Climate change impacts will have highly variegated impacts across regions and across sectors suggesting that they could have measurable effects on trade relations. This paper intends to explore the potential impact on trade by looking at some of the key channels that will affect economic production and demand around the globe. There are many other climate and trade related aspects that this paper will not cover, though they be of more immediate policy relevance:

- The carbon leakage effects of partial carbon policies (e.g. the European Trade System (ETS), or U.S. proposals for a cap and trade system)
- Border tariff adjustments to minimize carbon leakage and/or loss of competitiveness
- Green labeling
- Border taxes on ‘clean’ goods or goods produced by ‘clean’ processes
- ‘Clean’ technology transfers—who will be innovating and exporting
- Biofuels—including domestic support and border measures
- Terms of trade impacts of offsets and climate policy induced changes in fossil prices

One of the main purposes of this paper is to set the stage for the broad range of topics in this conference on climate change, trade and competitiveness. Where will the global economy be in 2050? How will baseline greenhouse gas emissions evolve in the absence of mitigation policies? Or in other words, how carbon intensive will be future growth over the next 40 years if we produce using existing technologies? What kind of climate impact will this have as measured by temperature change? What will be the repercussions on economic output and global trade?

In addition to the baseline scenario, often referred to as the business-as-usual scenario since it pre-supposes continuation of existing policies, this paper will also assess the impacts of a few policy scenarios that are directly related to trade issues. The first is how trade policies would affect the patterns of production and trade and their related emissions. The second is a set of ‘idealized’ carbon tax scenarios that will affect the relative cost of production across the globe and therefore country-specific competiveness and trade patterns.

The next section briefly describes the main model features including the climate-related economic effects. This is followed by a brief description of some of the key findings from the baseline scenario. The third section then unpacks how the different climate related effects impact growth and

1 See Weyant et al 2006.

trade. We then assess the policy scenarios including the impact of free trade on global production, trade and emissions and the carbon tax scenarios. This is followed by concluding remarks.

Analytical framework

The assessment of climate change and trade discussed in this paper are based on economic simulations of the World Bank's ENVISAGE Model. The key characteristics of the model and the dynamics are discussed in the Annex. For the purposes of this paper the global economy has been divided into 15 countries and regions including the European Union (EU27), Japan, the United States, Brazil, China, India and Russia with the remaining countries grouped into large regional aggregations. Economic activity is divided into 21 sectors with a heavy focus on energy and energy intensive manufacturing. The model runs from a base year of 2004 through 2050.

The analysis reported in this paper reflects significant changes to our analytical framework. As we surveyed the literature on modeling the economic impacts of climate some two years ago, it was readily apparent that there were significant gaps in the coverage of developing countries (with the exception of the two large emitters—China and India) and that the economic impacts of climate change were largely ignored. Our aim in this work is to focus more on the near and medium term consequences of climate change for a wide range of developing countries as it has become more evident that the (mostly) negative impacts of climate change are accelerating and require relatively prompt policy responses. Our new results thus reflect a synthesis of anticipated climate change impacts that include the following seven channels:

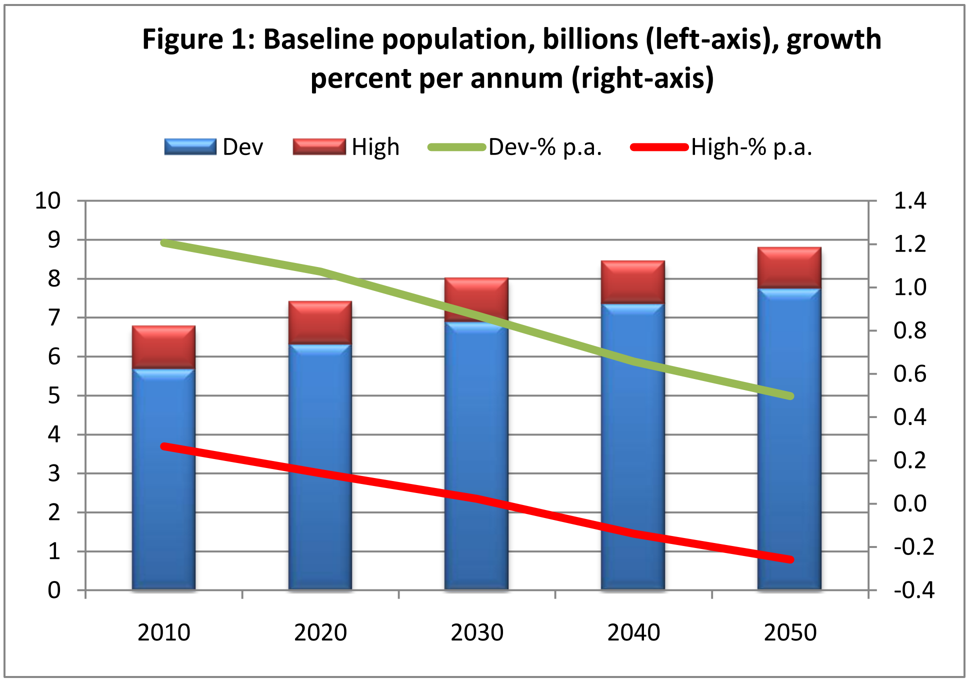
- Agricultural yields
- Sea level rise
- Water availability
- Tourist arrivals
- Energy demand (for additional cooling and less heating)
- Health effects
- Heat-related labor productivity

Each of these effects impacts the economy through different channels—sectoral productivity, factor stocks and demand parameters. The various channels are described in more detail in the Annex. Since they are generally sector and region specific they will also impact long-term trade relations on top of the impacts on welfare and factor returns. One objective of this paper is to elucidate how these climate-related economic effects will affect overall growth and trade, acknowledging all the while, that the results should be seen as exploratory as more detailed information becomes available.

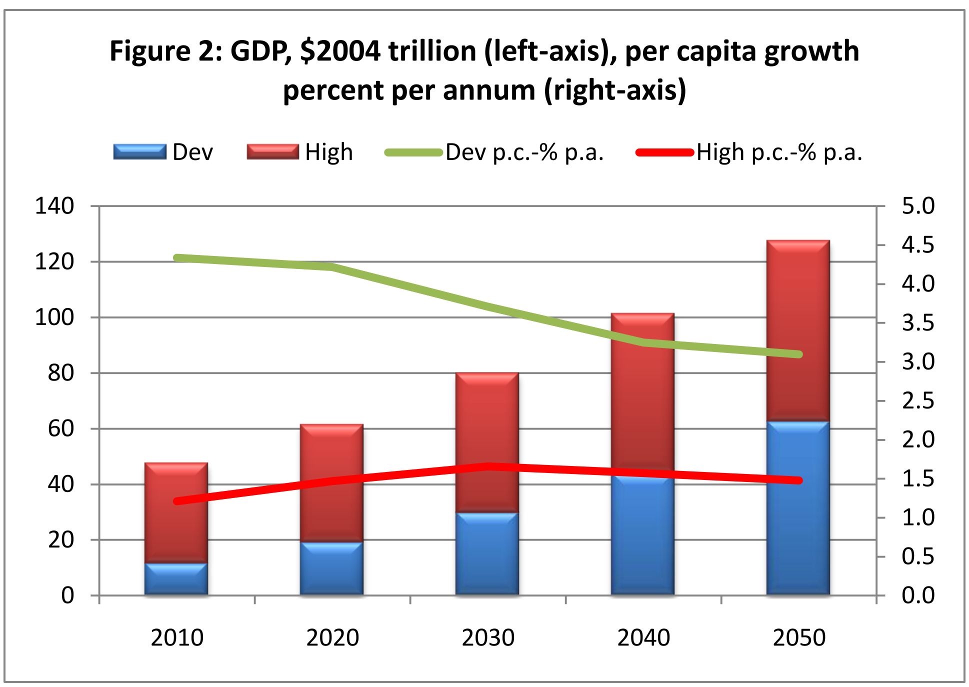
Business-as-Usual

Before undertaking alternative scenarios—either driven by different assumptions or policy changes—a baseline scenario is developed that is typically referred to as the business-as-usual (BaU) scenario. This latter designation suggests that there are few, if any changes to policies, e.g. trade or energy related.

Looking ahead to 2050, the baseline scenario has population growing from about 6.8 billion in 2010 to 8.8 billion, virtually all of the growth is in developing countries with South Asia and Sub-Saharan Africa accounting for around 2/3 of the incremental growth (Table 1 and Figure 1). This increase in population has generated considerable concerns of how to feed 9 billion persons in 2050 when combined with the potential negative impacts of climate change, the potential competition for land from biofuel production and the recent slowdown in the growth of agricultural productivity. Labor force growth parallels to some extent the overall population trends, but there are some notable features. Many of the high-income countries could see declines of 25 percent or more in the size of their labor force by 2050, the United States being one exception with some modest growth. And though labor force growth in most developing countries will be strong, for example SSA is expected to see an increase of over 100 percent, there are some that are likely to see declines—either large such as in parts of Europe & Central Asia, or modest as is the case for China.

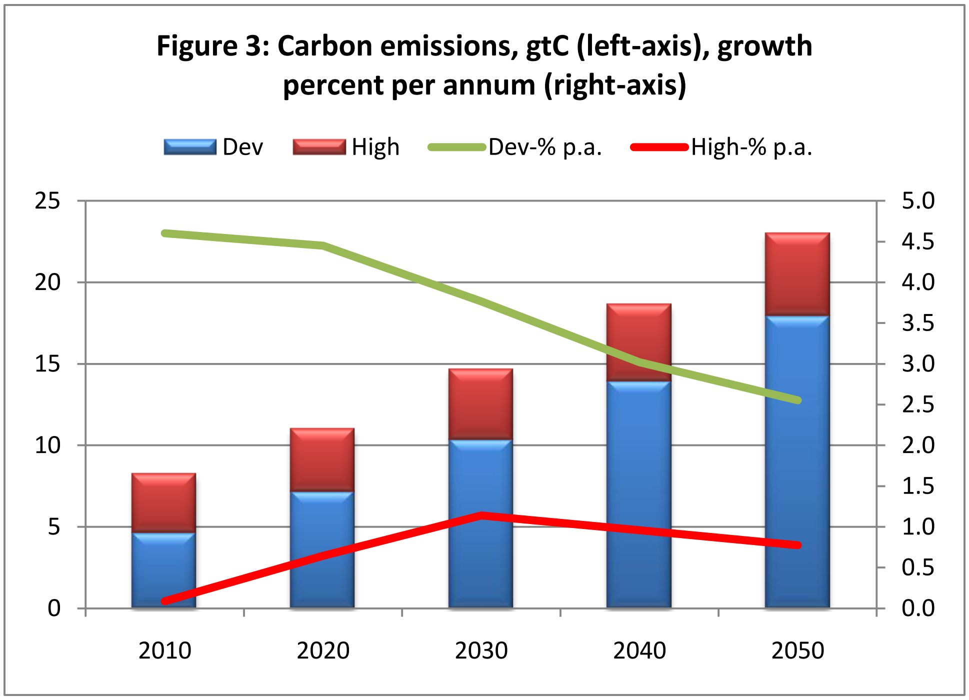


Economic output would increase from some \$47 trillion (in \$2004) in 2010 to \$130 trillion in 2050, with an average growth of 2.6 percent (Table 1 and Figure 2). The developing country share would rise from less than 25 percent in 2010 to just over 50 percent in 2050 (all at 2004 market exchange rates and prices). Per capita growth rates would level off at 1.5 percent per annum for high-income countries and after starting at 4.5

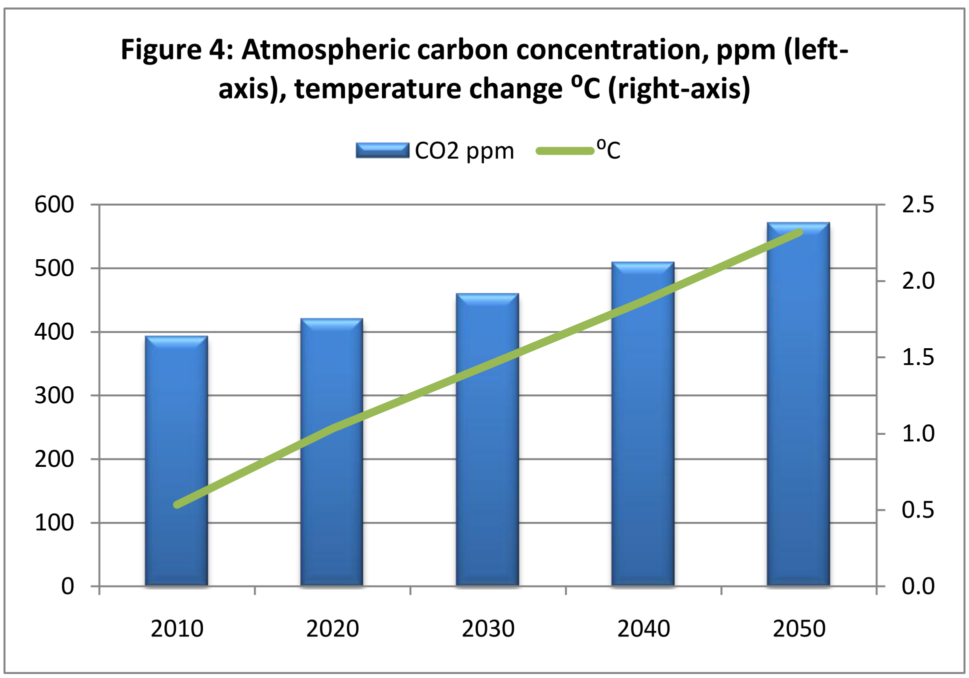


percent per annum in the first decade, per capita growth in developing countries would slow to a more modest 3 percent by 2050.

On the flip side, greenhouse gas emissions would rise in roughly similar proportion—despite improvements in energy efficiency (Figure 3 and Table 2). There are a number of channels for this result. First, energy intensive production will move towards countries that rely more on coal—coal remains largely abundant and relatively cheap. Second, oil and gas prices are expected to rise relative to coal thus all countries will see substitution towards coal where technology permits.



Should these patterns obtain atmospheric carbon concentration would rise from present day 390 parts per million (ppm) to 575 ppm, well above what many consider to be a prudent threshold of 450 ppm (Table 2 and Figure 4).[2] This concentration level translates into an increase in temperature of some 2.34° C (since 2000).



[2] There is ongoing debate about what is a safe threshold for greenhouse gas concentration as measured in carbon dioxide equivalents (CO2e). The Stern Review (Stern 2007) advocated a threshold of 550 ppm CO2e that roughly corresponds to 450 ppm CO2. Many others have argued for even a lower threshold of 450 ppm CO2e that has already been surpassed and it would require the implementation of new technologies, such as bioenergy plus sequestration to achieve the lower threshold.

The baseline scenario puts global warming on an accelerated warming path, higher than almost all of the scenarios used in the IPCC's Fourth Assessment Report (AR4).[3] The bulk of the socio-economic scenarios in AR4 were produced in the late 1990s—the end of a period of less than stellar economic growth in many parts of the world and a period of much less rapid growth in emissions as many countries moved towards market-based energy prices. Growth in the 2000s was thus much higher than had been foreseen (the recent economic crisis notwithstanding) and this was coupled with much higher energy demand and emissions growth.[4]

The standard baseline delinks the impacts of climate change, i.e. global mean temperature increase, from its impact on the global economy. The next section describes how the change in global mean temperature affects the global economy—differentiated by type of impact as described earlier and across the various regions of the world.

Alternative scenarios

Climate change impacts

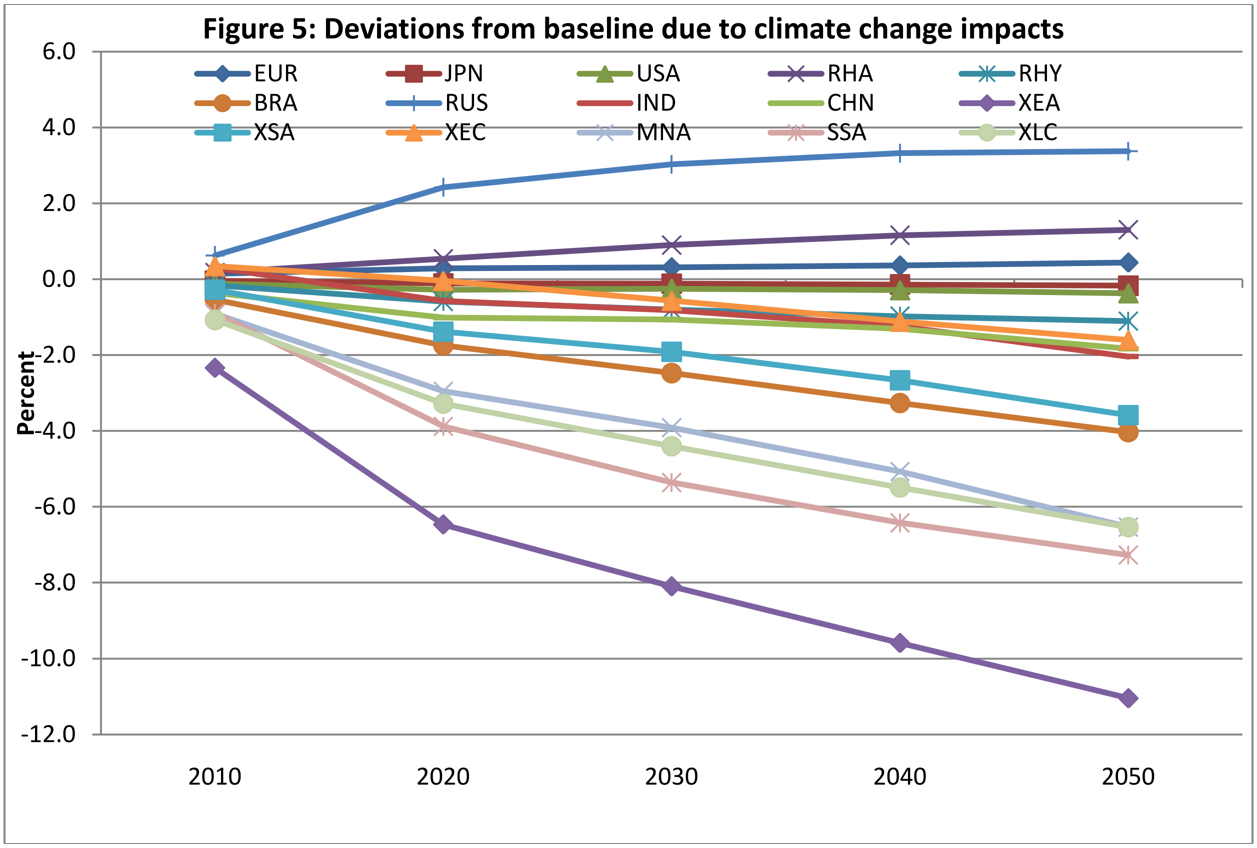
How important are the economic climate change impacts in our baseline scenario. In order to isolate the various economic channels of climate change we individually turn off each one of them—there are seven in total. We also turn all of them off simultaneously to get the aggregate impact.

At the global level when all of the climate change impacts are included, global output is some 1.8 percent less than in the standard baseline in the year 2050, i.e. the rise in mean temperature of 2.3º C induces an overall economic decline of 1.8 percent, translating into a loss of some $2.4 trillion (Table 3 and Figure 5).[5] Within this time horizon of 40 years there is not much evidence of a hump-shape for the regional impacts—countries that have a positive net impact largely stay positive, albeit flattening out and a large number of developing countries start in negative territory and stay that way. There is significant regional variation with South-East Asia (XEA) seeing a particularly large drop in output (11 percent in 2050), followed in order by Sub-Saharan Africa (SSA), Latin America and the Caribbean (XLC) and Middle East and North Africa. Overall the developing countries would bear the brunt of the negative impacts with an average net loss in output of 3.7 percent in 2050. Russia would be the only developing region (of the model) with positive gains. These results are further decomposed below. The high-income countries on average would see little loss if any, though there are regional variations as well amongst them.

3 The median temperature increase from all the models in the IPCC's Fourth Assessment Report was 3º C in 2100.

4 Bacon and Kojima 2009 document the structural break in energy use and emissions starting in the 2000s.

5 As an aside, we estimate the parameters of a quadratic damage function at the global level and the fit, as measured by R-squared is 99% and is thus consistent with Nordhaus' assumption of a quadratic global damage function (Nordhaus 2008).

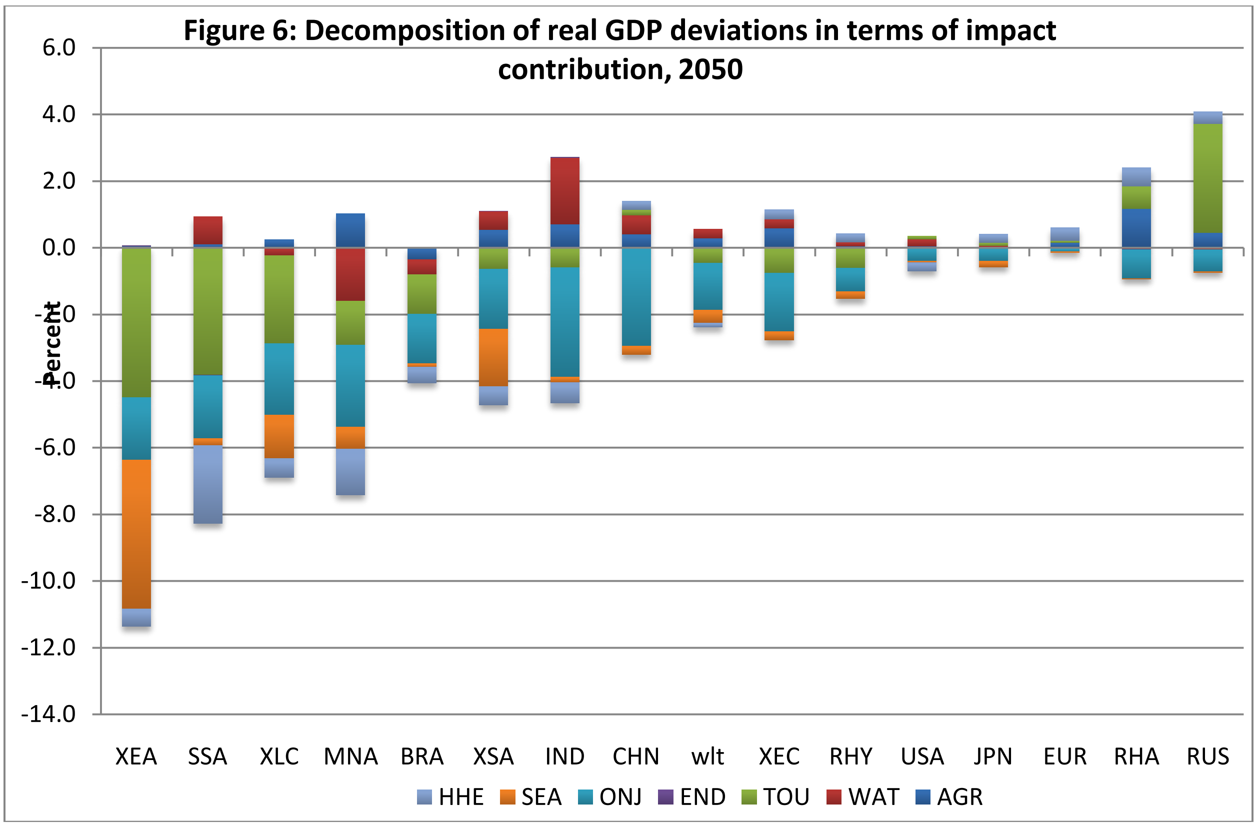


Decomposing the losses and gains at the global level shows that the impact on labor productivity (ONJ) dominates the losses—representing some $1.8 trillion of the total loss of $2.4 trillion in the year 2050 (Table 3 and Figure 6, 'wlt' bar chart). Global warming has a negative impact on tourism (TOU) (a loss of $0.6 trillion) and the sea-level rise (SEA) induces a loss of an additional $0.5 trillion. Health induced impacts (HHE) are relatively small at the global level at less than $0.2 trillion and changes in energy demand (END) have negligible impacts. Somewhat more surprisingly the temperature increase in 2050 leads to positive impacts for both agriculture (AGR) and water (WAT) at the global level—each generating a net gain of some $0.36 trillion and offsetting to some extent the other losses.[6] This reverses our past results that were largely based on Cline's compendium (Cline 2007) and will necessitate more analysis of the underlying empirical estimates across product lines and countries. The basic relationships are derived from the IPCC's Fourth Assessment Report[7] which stresses the degree of uncertainty in these estimates including the role of autonomous adaptation (that normally lowers the impact) and of carbon fertilization. Moreover, these estimates deal with changes in averages and most do not take into account changes in extreme events that are likely to be particularly costly. If we revert even partially to our previous results, we would expect to see an increase in the relative agricultural trade imbalance between the higher latitudes dominated by developed countries and the lower latitudes composed mostly of developing countries.

6 Pushing the simulation out to 2100 leads to an overall loss in 2100 of 4.6 percent, with the labor productivity impact still dominating the overall losses. The 2050 gain in agriculture is nonetheless reversed in 2100 as the rise in temperature of nearly 5º C impacts the maximal threshold for agricultural production in large parts of the world.

7 IPCC (2007), Volume II, pp. 284-286.

The decomposition of the climate change impacts across regions is substantially different as is the total impact. Figure 6 shows the decomposition for the year 2050 ranked in ascending order across region. Thus South East Asia (XEA) exhibits the largest decline (and Russia the greatest gain). A significant portion of the loss in South East Asia is related to sea-level rise (SEA) as well as loss in tourism revenues (TOU), with a lesser relative impact due to labor productivity effects. The significant impact of sea-level rise in this region is consistent with other studies, for example Asian Development Bank 2010 and Dasgupta et al 2007. The next most highly impacted region in relative terms is Sub Saharan Africa with a total loss in percentage terms or around 7.3 percent. Tourism is highly impacted as in East Asia (and the rest of Latin America as well), but health impacts are prominent as are labor productivity impacts. Agriculture and water could see a relative boost from global warming. The two largest developing economies—China and India, would see losses of around 2 percent largely dominated by lower labor productivity and with some significant positive offsets for agriculture and water. Brazil on the other hand would have no positive offsets, not even in agriculture and see a total loss of 4 percent.[8]



The impact of climate change on trade is not easy to discern as there are multiple channels that will affect trade. Overall trade would be expected to decline as global output declines. The re-shaping of world trade will depend on how the various productivity and other impacts are reflected in changes in competitiveness and prices. These impacts will vary considerably across sectors (for example reflecting the relative labor intensity of output) and across regions (reflecting both the product mix of output and labor intensity). Finally, a third channel comes from the assumption of a fixed current

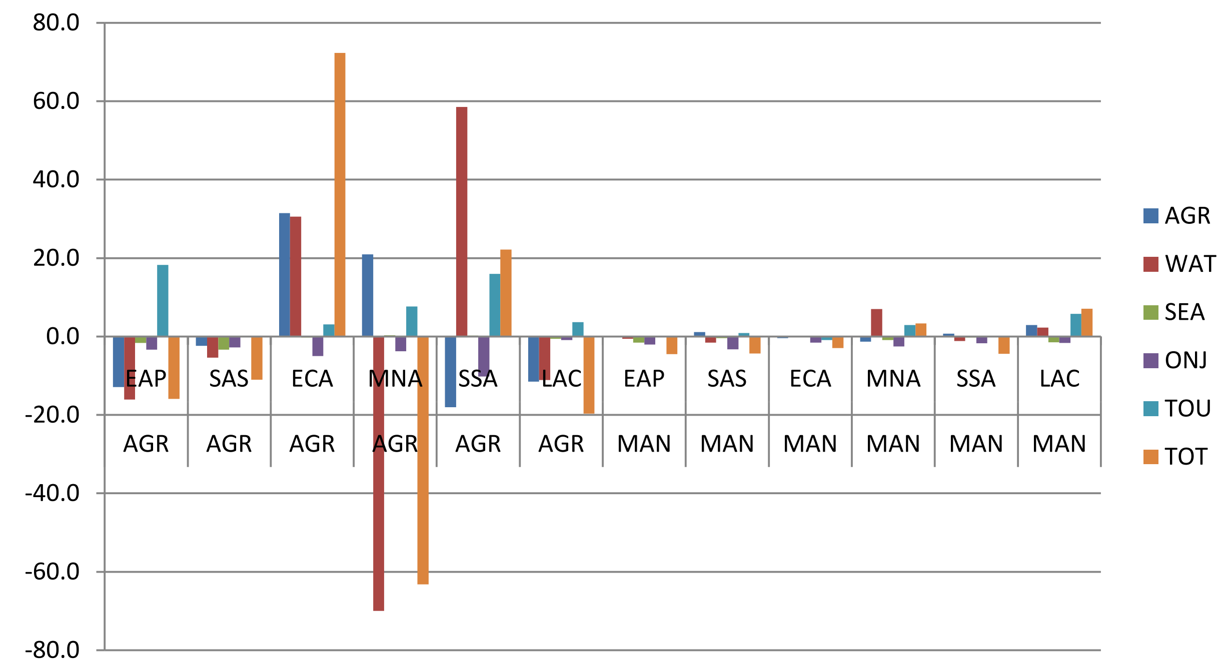
8 Part of the reason for these results in agriculture is that the IPCC report suggests a larger impact on wheat and corn yields than rice yields in the low latitudes.

account. Losses in tourist revenues, for example, would lead to a rise in exports of other goods and services to maintain a current account balance.

Our results suggest that aggregate world exports decline by some 3.6 percent in 2050 relative to a baseline scenario with no climate change impacts (Table 5). Ignoring price impacts, this suggests roughly an elasticity of 2 with respect to global output that declines by some 1.8 percent. Decomposing across the various climate impacts, it is heat-related changes in labor productivity that creates the largest decline in exports—it alone would account for over 42 percent of the total decline in trade. This effect is clearly linked to the decline in overall global production though there are likely to be differential impacts across sectors and regions as well. The impacts on tourism (24 percent) and sea level rise (20 percent) would represent the next largest impact on trade. The impact of changes to agricultural productivity has a relatively small impact on aggregate trade—less than 0.2 percent in 2050 when isolated from all of the other shocks—albeit positive unlike all of the other climate impacts. (As shown below, there are nonetheless strong regional impacts.) The impact of water related shocks is higher, with a decline in total trade of 0.4 percent at the global level. The other two impacts—energy demand and health do not register much impact at the global level.

In percentage terms it is agricultural trade that is most likely to see large changes due to climate change, albeit subject to caveats already mentioned. There are sharp declines in agricultural exports for East Asia and Pacific, South Asia, Middle East and North Africa and Latin America (Figure 7). Mostly it is the combination of both shocks to agricultural productivity and water availability—though in the case of the Middle East and North Africa, the decline in exports is largely driven by water stress. Europe and Central Asia would tend to see a large increase in agricultural exports and Sub-Saharan Africa would also see a positive impact on exports through a relative improvement in water availability. It should be noted that the global climate models exhibit low consensus on precipitation and we would treat these results with respect to water availability as highly tentative.

Figure 7: Climate change impacts and exports of agriculture and manufacturing for developing regions, percent deviation from baseline in 2050



There is much less overall impact on manufacturing exports with percent deviations on a regional basis in the range of -5 to 7 percent. The global economic decline is largely responsible for the manufacturing results for East Asia and Pacific and South Asia. The manufacturing declines in Europe and Central Asia and Sub-Saharan Africa would in some part reflect the improvement in agricultural exports as resources would transfer from manufacturing to agriculture. Latin America would see the reverse, with resources transferred to manufacturing as agricultural exports (a relatively large share of total exports) decline. Moreover, the loss in tourist arrivals would likewise need to be compensated by a rise in exports.

Trade protection

In this section we look at the role of trade protection on incomes, trade and emissions. There is a relatively long literature on trade protection and impacts on trade and incomes—Newfarmer 2006 provides a relatively complete and recent summary of the current state of play. To assess these impacts we run a rather idealized trade reform scenario that removes all existing trade barriers (import tariffs and export subsidies), and domestic protection (that is limited to agricultural sectors). The reforms start in 2012 and are completed by 2025—so there are 25 years of adjustments following the end of the reforms.

The long-term gains from full trade reform lead to a gain in global real income of 0.9 percent in 2050 relative to the baseline—0.5 percent for developed countries and 1.4 percent for developing economies (Table 6). Looking at the real income gains for 2030—some 5 years after the end of the reforms, the gains are 0.3 and 1.0 percent respectively for high income and developing countries implying that there are long-term dynamic gains that are only realized many years after the reform.[9] These dynamic gains are in part driven by the lower cost of capital as trade reform lowers the price of imported capital goods.

Global exports increase by nearly 16 percent—8 percent for developed countries and 21 percent for developing. South Asia sees the largest gains in exports as its import barriers are among the highest and large export gains are needed to pay for the large rise in imports as the barriers tumble. Globally, manufactured exports increase the most rising by 20 percent in 2050 relative to the baseline, closely followed by agricultural exports that rise by 16 percent. The growth of agricultural exports is particularly high for developing countries, rising by an average of 50 percent, whereas their manufactured exports rise by about 25 percent. The relevant numbers for high income countries are 3 and 10 percent.

With a rise in world output, global emissions would be expected to rise, but changes in the patterns of global production and trade, could also induce a further adjustment to global emissions as the carbon intensity of production differs across regions. Our results suggest that world greenhouse gas emissions increase by 2.7 percent, some three times more rapidly than global income (Table 7). South Asia would see the largest gains with emissions growing by around 8 percent. The change in emissions is not uniform with the largest rise occurring for CO_2 emissions (2.9%) whereas the other gases increase by around only 1.2 percent. Overall, free trade leads to somewhat more carbon intensive growth. The overall impact on temperature in 2050 is relatively small though will be somewhat larger in the long run as the transient temperature response takes time to fully reflect equilibrium changes in temperature. With emissions globally rising by a factor of around 2.5 (or 150%) between 2010 and 2050, the role of trade policies plays a relatively minor role in overall emissions growth. Other policy instruments are much more suitable to deal effectively with emissions than trade policies that would have only a very small dent.

Carbon mitigation

Efforts to control greenhouse gas emissions to date have been slight to say the least. The most ambitious international agreement, the Kyoto Protocol, was intended to limit greenhouse gas emissions in the high-income countries together with the transition economies with specific targets for 2012. Some countries were able to reach these targets, but for specific reasons that were not necessarily associated with direct control of emissions. Notably, the transition economies witnessed huge reductions in emissions as output fell in the early 1990s, there was significant structural transformation away from energy intensive production and energy prices were adjusted towards world levels.

Individual efforts are currently underway, even in the absence of an international agreement. The European Union is committed to cutting emissions by 20 percent relative to 1990 levels by 2020 and has set up the European Trading System (ETS) to allow for trading of carbon allowances (for a subset of industries). There have been some proposals in the U.S. Congress that would limit emissions by 17 percent by 2020, relative to 2005 levels. The timing of the passage of these proposals appears to be fluid.

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9 These dynamic gains also exclude whatever gains may emerge from changes in productivity induced by greater openness and access to higher quality inputs and capital. The more detailed results are available from the authors.

Negotiations for a successor treaty to Kyoto were held in Copenhagen in December 2009. Those negotiations failed to achieve firm commitments, in part because of differences between developed and developing countries. There were nonetheless some pledges with the EU and the U.S. committed to hard targets. The larger developing countries have made softer pledges. For example China has set a target for improving energy efficiency.

This section, like the previous, will therefore analyze some idealized emission control scenarios that are hardly reflective of what could or would be actually implemented in an international agreement. The basic intuition behind these idealized scenarios is that putting a price on carbon will affect relative competitiveness across countries and therefore have an impact on global trade. The scenarios implement a global uniform carbon tax—looking at different tax levels. From first principles one can deduce that a global uniform tax is optimal from a global perspective—though may not adequately deal with equity concerns. Regional or country-specific emission targets would lead to differentiated carbon taxes and therefore unrealized gains from having a single global price. A uniform global carbon tax is implemented assuming that the tax revenues generated by the tax are distributed internally.[10] A cap and trade system could lead to the same outcome depending on the allocation of tradable permits. Therefore a cap and trade system is one way to deal with equity concerns—but we are leaving these issues aside for the moment and simply focusing on the income, trade and emission impacts from joint implementation of a carbon tax. Note that a cap and trade system could have significant impacts additional impacts on trade. A country that sells a large amount of permits would be receiving a large income transfer that would be used to purchase additional imports thus creating additional trade.

To trace out the potential impacts of a carbon tax, we simulate a variety of different levels starting at $50 per ton of carbon to $500 per ton of carbon in increments of $50.[11] These levels are reached in 2050. They are initialized in 2012 to grow at a constant rate of 5 percent per annum till they reach their target level in 2050. Beyond the implausible simplicity of this regime, it should be noted that the model has limited new technologies that are available between now and 2050. Hydro expansion is limited by physical constraints. The other main clean sources of power include nuclear and renewable—but somewhat limited by baseline technical parameters. There is also only limited fuel switching. The lack of a larger portfolio of clean technologies will tend to dampen the emissions decline and raise the overall costs of the carbon tax.[12]

Global emissions in 2050 decline relative to the baseline by 20 percent with the relative small $50/tC tax and by over 2/3 with the much higher tax of $500/tC (Table 8). Relative to the 2005 base year, which is what most analysts focus on, the $500 tax simply more or less flattens the emissions profile with a small bump that starts declining in 2035 (Figure 8). Starting with the $250/tC tax we begin to see a profile of emissions that shows a declining trend before 2050. The global trend line for

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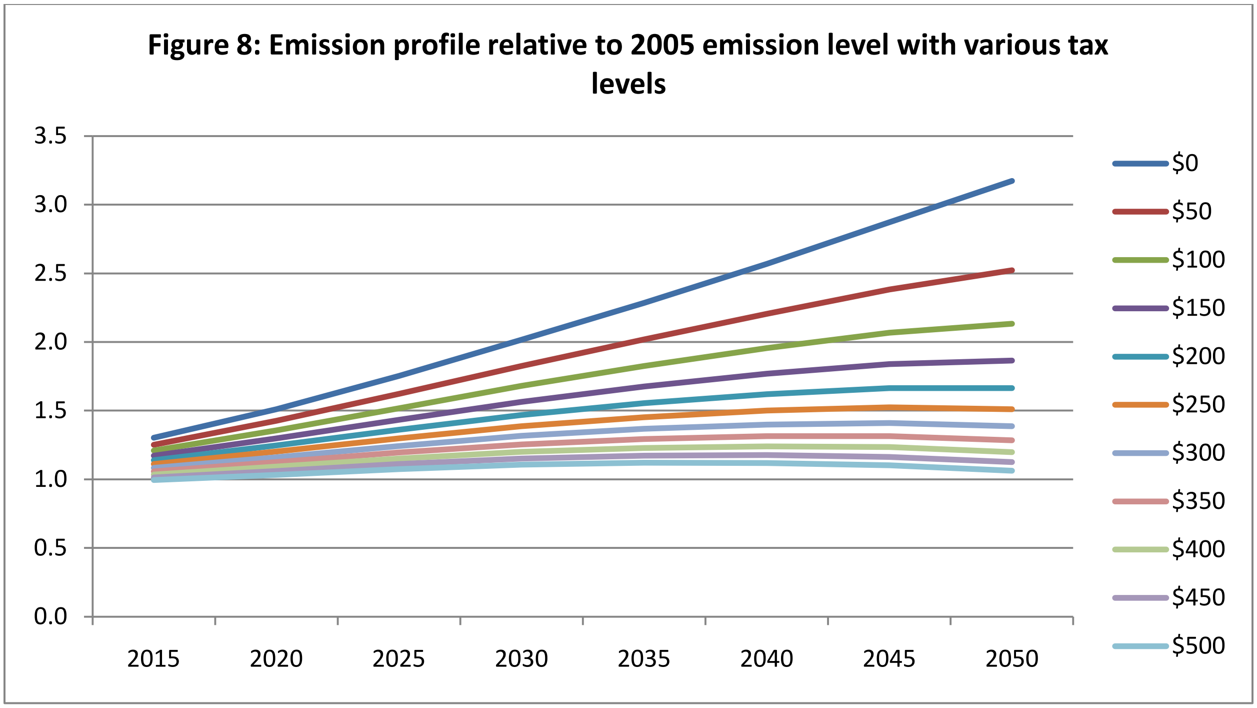
10 The carbon taxes are distributed in lump sum fashion to households that are then compensated by a reduction in direct taxes.

11 All carbon taxes in this paper are in $2004 per ton of carbon. To convert this into $ per ton of CO_2 one needs to divide by about 4 (or more precisely by $(44/12) \approx 3.67$). Thus $50/tC is equal to $13.6/t$CO_2$, and $500/tC is equal to $136.4/t$CO_2$.

12 The portfolio of clean technologies includes an acceleration of investments in existing technologies such as nuclear, solar and wind in the power, and biofuels and electricity in the transportation sector. There is also significant research in technologies that have yet to find implementation at large scale such as carbon capture and storage that could be used in the power sector (for both coal and gas) and in some large energy intensive manufacturing such as steel and cement production.

emissions belies that the trends across regions vary significantly. Countries that have relatively low energy prices to start with, that are relatively more carbon intensive and have greater overall flexibility would tend to see a greater percentage reduction in emissions for the same tax rate. Thus countries in Asia that have these three attributes would carry the greatest burden of emissions reductions whereas some of the developed countries, such as France or Japan would see lower reductions in emissions. There are countries in between—such as many in Latin America—that due to their relatively high dependence on clean energy (notably hydro power) would see less percent reduction in emissions than those in Asia.[13]



The impact on temperature is relatively small, even in the most extreme case. Under the baseline, global mean temperature would increase by 2.32º C. With the $500/tC tax, the temperature rise would still be 2.04º C and rising, though obviously at a slower pace than either in the baseline or the other lower tax rates.[14]

The impacts on real income in 2050 could be high for developing countries, albeit with the caveats mentioned above. For all developing countries, the $50/tC would lower 2050 real incomes by 0.8 percent and this would climb to 8.3 percent in the case of the higher $500/tC tax (Table 9). Compared to the gains from trade—estimated conservatively at 1.4 percent for developing countries, the mitigation regime could be quite costly. The highest losses occur in Europe & Central Asia and Middle East & North Africa as they suffer from both the higher cost of production but

13 These conclusions are elaborated in more detail in Matoo et al 2009.

14 The temperature response to changes in emissions takes decades to be fully measured as temperature reflects the impacts of atmospheric concentration of greenhouse gases, i.e. the stock in the atmosphere, and not the annual flow. Even if all emissions stopped in the year 2020, our climate module suggests that the emissions between 2004 and 2020 would lead to a rise in temperature of 1.6º C, peaking in 2050 as the transient response in temperature takes time to be reflected in the long-run equilibrium response. As the stock decays over time (in the absence of emissions) the temperature would slowly decline.

also a negative terms of trade impact as the producer price of fossil fuels declines significantly with the imposition of the carbon tax. The cost for developed countries is relatively small, 0.6 percent of baseline GDP in the scenario with the highest taxes. There is clearly potential for offsets, such as the design of an equitable system of permit trading.

World trade would decline substantially—first of all in line with the drop in world income. The macro elasticity of 2 seems to hold in this case as well despite the wide variations across sectors and regions (Table 10). Thus the 4 percent global drop in real income from the $500/tC is associated with an 8 percent decline in global trade. The burden however falls greatest on developing countries that see a decline of 10.4 in aggregate exports, whereas the high-income countries would see a decline of 4.3 percent. This implies that the regional export to GDP elasticity in this case is much higher for developed than for developing countries. The key reason for this outcome lies in two factors—the energy intensity of production is higher in developing countries than in developed countries (both in aggregate and at a sectoral level) and energy prices tend to be lower. Since the carbon tax is on excise tax on the carbon content of fuel, it has a higher percentage impact on low priced fuels.

In percentage terms the sector most impacted is the energy sector that would see a decline of 22 percent in aggregate global exports (Table 11). Agricultural exports would decline significantly as well, falling some 15 percent. Manufacturing exports would decline by a relatively more modest 7 percent, but its contribution to the overall decline would be significant as it represents the bulk of global exports. There are some interesting side stories. Latin America with its relatively clean energy would see an expansion of manufactured exports as would Sub-Saharan Africa, and the high income countries would see only a modest decline as the uniform carbon tax would weigh less on competitiveness for them than for carbon intensive and countries with relatively cheap energy. These results could be modified under a regime of cap and trade as the exchange rate impacts of international transfers could generate differences in relative prices and relative competiveness. These issues are discussed in more detail in Mattoo et al 2009.

Conclusions

While the global economy is roiled by the ongoing financial crisis that has severely impacted high-income countries, though less so for developing countries, climate change continues to be at the top of the international policy agenda—and for good reasons. The current crisis is most likely to be a blip, even if prolonged, if one takes a long term view through 2050 or 2100. Global GDP will jump from $47 trillion to $127 trillion in our baseline—under relatively modest assumptions. Emissions are likely to follow suit unless a miracle technology suddenly appears or incentives are changed that lead to a less energy and/or carbon intensive growth pattern. Under our baseline, temperatures will climb by over 2º C by 2050, on an accelerated path compared to most scenarios reported just three years ago (IPCC 2007).

The impacts of climate change itself will have relatively modest impacts on aggregate trade that is increasingly manufactured and services oriented and less sensitive to changes in climate than agriculture. Agricultural trade could be heavily impacted, particularly for some regions. This result is likely to hold no matter what the exact relation is between climate change, agricultural yields and water availability. Our results reflect a rather benign scenario with yields broadly increasing over the range of temperature between now and 2050 and water stress limited essentially to the Middle East and North Africa and world prices declining modestly. Pushing out the scenario beyond 2050 shows a strong reversal in these trends as temperatures rise above optimum and yields start declining. The medium-term impacts are subject to significant uncertainty—the degree of adaptability of producers, the positive effect of carbon fertilization, and importantly, the level of moisture available for crops.[15]

The removal of remaining trade barriers would have a potentially sizeable impact on global trade, particularly for some regions where trade barriers remain high, for example in South Asia. The greater carbon intensity of production in developing countries would lead to an increase in greenhouse gas emissions, but modest relative to the overall growth in emissions in the baseline. This reinforces the notion that trade policy is a relatively blunt instrument to deal with environmental concerns.

Achieving an international agreement to address climate change has proven, and will continue, to be difficult. Developed countries may be ready to price carbon, but it could be extremely costly for them in the absence of offsets, and is likely to have relatively small impacts on climate change due to the momentum built into the current climate combined with the growing rate of emissions from developing countries. Developing countries are more reluctant as they still face a significant development challenge and can argue that their responsibility for the current atmospheric concentrations is relatively small. There is another possible incentive problem. Developed countries may be significantly less impacted by climate change than developing countries—and some could even benefit, at least in the medium term.

Policies to limit greenhouse gases, unless designed appropriately will have a greater impact on developing countries than on the developed. With their relative greater carbon intensity and lower fuel prices, developing countries would suffer greater losses in competiveness than developed countries. Nor should all developing countries be seen as identical as some, due to natural endowments—for example parts of Latin America—are less carbon intensive than others. The manufacturing export powerhouses in Asia could be particularly affected by carbon taxes and we exclude any externalities that might be associated with manufacturing export growth. Another key negative factor for world trade is trade in fossil fuels—a natural outcome of taxing carbon, but one with negative consequences for countries largely dependent on fossil fuel exports. They suffer from at least three channels—declines in export volumes, declines in export prices, and a real exchange rate depreciation as they replace their former fuel exports with non-fuel exports.

Many of the findings from this paper should be seen as tentative as there is large uncertainty about a) how emissions will eventually impact local weather patterns, particularly precipitation and water availability; b) the relationship between climate change and economic variables; c) how easy and cheap it will be to adapt to changes in climate; d) what new technologies may emerge to affect both adaptation and mitigation costs. On this latter point, our estimates are likely on the high side as the pricing of carbon is likely to induce significant innovation that are only partially captured in the existing framework.

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15 Even if average precipitation increases, higher temperatures could lead to greater evaporation and drier soils. Moreover, the timing of the precipitation is critical for plant development. While this is an area of intense research, there is a clear lack of consensus across climate models.

References

Asian Development Bank (2010), *Ho Chi Minh City adaptation to climate change*, Mandaluyong City, Philippines: Asian Development Bank.

Bacon, Robert and Masami Kojima (2009). *Changes in CO_2 Emissions from Energy Use*. Extractive Industries for Development Series #11. Washington, DC: The World Bank.

Bosello, F., R. Roson and R.S.J. Tol (2006), "Economy wide estimates of the implications of climate change: human health", *Ecological Economics*, vol. 58, pp. 579-591.

Bosello, F., R. Roson and R.S.J. Tol (2007), "Economy wide estimates of the implications of climate change: sea level rise", *Environmental and Resource Economics*, vol. 37, pp. 549-571.

Cline, William R. (2007). *Global Warming and Agriculture: Impact Estimates by Country*, Washington. DC: Center for Global Development and Peterson Institute for International Economics

Dasgupta, Susmita, Benoit Laplante, Craig Meisner, David Wheeler and Jianping Yan (2007), "The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis", *World Bank Policy Research Working Paper*, 4136, Washington, DC: The World Bank.

De Cian, E., Lanzi, E. and R. Roson (2007), *The Impact of Temperature Change on Energy Demand: A Dynamic Panel Analysis*, FEEM Working Paper N.46.2007.

Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F.N. Tubiello, (2007), "Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate", in: Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 273-313.

Eboli, Fabio, Ramiro Parrado, and Roberto Roson (2009), Climate Change Feedback on Economic Growth: Explorations with a Dynamic General Equilibrium Model, Working Paper 2009.43, Fondazione Eni Enrico Mattei.

Hamilton J.M. , Maddison D.J. and Tol R.S.J (2005), "Effects of climate change on international tourism", *Climate Research*, 29, pp. 245–254.

IPCC (2007). *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Metz, B., O. Davidson, P. Bosch, R. Dave and L. Meyer (eds). Cambridge, UK and New York, NY: Cambridge University Press.

Kiellstrom T., R.S. Kovats, S.J. Lloyd, T. Holt, R.S.J. Tol (2008), *The direct impact of climate change on regional labor productivity*, ENSEMBLES Deliverable D7.8, European Commission, VI Framework Programme.

Mattoo, Aaditya, Arvind Subramanian, Dominique van der Mensbrugghe, Jianwu He (2009), "Can Global De-Carbonization Inhibit Developing Country Industrialization?" *World Bank Policy Research Working Paper*, 5121, Washington, DC: The World Bank.

Newfarmer, Richard, editor (2006), *Trade, Doha, and Development: A Window into the Issues*, Washington, DC: The World Bank.

Nordhaus, William (2008). A *Question of Balance*. New Haven, CT: Yale University Press.

Roson, R. and M. Sartori (2010), *The ENVIRONMENTAL IMPACT AND SUSTAINABILITY APPLIED GENERAL EQUILIBRIUM (ENVISAGE) Model. Introducing Climate Changes Impacts and Adaptation. Changes in the Model Structure and Parameters' Estimation*, Processed, The World Bank.

Stern, Nicholas (2007). *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.

Strzepek, K. and B. Boehlert (2009), *Competition for Water for the Food System*, Mimeo.

van der Mensbrugghe, Dominique (2008). The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model. *Processed*, The World Bank.

van der Mensbrugghe, Dominique, (2010), "Climate Change Policy Options for Asian Economies: Findings from an Integrated Assessment Model," *Asian Economic Policy Review*, 2010, pp. 63–83.

Vafeidis A. T., R. J. Nicholls, L. McFadden, R. S. J. Tol, J. Hinkel, T. Spencer, P. S. Grashoff, G. Boot, R. J. T. Klein (2008), A New Global Coastal Database for Impact and Vulnerability Analysis to Sea-Level Rise, *Journal of Coastal Research*, 24(4), pp. 917-924.

Weyant, John P., Francisco. C. de la Chesnaye and Geoffrey. J. Blanford (2006). Overview of EMF-21: Multigas Mitigation and Climate Policy. *The Energy Journal*: Special Issue, Multi-Greenhouse Gas Mitigation and Climate Policy, 1-32.

Annex A: Summary description of the Envisage Model

The results in this paper rely on the World Bank's Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model.[16] The ENVISAGE model's core is a relatively standard recursive dynamic global general equilibrium (CGE) model. Incorporated with the core CGE model is a greenhouse gas (GHG) emissions module that is connected to a simple climate module that converts emissions into atmospheric concentrations, radiative forcing and changes in mean global temperature. The climate module has feedback on the economic model through so-called damage functions, affecting a number of parameters in the model, as it will be explained in more detail below. The combination of the socio-economic CGE model with the climate module is commonly referred to an integrated assessment model (IAM).

ENVISAGE is calibrated to Release 7.1 of the GTAP dataset with a 2004 base year. It has been used to simulate dynamic scenarios through 2100. The 112 countries/regions and 57 sectors of GTAP are aggregated to a smaller set of countries/regions and sectors to facilitate computing. The GTAP data is supplemented with satellite accounts that include emissions of the so-called Kyoto gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (F-gases), different electricity production activities (coal, oil and gas, hydro, nuclear and other), and potential land and hydro supplies.

Within each time period a full equilibrium is achieved given the fixed regional endowments, technology and consumer preferences. Production is modeled as a series of nested constant-elasticity-of-substitution (CES) functions that are designed to reflect the substitution and complementarity of inputs. Unlike many standard models, energy plays a key role as an input and is modeled as a complement to capital in the short-run but a substitute to capital in the long run. This reflects the putty/clay specification of production that incorporates vintage capital. The key assumption is that there is greater substitution across inputs in the long run (i.e. with new capital) than in the short run (with old or installed) capital. One consequence of this specification is that countries that have higher growth and higher rates of investment typically have a more flexible economy in the aggregate. There is a single representative household that consumes goods and services and saves. The savings rate is partially a function of the demographic structure of the region. Savings rise as either the elderly or youth dependency ratios fall. The government sector is relatively passive. Aggregate expenditures are fixed as a share of total GDP and revenues adjust to maintain fiscal balance (through a lump sum tax on households). Investment is savings driven.

Aggregate demand by sector is summed across all domestic agents and represents a composite of domestically produced goods and imports—the so-called Armington aggregate. The aggregate Armington good is allocated between domestic production and imports using a two-nested CES specification. The first nest allocates aggregate demand between domestic production and an aggregate import bundle. The second nest decomposes aggregate imports into import by region of origin. This generates a bilateral trade flow matrix. Domestic producers are assumed to supply both domestic and export markets without friction, i.e. the law of one price holds for domestically produced goods irrespective of their final destination. Bilateral trade is associated with three price wedges. The first wedge reflects differences between producer prices and the border (FOB) price, i.e. an export tax or subsidy. The second wedge reflects international trade and transport margins,

[16] A detailed description is given in van der Mensbrugghe 2009.

i.e. the difference between FOB and CIF prices. The third wedge reflects the difference between the CIF price and the end-user price, i.e. import tariffs. All three wedges are fully bilateral.

Model closure is consistent with long-term equilibrium. As stated above, fiscal balance is maintained through lump sum taxes on households under the assumption of fixed public expenditures (relative to GDP). Changes in revenues, for example carbon tax revenues, imply a net decrease in household direct taxes. Investment is savings driven. This assumption implies that changes in investment are likely to be relatively minor since public and foreign savings are fixed and household savings will be relatively stable relative to income. The third closure rule is that the capital account is balanced. Ex ante changes in the trade balance are therefore offset through real exchange rate effects. A positive rise in net transfers, for example through a cap and trade scheme, would tend to lead to a real exchange rate appreciation.

The model dynamics are relatively straightforward. Population and labor force growth rates are based on the UN population's projection —with the growth in the labor force equated to the growth of the working age population (15-64). Investment, as mentioned above, is savings driven and the latter is partially influenced by demographics. Productivity growth in the baseline is 'calibrated' to achieve a target growth path for per capita incomes—differentiated for agriculture, manufacturing and services.

Emissions of GHGs have three drivers. Most are generated through consumption of goods—either in intermediate of final demand—for example the combustion of fossil fuels. Some are driven by the level of factor input—for example methane produced by rice is linked to the amount of cultivated land. And the remainder is generated by aggregate output—for example waste-based methane emissions. The climate module takes as inputs emissions of GHGs and converts them to atmospheric concentration, then radiative forcing and finally temperature change. The temperature change is linked back to the socio-economic model through damage functions.

Climate change impacts

ENVISAGE incorporates a wide set of impact (or damage) functions[17] that considerably encompass the economy-wide effects of climate change. These impact functions, calibrated to estimates in the literature, relate changes in temperature to economic variables such as agricultural yields, labor productivity, infrastructure destruction, etc.

Following Eboli, Parrado and Roson 2009, parameters for the impacts are obtained from a number of different sources and specific micro-sectoral studies. The ENVISAGE model is therefore used as a sort of common platform, allowing to assess multiple impacts simultaneously and with a global perspective.

Disaggregated, sectoral climate change impacts have been introduced for the ENVISAGE model by Roson and Sartori 2010. A number of damage functions, one for each type of impact, relate changes in average temperature, by region and year, to changes in a number of parameters and variables of

[17] Even though the climate related impacts are typically referred to as damage functions, there are sectors, regions and time periods for which climate impacts are positive and not negative. For example, longer growing seasons in the northern and southern latitudes will have positive impacts, and a reduction in the demand for heat would also be seen as positive.

the model. Climate change impacts are therefore introduced as exogenous parameter variations, affecting the general equilibrium in all time steps of the recursive dynamics.

The impacts normally affect exogenous variables, like stocks of land and capital/infrastructure (e.g., in the case of sea level rise), or parameters, like factor or multi-factor productivity (e.g., in the case of agricultural yield). In a few instances, for example for changes in energy demand due to varying needs for cooling/heating, impacts affect naturally endogenous variables, like household energy consumption, through shifting factors in the demand equations.

Most of the relationships are linear, with the notable exception of climate change impacts on agriculture productivity, which are typically positive for small increases in temperature (and concentrations of carbon dioxide in the atmosphere) and negative for larger variations.

Seven types of impacts are considered in this work: agriculture productivity, sea level rise, water availability, tourism, energy demand, human health and labor productivity. Catastrophic events and extreme weather are not taken into account. In the following, we briefly describe how each impact has been modeled and how parameters have been estimated.

Agriculture

Variations in agricultural yield are modeled as changes in multifactor productivity for agricultural activities, so that output volumes are varied when using the same mix of production factors. The relationship between agricultural yield and average temperature is a non-linear one.[18]

Parameters were obtained through elaboration from data presented in the latest IPCC report (Easterling et al. 2007, page 286), where a meta-analysis can be found, summarizing results from many different studies. Central values for 1, 3 and 5 degrees changes were collected for three crops (maize, wheat, rice) and for high and low latitudes regions, to estimate parameters of a second-degree polynomial. Table 1 summarizes the central estimates for a three 3° C variation in local mean temperature, under the scenario "with adaptation".

Table 1 – Estimates of yield changes for 3°C degrees changes in temperature

	Mid-High Latitude	Low Latitude
Maize	2%	-2%
Wheat	18%	-1%
Rice	5%	1%

Region specific parameters for the impact function in this study were obtained through: (1) weighted average of crop functions, with weights given by the relative share of each crop in total agricultural output, as well as by the relative allocation of each region in the two areas (high and low latitudes), and (2) by forcing the function to be zero at zero changes in temperature.

18 Earlier versions of ENVISAGE also incorporated climate-related damage functions for agriculture that linked agricultural productivity to changes in global mean temperature. The agricultural damage functions were calibrated to productivity effects described in Cline 2007. These damage functions were less than ideal because they had no sector specificity and were calibrated using linear functions, thus most likely overestimating damages in the short-run and underestimating them in the long run.

As an example, Figures 1 and 2 show the estimated relationship between temperature changes (in °C, with respect to mean temperature in 2000) and average agricultural productivity for USA and China.

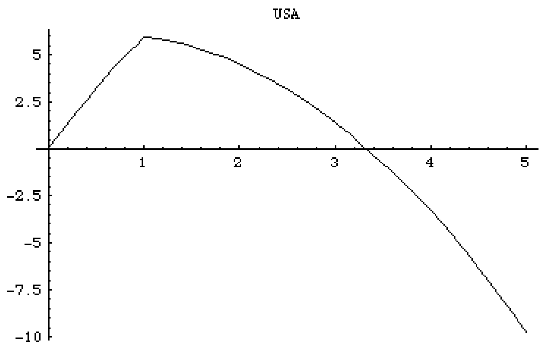

Figure 1. Agriculture productivity USA

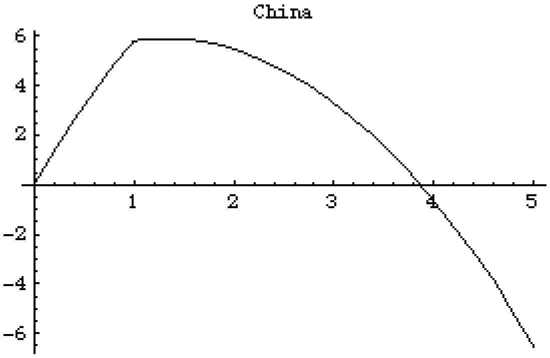

Figure 2. Agriculture productivity China

Sea Level Rise

Sea level rise is modeled through reductions in the available stocks of capital and land. Parameters were estimated for a static CGE model (Bosello, Roson and Tol 2007) from simulation results of the DIVA model (Vafeidis et al. 2008). Parameters for 16 regions in the original CGE model were initially mapped to 10 regions for a specific version of the ENVISAGE model, to conduct preliminary simulation experiments. Subsequently, parameters for all 112 GTAP7 regions have been obtained on the basis of the relative total coast length / total agriculture land ratio.

Although the effects of sea level can be dramatic in some specific areas, the amount of land and capital endowments lost in large regions, like those considered in the present study, is generally limited. Some exceptions are the Rest of East Asia (XEA) region, where about 0.87% of land and capital stocks are lost for 1°C degree increase in temperature, and Rest of South Asia (XSA), where the loss is restricted to 0.35%.

Water

Water availability affects multifactor productivity (yield) in agriculture. It is assumed that changes in productivity depend on changes in Mean Annual Runoff (MAR) in each country, with effects depending on how much each region is constrained by its water resources. This is estimated on the basis of the current ratio between water demand and available surface water.

This implicitly amounts to assume that: (a) the shares of water resources employed for municipal and industrial uses, as well as for preserving aquatic ecosystems, do not change in the future, (b) there are no changes in water productivity or there is no possibility of substitution between water and other factors in the production processes.

Data for MAR 2000, municipal and industrial demand, environmental flow requirements, and estimates of MAR 2050 according to two different climate GCM models (a simple average of the two scenarios is used here), are taken from Strzepek and Boehlert 2009.

Climate models generally predict a change in the pattern of total precipitation, with more precipitation occurring in temperate and high latitude regions, and less precipitation in lower latitudes. Effects on agricultural productivity depend on how much a certain region is constrained by water resources. For the regional aggregation used in this study, we estimate a strong negative effect of reduced water availability for the Middle East and North Africa (-8.13% change in agriculture productivity for a one degree increase in temperature) and a positive effect for China (CHN), India (IND), and Sub-Saharan Africa (SSA).

Tourism

Changes in tourism flows, due to variations in climate conditions, are modeled as adjustments in international income transfers, to account for changes in the expenditure of incoming or outgoing tourists. Parameters for tourism have been derived from the Hamburg Tourism Model (Hamilton, Maddison and Tol 2005). This econometric model estimates changes in tourism flows by country, as a function of several variables, including climate conditions. Average spending for incoming and outcoming tourists have been obtained from the Balance of Payment Statistics (IMF, 2007), by dividing tourism revenue by total tourists in a reference year.

Since income transfers must be globally balanced, the algebraic sum of them is always zero. Positive income transfers are experienced by the United States (becoming, all else equal, a more attractive tourism destination), whereas negative effects are particularly felt in African countries.

Energy Demand

A model of household energy demand, by fuel type, has been estimated by DeCian, Lanzi and Roson 2007, using econometric techniques and a global panel data base. Energy demand is expressed as dependent, among other factors, on seasonal average temperatures.

By increasing exogenous temperatures, in all seasons, by 1° C, it is possible to estimate the implied (long-run) change in energy demand, for electricity, gas, and oil products consumption. In ENVISAGE, the corresponding parameter of percentage variation in demand has been estimated as a weighted average of changes in the three fuel components, using data on household consumption from the GTAP7 data base.

For most of the regions, climate change is estimated to reduce the total energy demand by households, as reduced warming needs more than compensate the increased cooling needs. However, some regions do experience an increase in energy demand. These are: Rest of East Asia (XEA), India (IND), Rest of South Asia (XSA) and Brazil (BRA).

Human Health

Bosello, Roson and Tol 2006 study the economic impacts of climate-change-induced change in human health, viz. cardiovascular and respiratory disorders, diarrhea, malaria, dengue fever and schistosomiasis. Changes in morbidity and mortality are interpreted as changes in labor productivity and demand for health care, and are used to shock exogenous parameters in a computable general equilibrium model, including 16 regions. The same variations in labor productivity are used here and applied to all countries inside the same macro-region.

Changes can be both positive and negative. Positive variations of labor productivity are expected when climate change reduces the incidence of some, cold-related, diseases. Positive effects are estimated for China (CHN), Russia (RUS), and other regions. Negative and significant effects, however, are estimated for Sub-Saharan Africa (SSA), Middle East and North Africa (MNA), India (IND), Rest of South (XSA) and East (XEA) Asia, United States (USA) and Rest of the World (XLC).

Labor Productivity

We consider the ability to work under different climate conditions. Increased temperature and humidity reduce the labor productivity in a number of occupations, requiring open air activity. Kjellstrom et al. 2008 estimate the direct impact of climate change on regional labor productivity. Bosello and Roson elaborated on these results to get estimates of variations in labor productivity for 1°C increase in temperature and for 10 macro-regions.

Variations of labor productivity are always negative and especially significant in China (CHN), India (IND) and in most developing countries, where the incidence of agriculture and other open-air activities is relatively larger.

Tables

Table 1: Baseline scenario for population and GDP

	Population (million)		GDP ($2004 trillion)		GDP per capita ($2004, MER)		GDP per capita (%)
	2010	2050	2010	2050	2010	2050	2010/50
World total	6,760	8,793	47.2	127.4	6,983	14,491	1.8
Developing countries	5,688	7,745	11.3	62.7	1,991	8,094	3.6
East Asia and Pacific	1,911	2,247	3.8	28.2	1,969	12,568	4.7
China	1,349	1,492	2.8	23.9	2,099	16,044	5.2
South Asia	1,635	2,322	1.3	11.9	781	5,125	4.8
India	1,167	1,585	1.0	10.5	868	6,593	5.2
Europe and Central Asia	301	287	1.1	5.4	3,773	18,783	4.1
Russia	139	114	0.8	2.9	5,615	25,380	3.8
Middle East and North Africa	445	668	1.8	4.2	4,035	6,268	1.1
Sub-Saharan Africa	807	1,410	0.7	4.7	889	3,346	3.4
Latin America and Caribbean	589	811	2.6	8.2	4,472	10,175	2.1
Brazil	191	248	0.8	2.1	3,962	8,654	2.0
High income countries	1,073	1,048	35.9	64.7	33,452	61,766	1.5
EU27 with EFTA	497	448	14.7	25.5	29,560	56,986	1.7
Japan	126	105	4.8	6.3	38,257	60,153	1.1
United States	307	354	12.9	24.5	41,922	69,282	1.3
Rest of high income Annex 1	58	61	1.9	3.6	33,270	58,639	1.4
Rest of high income	84	80	1.6	4.8	18,491	59,755	3.0

Table 2: Baseline emissions and climate results

	Emissions (gigatons of carbon equivalent)					Concentration (ppm)	Temperature (º C)
	Carbon	Methane	Nitrous Oxide	F-gases	Total	Carbon	
2010	8.2	1.7	0.8	0.2	10.9	392	0.53
2015	9.5	1.8	0.8	0.2	12.2	405	0.82
2020	11.0	1.9	0.8	0.3	13.9	420	1.04
2025	12.7	2.0	0.8	0.3	15.8	439	1.25
2030	14.6	2.1	0.8	0.4	17.8	460	1.45
2035	16.6	2.2	0.8	0.4	19.9	484	1.67
2040	18.7	2.3	0.8	0.4	22.1	511	1.88
2045	20.8	2.4	0.8	0.5	24.5	542	2.10
2050	23.0	2.4	0.8	0.5	26.8	575	2.34

Table 3: Decomposition of climate change impacts on real GDP in 2050

	Impacts on real GDP in 2050 in $2004 trillion							
	AGR	WAT	SEA	ONJ	HHE	END	TOU	TOT
World total	365	359	-498	-1,840	-164	-2	-592	-2,375
Developing countries	271	309	-457	-1,631	-247	0	-630	-2,378
East Asia and Pacific	102	138	-278	-811	38	0	-177	-981
China	99	139	-62	-720	63	0	40	-447
South Asia	83	221	-43	-377	-75	0	-73	-271
India	75	213	-18	-350	-66	0	-63	-217
Europe and Central Asia	28	5	-7	-63	17	0	72	54
Russia	13	-2	-1	-18	10	0	91	95
Middle East and North Africa	45	-72	-30	-110	-62	0	-59	-293
Sub-Saharan Africa	5	42	-11	-96	-119	0	-195	-370
Latin America and Caribbean	8	-26	-88	-173	-47	0	-199	-517
Brazil	-8	-10	-2	-33	-11	0	-26	-90
High income countries	94	50	-41	-209	83	-1	38	2
EU27 with EFTA	38	-8	-7	-22	100	-1	15	112
Japan	2	2	-11	-25	16	0	6	-11
United States	11	52	-12	-97	-65	0	22	-91
Rest of high income Annex 1	41	-2	0	-31	20	0	24	46
Rest of high income	2	6	-11	-34	12	0	-30	-54

	Impacts on real GDP in 2050 as percent change relative to a no-climate baseline							
World total	0.3	0.3	-0.4	-1.4	-0.1	0.0	-0.5	-1.8
Developing countries	0.4	0.5	-0.7	-2.5	-0.4	0.0	-1.0	-3.7
East Asia and Pacific	0.3	0.5	-1.0	-2.8	0.1	0.0	-0.6	-3.4
China	0.4	0.6	-0.3	-3.0	0.3	0.0	0.2	-1.8
South Asia	0.7	1.8	-0.4	-3.1	-0.6	0.0	-0.6	-2.2
India	0.7	2.0	-0.2	-3.3	-0.6	0.0	-0.6	-2.0
Europe and Central Asia	0.5	0.1	-0.1	-1.2	0.3	0.0	1.4	1.0
Russia	0.5	-0.1	0.0	-0.7	0.4	0.0	3.3	3.4
Middle East and North Africa	1.0	-1.6	-0.7	-2.5	-1.4	0.0	-1.3	-6.5
Sub-Saharan Africa	0.1	0.8	-0.2	-1.9	-2.3	0.0	-3.8	-7.3
Latin America and Caribbean	0.1	-0.3	-1.0	-2.0	-0.5	0.0	-2.3	-5.9
Brazil	-0.4	-0.4	-0.1	-1.5	-0.5	0.0	-1.2	-4.0
High income countries	0.1	0.1	-0.1	-0.3	0.1	0.0	0.1	0.0
EU27 with EFTA	0.2	0.0	0.0	-0.1	0.4	0.0	0.1	0.4
Japan	0.0	0.0	-0.2	-0.4	0.3	0.0	0.1	-0.2
United States	0.0	0.2	0.0	-0.4	-0.3	0.0	0.1	-0.4
Rest of high income Annex 1	1.2	-0.1	0.0	-0.9	0.6	0.0	0.7	1.3
Rest of high income	0.0	0.1	-0.2	-0.7	0.3	0.0	-0.6	-1.1

Note: The climate change impacts include multi-factor productivity in agriculture (AGR), agricultural multi-factor productivity due to changes in water (WAT), sea-level rise (SEA), temperature related labor productivity (ONJ), health impacts on labor productivity (HHE), changes due to energy demand (END), impacts on tourist arrivals (TOU) and the aggregation of all seven impacts (TOT).

Table 4: Decomposition of climate change impacts on real exports by region in 2050

	Impacts on aggregate real exports in 2050 as percent change relative to a no-climate baseline							
	AGR	WAT	SEA	ONJ	HHE	END	TOU	TOT
World total	0.2	-0.4	-0.7	-1.5	-0.2	0.0	-0.8	-3.6
Developing countries	0.0	-0.9	-1.0	-2.0	-0.4	0.0	0.5	-3.8
East Asia and Pacific	-0.1	-0.7	-1.5	-2.0	0.0	0.0	-0.2	-4.4
China	-0.1	-1.0	-0.4	-2.0	0.1	0.0	-0.2	-3.6
South Asia	0.5	-2.4	-0.4	-3.2	-0.7	0.0	0.9	-5.3
India	0.5	-2.8	-0.2	-3.4	-0.7	0.0	0.9	-5.7
Europe and Central Asia	-0.5	-0.1	-0.1	-1.5	0.2	0.0	-1.6	-3.6
Russia	-1.5	0.0	0.0	-0.6	0.2	0.0	-6.4	-8.4
Middle East and North Africa	1.3	-1.8	-0.7	-2.1	-1.2	0.0	1.8	-3.7
Sub-Saharan Africa	0.3	0.0	-0.3	-1.7	-2.0	0.0	0.8	-2.9
Latin America and Caribbean	-0.8	-1.1	-1.0	-1.6	-0.4	0.0	4.5	-0.2
Brazil	-3.4	-3.1	-0.3	-0.8	-0.2	0.0	3.0	-4.3
High income countries	0.4	0.4	-0.2	-0.7	0.1	0.0	-3.1	-3.1
EU27 with EFTA	0.1	0.2	-0.1	-0.6	0.2	0.0	-0.9	-1.4
Japan	0.1	0.3	-0.2	-0.6	0.3	0.0	-3.3	-3.4
United States	0.1	1.1	-0.2	-0.6	-0.2	0.0	-6.2	-6.0
Rest of high income Annex 1	3.3	-0.1	0.0	-0.8	0.4	0.0	-8.1	-5.7
Rest of high income	0.0	0.1	-0.3	-0.9	0.2	0.0	0.5	-0.4

Note: The climate change impacts include multi-factor productivity in agriculture (AGR), agricultural multi-factor productivity due to changes in water (WAT), sea-level rise (SEA), temperature related labor productivity (ONJ), health impacts on labor productivity (HHE), changes due to energy demand (END), impacts on tourist arrivals (TOU) and the aggregation of all seven impacts (TOT).

Table 5: Decomposition of climate change impacts on real exports across sectors in 2050

	Impacts on real exports in 2050 as percent change relative to a no-climate baseline							
	AGR	WAT	SEA	ONJ	HHE	END	TOU	TOT
Developing countries								
Agriculture	-6.6	-16.6	-0.4	-1.9	-1.0	0.0	5.0	-23.9
Other industries	0.4	0.0	-0.9	-1.2	-0.3	0.0	0.3	-1.8
Energy	0.3	0.4	-0.7	-1.5	-0.3	0.0	-0.1	-1.8
Manufacturing	0.3	-0.3	-1.2	-2.1	-0.4	0.0	0.4	-3.3
Services	-0.3	-1.7	-0.7	-2.2	-0.4	0.0	0.9	-4.2
All goods and services	0.0	-0.9	-1.0	-2.0	-0.4	0.0	0.5	-3.8
High income countries								
Agriculture	4.8	3.5	-0.5	-0.5	0.4	0.0	-4.8	1.6
Other industries	0.2	1.2	-0.1	-0.9	0.0	0.0	-2.7	-2.4
Energy	0.3	0.3	-0.9	-1.8	-0.3	0.0	-2.2	-4.6
Manufacturing	-0.2	0.1	-0.1	-0.7	0.0	0.0	-3.1	-3.9
Services	0.3	0.1	-0.4	-0.7	0.1	0.0	-2.1	-2.6
All goods and services	0.4	0.4	-0.2	-0.7	0.1	0.0	-3.1	-3.1
World trade								
Agriculture	0.8	-3.6	-0.5	-1.0	-0.1	0.0	-1.4	-7.4
Other industries	0.3	0.4	-0.7	-1.1	-0.2	0.0	-0.7	-2.0
Energy	0.3	0.4	-0.7	-1.6	-0.3	0.0	-0.3	-2.1
Manufacturing	0.1	-0.2	-0.8	-1.6	-0.2	0.0	-0.9	-3.5
Services	0.0	-0.8	-0.5	-1.5	-0.1	0.0	-0.6	-3.4
All goods and services	0.2	-0.4	-0.7	-1.5	-0.2	0.0	-0.8	-3.6

Note: The climate change impacts include multi-factor productivity in agriculture (AGR), agricultural multi-factor productivity due to changes in water (WAT), sea-level rise (SEA), temperature related labor productivity (ONJ), health impacts on labor productivity (HHE), changes due to energy demand (END), impacts on tourist arrivals (TOU) and the aggregation of all seven impacts (TOT).

Table 6: Impacts of global free trade on real incomes and exports, percent change in 2050 relative to baseline

	Real income	Export volume					
		Agricul-ture	Other industries	Energy	Manu-facturing	Services	Total
World total	0.9	16.1	6.7	10.0	19.8	1.4	15.8
Developing countries	1.4	48.4	5.9	8.1	25.4	2.3	20.8
East Asia and Pacific	1.1	254.8	-5.4	17.1	21.8	-3.3	18.7
China	0.9	490.1	-2.7	24.9	21.2	-3.2	18.5
South Asia	1.3	137.6	10.1	67.3	56.3	6.2	43.1
India	1.1	224.7	11.2	106.2	57.0	6.9	44.4
Europe and Central Asia	1.1	40.1	10.0	10.8	8.6	8.4	8.9
Russia	1.7	71.2	11.8	10.5	18.6	9.9	14.4
Middle East and North Africa	2.0	84.4	14.8	4.9	33.5	3.1	13.5
Sub-Saharan Africa	2.5	113.9	12.0	8.9	26.6	11.3	22.2
Latin America and Caribbean	1.6	35.5	-4.1	9.6	20.1	1.6	18.7
Brazil	3.2	23.4	-23.8	114.4	48.3	-24.0	30.5
High income countries	0.5	2.9	8.4	25.5	10.2	0.4	7.8
EU27 with EFTA	0.3	6.4	13.6	27.5	17.1	2.5	12.6
Japan	0.2	3.6	-3.4	11.7	14.6	-4.2	11.9
United States	0.3	-12.6	7.2	12.1	4.2	5.6	1.4
Rest of high income Annex 1	1.6	33.7	-10.9	0.0	-6.3	-9.6	6.3
Rest of high income	1.6	58.7	30.1	45.3	11.5	-7.8	9.3

Table 7: Impacts of global free trade on greenhouse gas emissions, percent change in 2050 relative to baseline

	Carbon	Methane	Nitrous oxide	F-gases	Total
World total	2.9	1.2	1.2	0.4	2.7
Developing countries	3.3	0.6	1.7	0.9	2.9
East Asia and Pacific	2.1	-1.3	-3.2	-0.6	1.6
China	1.8	-2.6	-4.7	-0.6	1.3
South Asia	8.7	-1.3	-0.4	8.1	7.0
India	10.0	-1.7	-2.0	7.9	8.0
Europe and Central Asia	1.5	1.8	-1.8	0.9	1.5
Russia	1.5	1.9	-2.1	0.0	1.5
Middle East and North Africa	2.1	2.1	0.9	4.4	2.1
Sub-Saharan Africa	3.8	2.9	4.6	7.4	3.7
Latin America and Caribbean	3.3	7.4	16.4	-7.9	4.6
Brazil	3.7	23.2	23.2	-21.4	10.5
High income countries	1.6	7.1	-1.2	-1.0	1.7
EU27 with EFTA	1.8	-18.0	-11.6	-0.9	0.8
Japan	2.1	-7.8	-9.8	-1.0	1.9
United States	0.8	-4.9	-8.3	-1.0	0.4
Rest of high income Annex 1	1.2	42.9	31.1	-9.3	9.3
Rest of high income	4.9	-0.2	0.9	3.2	4.7

Table 8: Impact of carbon tax ($/tC) on carbon emissions in 2050

	Percent change in carbon emissions in 2050 relative to baseline									
	$50	$100	$150	$200	$250	$300	$350	$400	$450	$500
2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	-3.8	-7.1	-9.9	-12.4	-14.7	-16.8	-18.7	-20.5	-22.1	-23.7
2020	-5.6	-10.2	-14.1	-17.5	-20.5	-23.2	-25.6	-27.8	-29.8	-31.6
2025	-7.4	-13.3	-18.2	-22.3	-25.9	-29.0	-31.8	-34.3	-36.6	-38.6
2030	-9.5	-16.6	-22.4	-27.2	-31.2	-34.7	-37.8	-40.5	-42.9	-45.1
2035	-11.7	-20.1	-26.7	-32.0	-36.4	-40.2	-43.4	-46.2	-48.7	-51.0
2040	-14.1	-23.9	-31.2	-36.9	-41.6	-45.5	-48.9	-51.7	-54.2	-56.4
2045	-17.0	-28.0	-35.9	-42.0	-46.9	-50.9	-54.2	-57.0	-59.5	-61.6
2050	-20.5	-32.7	-41.2	-47.5	-52.4	-56.3	-59.5	-62.2	-64.5	-66.5

	Percent change in carbon emissions in 2050 relative to 2005									
2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
2015	25.3	21.0	17.3	14.0	11.0	8.3	5.8	3.5	1.4	-0.6
2020	42.7	35.7	29.8	24.7	20.2	16.1	12.5	9.2	6.1	3.3
2025	62.1	51.8	43.3	36.1	29.8	24.3	19.4	15.1	11.1	7.5
2030	82.5	68.0	56.4	46.8	38.7	31.6	25.4	20.0	15.1	10.7
2035	101.9	82.6	67.5	55.4	45.3	36.7	29.3	22.9	17.1	12.1
2040	120.6	95.6	76.8	62.0	50.0	39.9	31.4	24.0	17.6	11.9
2045	138.3	106.7	83.9	66.4	52.5	41.1	31.5	23.4	16.4	10.2
2050	152.3	113.3	86.4	66.5	51.0	38.7	28.5	19.9	12.6	6.2

Table 9: Percent change on real income in 2050 relative to baseline from a global carbon tax ($/tC)

	$50	$100	$150	$200	$250	$300	$350	$400	$450	$500
World total	-0.4	-0.9	-1.3	-1.8	-2.3	-2.7	-3.1	-3.5	-3.9	-4.3
Developing countries	-0.8	-1.7	-2.7	-3.6	-4.5	-5.3	-6.1	-6.9	-7.6	-8.3
East Asia and Pacific	-0.9	-1.9	-2.8	-3.7	-4.6	-5.4	-6.2	-6.9	-7.6	-8.2
China	-1.0	-2.1	-3.1	-4.1	-5.1	-5.9	-6.8	-7.5	-8.2	-8.9
South Asia	-0.6	-1.3	-2.1	-2.9	-3.7	-4.4	-5.1	-5.8	-6.4	-7.0
India	-0.6	-1.3	-2.1	-2.9	-3.6	-4.3	-5.0	-5.7	-6.3	-6.9
Europe & Central Asia	-1.0	-2.3	-3.5	-4.8	-6.0	-7.1	-8.2	-9.3	-10.3	-11.3
Russia	-1.4	-3.2	-5.0	-6.7	-8.4	-10.0	-11.5	-12.9	-14.3	-15.6
Middle East & North Africa	-1.0	-2.2	-3.5	-4.8	-6.1	-7.5	-8.8	-10.1	-11.4	-12.6
Sub-Saharan Africa	-0.7	-1.6	-2.5	-3.3	-4.1	-4.8	-5.5	-6.2	-6.8	-7.4
Latin America & Caribbean	-0.6	-1.3	-2.0	-2.6	-3.3	-3.9	-4.5	-5.1	-5.7	-6.2
Brazil	-0.1	-0.2	-0.3	-0.4	-0.6	-0.7	-0.8	-1.0	-1.1	-1.3
High income countries	0.0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.4	-0.5	-0.5	-0.6
EU27 with EFTA	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1
United States	0.0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9
Rest of high income Annex 1	-0.3	-0.5	-0.8	-1.0	-1.1	-1.3	-1.5	-1.7	-1.8	-2.0
Rest of high income	0.1	0.1	0.1	0.0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6

Table 10: Percent change in export volume in 2050 relative to baseline from a global carbon tax ($/tC)

	$50	$100	$150	$200	$250	$300	$350	$400	$450	$500
World total	-1.0	-2.0	-2.9	-3.8	-4.6	-5.4	-6.1	-6.8	-7.4	-8.0
Developing countries	-1.4	-2.7	-3.9	-5.1	-6.1	-7.1	-8.0	-8.8	-9.7	-10.4
East Asia and Pacific	-1.6	-3.1	-4.6	-5.9	-7.2	-8.3	-9.4	-10.4	-11.4	-12.3
China	-2.0	-3.8	-5.5	-7.1	-8.6	-10.0	-11.2	-12.4	-13.5	-14.5
South Asia	-1.9	-3.5	-5.0	-6.3	-7.5	-8.6	-9.7	-10.7	-11.7	-12.6
India	-2.1	-3.8	-5.4	-6.8	-8.1	-9.4	-10.6	-11.7	-12.7	-13.7
Europe & Central Asia	-1.7	-3.2	-4.6	-5.9	-7.1	-8.2	-9.3	-10.3	-11.3	-12.2
Russia	-1.9	-3.0	-4.0	-4.9	-5.7	-6.5	-7.3	-8.0	-8.8	-9.5
Middle East & North Africa	-0.7	-1.3	-1.9	-2.4	-2.8	-3.3	-3.7	-4.1	-4.5	-4.9
Sub-Saharan Africa	-0.6	-1.1	-1.6	-2.0	-2.5	-2.9	-3.2	-3.6	-4.0	-4.3
Latin America & Caribbean	-0.9	-1.6	-2.3	-3.0	-3.5	-4.1	-4.6	-5.0	-5.5	-5.9
Brazil	-1.4	-2.6	-3.8	-4.8	-5.8	-6.7	-7.5	-8.3	-9.0	-9.7
High income countries	-0.4	-0.8	-1.3	-1.8	-2.2	-2.7	-3.1	-3.5	-3.9	-4.3
EU27 with EFTA	-0.3	-0.7	-1.0	-1.4	-1.8	-2.2	-2.6	-3.0	-3.4	-3.7
Japan	-0.3	-0.6	-0.9	-1.2	-1.6	-1.9	-2.3	-2.6	-2.9	-3.3
United States	-0.6	-1.3	-1.9	-2.6	-3.2	-3.8	-4.3	-4.9	-5.4	-5.9
Rest of high income Annex 1	0.0	-0.2	-0.5	-0.9	-1.2	-1.5	-1.9	-2.2	-2.5	-2.8
Rest of high income	-0.4	-0.8	-1.2	-1.6	-2.0	-2.4	-2.8	-3.2	-3.5	-3.9

Table 11: Impacts on exports across sectors from a $500/tC carbon tax, percent change in 2050 relative to baseline

	Export volume					
	Agricul-ture	Other industries	Energy	Manu-facturing	Services	Total
World total	-14.9	-11.5	-22.0	-6.9	-4.3	-8.0
Developing countries	-6.4	-10.6	-23.5	-10.3	-1.3	-10.4
East Asia and Pacific	-1.5	-13.3	-36.9	-12.7	-6.7	-12.3
China	-3.0	-14.7	-37.8	-15.4	-5.2	-14.5
South Asia	1.7	-16.1	-3.7	-18.2	9.0	-12.6
India	-5.7	-21.6	9.5	-19.4	8.2	-13.7
Europe and Central Asia	-19.7	-8.5	-29.1	-12.1	1.3	-12.2
Russia	53.0	-3.6	-25.4	-2.8	10.9	-9.5
Middle East and North Africa	67.6	27.1	-14.2	5.5	10.1	-4.9
Sub-Saharan Africa	6.2	-13.5	-26.8	1.5	-2.4	-4.3
Latin America and Caribbean	-14.5	4.8	-37.1	9.4	-10.0	-5.9
Brazil	-17.6	0.7	-10.1	5.5	-9.6	-9.7
High income countries	-18.4	-13.6	-9.7	-1.0	-7.1	-4.3
EU27 with EFTA	-27.8	-13.0	4.7	-0.2	-8.6	-3.7
Japan	-29.5	-11.2	1.2	-2.1	-7.4	-3.3
United States	-19.3	-12.9	-51.8	0.0	-7.6	-5.9
Rest of high income Annex 1	-13.5	-12.5	-28.7	6.7	-0.7	-2.8
Rest of high income	-28.5	-25.4	15.1	-4.2	-4.4	-3.9