Agriculture, Climate Change and the Global Economy

WORKING PAPER

Version 15 March 2012

DRAFT REPORT: PLEASE DO NOT QUOTE

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Abstract

This article evaluates the economic consequences of climate impacts on the agriculture sector. A set of 27 climate change runs of the 2080s is analysed, covering three alternative climate futures: 2°C (E1 scenario), 4°C (A1B scenario) and high emission scenario (RCP scenario). The agriculture yield changes due to climate change are estimated with a bottom-up methodology. A global general equilibrium economic model is used to explore the implications of those scenarios on the world economy, mainly on economic activity (GDP) and economic welfare. If the 2080s climate would occur today, global welfare would fall by 0.5% under the high emission scenarios and by 0.3% in the lower emission scenario (E1). The regional impacts vary largely, with Africa, Asia, Latin America and India in particular being the most negatively affected, and experiencing significant agriculture price increases. The overall welfare loss for the world economy is estimated to be $200 bn for the high emission scenarios.

1 Introduction

Climate change can affect the economy through multiple channels, such as via the impacts on agricultural yields, the effects on coastal areas or the influence on tourism destinations. The literature has numerous references addressing the economic impacts of climate change, e.g. the Stern review (Stern, 2007), and Hitz and Smith (2004).

Among the various climate impact categories, agriculture is probably one of the most significant, i.e. impacts in agriculture can account for a large share in the overall climate damage. Indeed, as agriculture yields largely depend on climatic conditions, such as precipitation and temperature (e.g. Schlenkel and Roberts, 2009; Barrios et al., 2010), the link between climate change and the agriculture sector is direct.

Several studies have assessed the economic implications of climate change. Jorgenson et al. (2004) studied the economic consequences of a number of impact categories in the US economy. They found that the impacts due to agriculture represent around 3/4 of the overall impact. In a similar way, Ciscar et al. (2011) analysed the climate impacts in Europe. They concluded that among the four impact categories considered in the study (agriculture, coastal systems, river floods and tourism), the impacts on agriculture are among the largest ones, together with impacts on coastal areas.

Moreover, the impacts in the agriculture sector can have serious equity consequences. Less developed countries and low income social groups appear to be more vulnerable to changes in agriculture prices, which can be potentially largely affected by climate change (e.g. Hertel et al. 2010).

Several studies have addressed the implications of climate change for agricultural yields, including Parry et al. (2004), Cline (2007) and Reilly et al. (2007).

The main purpose of this article is to analyse the general equilibrium consequences of climate change in agriculture at the world level. A comparative static computable general equilibrium (CGE) framework is used to assess the economic implications in terms of economic activity (GDP) and household welfare. The CGE methodology also allows exploring the implications for different regions and sectors.

This analysis extends the study of Ciscar et al. (2011), which addressed climate change impacts in Europe only, to the world level, but only considering the agriculture impacts. The methodology integrates three elements of the analysis: high-resolution climate data, a bottom-up simulation of the impacts in the agriculture sector and, thirdly, the integration of those biophysical impacts within a CGE model.

Most of the references of the literature on climate agriculture impacts have assumed a certain regional pattern of yield changes, based on results from the literature (e.g. Hertel et al., 2010). The new element of our analysis is the use of a set of consistent global climate data, from which the yield changes are estimated running a high-resolution agriculture model (Iglesias et al. 2012). The climate dataset is derived from global circulation models (GCMs), therefore benefitting from consistency in the spatial correlation among climate variables. The CGE analysis also keeps consistency on the spatial dimension thanks to the appropriate modelling of international trade flows.

To date, however, no study has consistently made use of such bottom-up results to draw estimates of damage functions, nor have the assessment been made on a global scale. Such damage functions could be used to update the available evidence on climate impacts (dating in most cases from the 1990s) and overcoming their severe data and methodological limitations, as noted e.g. by Hanemann (2008).

The article is organised in five sections, including this introduction. Section 2 presents the methodology. Section 3 explains the main features of the agriculture yield changes induced by climate change, which is the input to the CGE analysis. Section 4 discusses the economic results of the analysis, including a first exploration of the shape of the agriculture damage function for some large economies. Section 5 concludes noting possible extensions of the paper.

2 Methodological approach

The methodology of this study has several steps. Firstly, detailed climate data are obtained from GCM runs. Secondly, the temperature and precipitation data from the GCMs are introduced into an agriculture modelling system to compute the agricultural yield changes. Thirdly, the yield changes are interpreted as productivity shocks that affect a global CGE model, world GEM-E3. This section explains those steps.

2.1 Climate change data

Agriculture yield changes are simulated using projections of temperature and precipitation from GCMs. 27 climate data sets have been considered in this study. The climate data were elaborated in the ClimateCost project (Christensen et al. 2011), and were originally computed in the FP6 ENSEMBLES project.

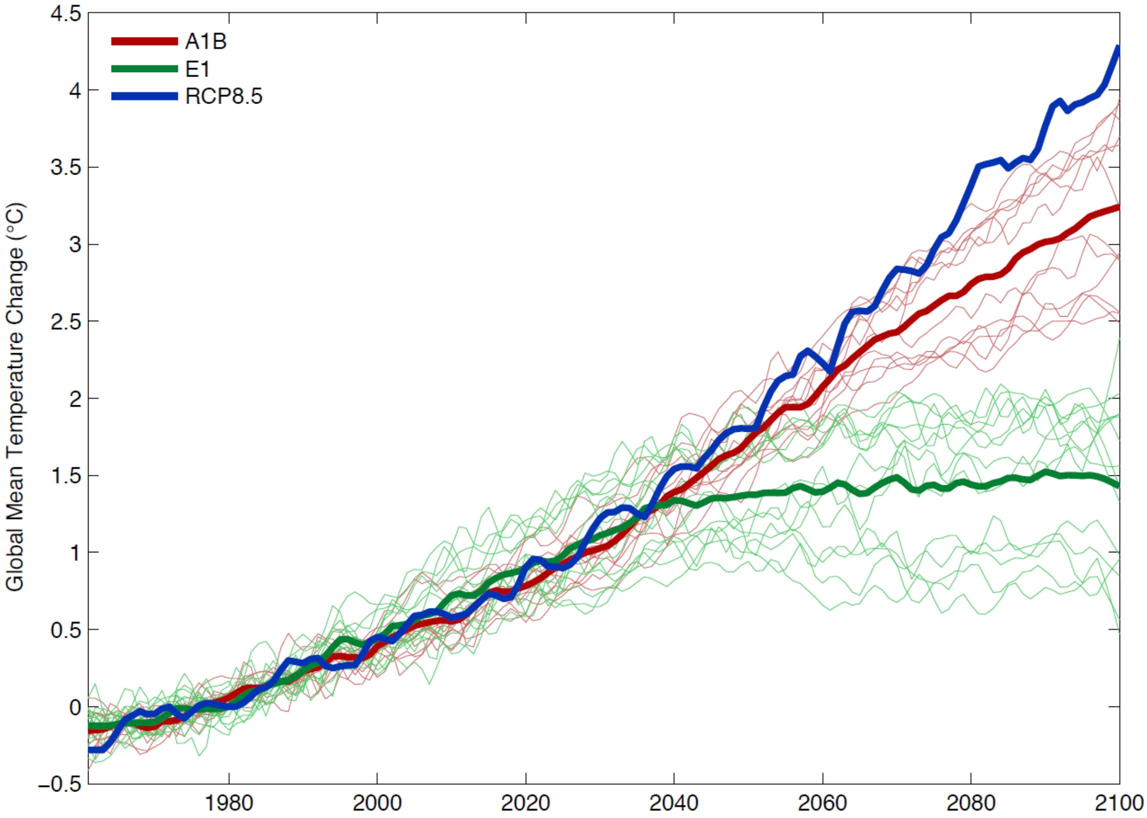
There are three climate change scenarios, defined as those derived from the same set of socioeconomic determinants, mainly population dynamics and economic growth. The first scenario is the A1B scenario of the IPCC SRES (Nakicenovic and Swart, 2000), which implies approximately a global temperature increase of 4°C, compared to the pre-industrial level. The second scenario is the E1 scenario, which would lead to a global temperature increase of 2°C. The third scenario, called RCP, is a high emission scenario, derived from the recent reduction concentration pathways (Moss et al., 2010)[1].

There are twelve runs for the A1B scenario, fourteen runs for the E1 scenario and one for the RCP scenario. Figure 1 represents the global temperature increase of the individual runs (thin lines) and the average of the GCM results for each scenario (thick lines), all compared to the 1961-1990 period. One can see the large range of temperature projections from the same climate scenario. Indeed, different combinations of GCMs and regional climate models (RCMs) lead to different climate runs. Annex 1 has a table

[1] RCP stands for reduction concentration pathway. The scenario here used is called RCP8.5, referring to radiative forcing of 8.5 W/m^2.

that details the specific climate models used in each run, as well as the climate modelling centre where they have been computed.

Figure 1. Projected change in global mean temperature (°C) with respect to the 1961-1990 baseline for the A1B (red) and E1 (green) emissions scenarios. Results from the ENSEMBLES project GCM runs. Blue line shows the EC-Earth RCP8.5 model run, thin lines show individual models, and thick red and green lines show ensemble mean.



Source: ClimateCost project (Christensen et al., 2011).

2.2 The bottom-up modelling of yield changes

The bottom-up agriculture impact assessment (Iglesias et al. 2011; Iglesias et al. 2012) uses the process-based DSSAT crop growth model. DSSAT models the relationship between agriculture yields of different crops and their determinants, i.e. soil characteristics, CO2 concentration, crop water (precipitation and irrigation), temperature over the growing season and management measures, taking into account adaptation at farm level. The model's main output is yield changes.

Three crops have been considered (maize, wheat and rice), which account approximately for 75% of global trade of agriculture goods.

The yield changes at country level have been computed by simple weighting of the yield changes for the sites in each country. A total of 1141 climatic sites are considered in the world. The world is divided into 73 agroclimatic regions and the modelling framework considers that there can be shifts in the agroclimatic regions due to climate change.

Regarding adaptation, it is assumed that farmers can change the planting dates without an extra cost. Other farm-level adaptation options, such as water irrigation and fertilizers use, are not considered in this exercise.

It should be noted that the CGE modelling setup implicitly considers some adaptation as the production technology[2] allows some substitution between agricultural inputs (e.g. labour, capital, intermediates) in response to changing relative prices in the economy. However, this substitution is not based on detailed biophysical modelling.

2.3 World GEM-E3 model

The global version of the General Equilibrium Model for Energy-Economy-Environment interactions (GEM-E3) is a multi-country, multi-sector computable general equilibrium model of the world economy linking the economies through endogenous bilateral trade (E3MLAB, 2010). The GEM-E3 database is based on GTAP 7 (base year 2004)[3].

Twelve regions are considered in the model: Japan, USA, Canada, Australia and New Zealand, EU15, New EU member states, rest of EU, China, India, Former Soviet Union, Brazil and a tenth region (Rest of the World) formed by Africa and all countries not included elsewhere. In this way, all countries of the world are covered by both the agricultural and CGE models (albeit at a high level of aggregation in the latter case).

GEM-E3 covers the interactions between the economy, the energy system and the environment. It allows the evaluation of the welfare and distributional effects of various environmental policy scenarios, and exogenous shocks such as climate change. The output of GEM-E3 includes

[2] The GEM-E3 model production function is a multi-level nested constant elasticity of substitution (CES) structure.

projections of input-output tables, employment, capital flows, government revenues, household consumption and welfare, energy use, and emissions, among other variables.

The model computes simultaneously the equilibrium prices of goods, services, labour, and capital. The model considers the following economic agents: households, firms, government and foreign sector. The Government behaviour is exogenous in GEM-E3. Under general equilibrium the supply in any market equals the demand and all agents maximize their objective function (benefits for firms and welfare for households) given the corresponding budget restrictions. The global model has ten productive sectors (Table 1).

Table 1. Sectors of the world GEM-E3 model

Agriculture
Fuels
Electricity
Energy Intensive
Consumer Goods
Industry
Construction
Trade and Transport
Market Services
Non market Services

The economic agents (firms and consumers) optimise their objective, subject to various constraints, and determine the supply or demand of capital, energy, environment, labour and other goods. The firms' production uses capital, labour, energy (i.e. electricity and fuels) and intermediate consumption of goods from other branches. For each region, a representative consumer allocates his total expected income between consumption of goods and services, savings and leisure. The demand of goods by the consumers, the firms (for intermediate consumption and investment) and the public sector constitutes the total domestic demand. This total demand is allocated between domestic goods and imported goods, depending on the relative prices[4].

[3] https://www.gtap.agecon.purdue.edu/

[4] The CGE model follows the Armington assumption (Armington, 1969).

2.4 The implementation of the climate sectoral shocks in GEM-E3

The agricultural model computes the changes in yields, in t/Ha. These would be naturally implemented in a CGE model with land as a production factor as a shock to land productivity. However, the current world version of GEM-E3 does not feature land as an individual production factor.

Therefore, the yield changes have been implemented in the GEM-E3 model as a change in total factor productivity (TFP) in the agriculture sector[5], the same way as in Ciscar et al. (2012)[6]. The TFP term can be interpreted as capturing the elements affecting output that are not accounted for by the included production factors, such as combinations of intermediate and factor inputs or technological progress.

The 2080s productivity shocks are implemented in the year 2010. Such comparative static approach[7] avoids adding other sources of uncertainty into the exercise, for instance regarding economic growth over 70 years.

3 The shock to the model: agriculture yield changes

Agriculture yield changes for each climate scenario refer to a set of 161 countries. Two transformations are necessary in order to derive the yield changes of the 12 countries of the world GEM-E3 model. Firstly, the yield changes have to be aggregated to the 12 regions of the model. Secondly, as the agriculture sector in the GEM-E3 model also includes forestry, fisheries and livestock the productivity change has to be adjusted.

The net production of crops in value terms from FAOSTAT (FAO, 2012) has been used to weight the country-level yield changes and obtain yield changes for the GEM-E3 regions. Table 2 represents the resulting yield changes for the average or ensemble of the A1B and E1 scenarios (named respectively as

[5] The cost induced by farm level adaptation (e.g. fertilizer or irrigation cost) are not included.

[6] An alternative would be to change capital productivity according to the yield changes. In the world version of the GEM-E3 model capital and land are aggregated into a single production factor called capital. This option is being texted currently by the authors and could be presented in the workshop.

[7] This approach has been also followed by Aaheim et al. (2009) and Hertel et al. (2010).

A1B_AV and E1_AV in the following tables), and for the RCP scenario. Globally, yield loss (excluding the effects of any climate-induced land-use change) is estimated at 8% in high emission scenarios and 6% in the E1 scenario. Regarding the developing countries, India and the Rest of the World region are the most negatively affected by climate change, with yield change losses between 15% and 20% for the high emission scenarios. The yield losses are reduced approximately by half under the E1 scenario.

Table 2. Yield changes for the GEM-E3 regions in the ensembles scenarios

	Estimated Change in Crop Yield 2071-2100		
	A1B_AV	E1_AV	RCP
China	8%	-2%	11%
Japan	-19%	-11%	-21%
India	-21%	-10%	-22%
Canada	17%	10%	21%
USA	-12%	-6%	-15%
Brazil	-3%	-8%	1%
EU-15	-12%	-3%	-11%
EU-New Member States	-1%	1%	0%
Australia & New Zealand	2%	9%	5%
Norway & Switzerland	17%	12%	23%
Former Soviet Union	10%	6%	13%
Rest of the World	-16%	-8%	-18%
Global Average	-8%	-6%	-6%

Source: authors' own calculations

Regarding the share of agriculture crops in the agriculture sector, the GTAP dataset has been used to compute it for each model region. Multiplying the yield changes from Table 2 with the share of crops in GDP, we derive the 'initial' GDP shock[8] – that is the value of the yield change relative to initial GDP (before general equilibrium effects are taken into account). In Table 3, we see that regions such as Japan and USA experience yield losses that are large in proportional terms, but small when expressed as a percentage of GDP due to the relatively small size of the agricultural sector. On the other hand, in the Rest of the World and, especially, India (regions that account for

[8] One could interpret this initial shock as the direct impact on the economy, before taking into account the reaction of firms and households to relative price changes.

over half of current global population[9]), the yield shock equates to a larger share of GDP (over 0.5% and 3% respectively in the high emission scenarios).

Table 3. Size of ensembles scenario yield shock in relation to regional GDP

	Crop Share of GDP	Yield Shock expressed as % of 2010 baseline GDP		
	2010 Baseline	A1B_AV	E1_AV	RCP
China	5.22%	+0.41%	-0.11%	+0.56%
Japan	0.90%	-0.17%	-0.10%	-0.19%
India	14.94%	-3.20%	-1.51%	-3.27%
Canada	0.85%	+0.15%	+0.08%	+0.18%
USA	0.54%	-0.07%	-0.03%	-0.08%
Brazil	4.84%	-0.14%	-0.39%	+0.06%
EU-15	1.09%	-0.13%	-0.04%	-0.12%
EU-New Member States	3.14%	-0.04%	+0.02%	+0.01%
Australia & New Zealand	2.05%	+0.04%	+0.18%	+0.10%
Norway & Switzerland	0.78%	+0.14%	+0.09%	+0.18%
Former Soviet Union	3.06%	+0.30%	+0.17%	+0.40%
Rest of the World	5.21%	-0.83%	-0.43%	-0.94%
Global Average	2.09%	-0.17%	-0.12%	-0.12%

Source: authors' own calculations

The yield shock as % of GDP expressed in Table 3 is the product of three elements, each of which have a greater impact on India than any other region. Firstly, India suffers the greatest fall in yield of any region in each scenario. This might be because India already experiences relatively high stress levels, and would therefore suffer more than other regions from additional stress caused by climate change[10]. Secondly, India has the highest share of agriculture in GDP and thirdly the highest share of crop production in agriculture (according to the GTAP7 database, from which GEM-E3 economic inputs are derived).

[9] According to UN Population Statistics (www.un.org/popin), Africa, Asia and Latin America (excluding China, India, Brazil and Japan) accounted for 41% of world population in 2010. India alone accounts for a further 17%.

[10] Cline (2007) also concludes that India would be one of the countries experiencing highest losses of agricultural output potential.

4 Results

This section presents and analyses the main results of the economic integration with the GEM-E3 model. In a first subsection, the overall impacts in GDP, prices and welfare are studied. The second subsection examines the effects on international trade across the world regions. A third subsection explores the shape of the agriculture damage function.

4.1 Impact on production (GDP), prices and welfare

GDP

Entering the yield changes discussed in previous sections into the GEM-E3 model allows us to observe the general equilibrium (GE) effects of the agricultural climate change scenarios, which take into account the sectoral and regional interactions across the global economy. In terms of GDP change, the GE effect (shown in Table 4) is typically between 1.5 and 2 times as large as the initial shock (shown in Table 3).

Table 4. Change in 2010 GDP due to ensembles yield changes

	Change in 2010 GDP due to Yield Shock		
	A1B_AV	**E1_AV**	**RCP**
China	+0.71%	-0.23%	+0.98%
Japan	-0.34%	-0.19%	-0.37%
India	-5.22%	-2.38%	-5.34%
Canada	+0.31%	+0.17%	+0.38%
USA	-0.14%	-0.06%	-0.17%
Brazil	-0.34%	-0.78%	+0.04%
EU-15	-0.29%	-0.08%	-0.27%
EU-New Member States	-0.18%	+0.02%	-0.03%
Australia & New Zealand	+0.05%	+0.30%	+0.15%
Norway & Switzerland	-0.07%	+0.01%	-0.02%
Former Soviet Union	+0.51%	+0.30%	+0.69%
Rest of the World	-1.51%	-0.77%	-1.69%
Global Average	-0.40%	-0.21%	-0.39%

Source: authors' own calculations

In principle, we would expect the GE shock to be larger than the initial shock since non-agricultural sectors (e.g. the food industry and manufacturing in general) would also be affected. However, the GE impact may be mitigated by the ability of producers and consumers to respond to price changes by changing consumption patterns and choices of productive inputs. In addition, at a regional level some exporters of agricultural products may benefit from improved terms of trade (an increase in the price of exports relative to price of imports).

In our results, the first type of effect is dominant. This can be seen by the fact that regions experience changes in GDP that are greater than the yield shock and acting in the same direction. The regions made worse off by this (experiencing a fall in yield and greater fall in GDP) are India and Rest of the World, while China and Canada are the greatest beneficiaries (experiencing increased yield and greater increase in GDP).

The two regions that do not always experience GDP and yield changes in the same direction are: Norway & Switzerland in the high emission scenarios and EU-New Member States in the RCP scenario. In each case, increases in crop yields (of over 15% in the case of Norway & Switzerland) are outweighed by a smaller global economy and higher prices.

Prices

The change in producer prices for agricultural products follows a similar regional pattern to the yield shock (see Table 5). Regions experiencing yield increases see falls in prices (Canada, China, former Soviet Union) while prices increase by over 10% in India, Rest of the World and Japan. Changes in the consumer price index are smaller, though the consumer price impact remains conspicuously high for India, reaching over 6% above the Reference scenario in the A1B and RCP. In the regions where agricultural prices fall (and where yield effects are positive), the fall in producer prices is essentially wiped out when aggregated into the consumer price index. This could partly be due to the small contribution of agriculture to consumer prices and partly related to the rise in incomes experienced as a result of the yield increase.

Table 5. Change in agricultural producer prices and overall consumer price index in ensembles scenarios

	Change in Agricultural Producer Prices (vs. 2010 Reference)			Change Consumer Price Index (vs. 2010 Reference)		
	A1B_AV	E1_AV	RCP	A1B_AV	E1_AV	RCP
China	-3.68%	1.40%	-5.05%	-0.47%	0.50%	-0.78%
Japan	15.01%	8.08%	16.55%	0.36%	0.19%	0.38%
India	22.15%	9.41%	22.73%	6.48%	2.88%	6.66%
Canada	-5.91%	-3.47%	-7.19%	0.67%	0.35%	0.74%
USA	7.42%	3.39%	9.08%	0.12%	0.06%	0.12%
Brazil	3.22%	7.13%	-0.02%	0.77%	0.35%	0.82%
EU-15	7.25%	2.06%	6.60%	0.52%	0.22%	0.51%
EU-New Member States	1.52%	-0.11%	0.32%	0.57%	0.22%	0.48%
Australia & New Zealand	-0.46%	-3.97%	-1.83%	0.45%	0.13%	0.42%
Norway & Switzerland	-6.39%	-4.42%	-8.44%	0.41%	0.18%	0.39%
Former Soviet Union	-4.70%	-2.80%	-6.35%	0.00%	0.00%	-0.15%
Rest of the World	11.97%	5.92%	13.66%	1.44%	0.74%	1.55%

Source: authors' own calculations

Welfare

The effect on equivalent variation (EV) in percentage terms is similar to the GDP change (see Table 6). In almost all cases the change in EV is slightly larger (and therefore more negative for India and Rest of the World and more positive for China). We see only two cases where the changes in GDP and EV are in opposite directions (Australia & New Zealand A1B and Norway & Swizerland RCP). In each one, the relative changes in GDP and EV are among the smallest recorded.

Table 6. Change in Equivalent Variation in ensembles scenarios

	Change in Welfare (Equivalent Variation) due to Yield Shock					
	% Change			Absolute (bn $2004)		
	A1B_AV	E1_AV	RCP	A1B_AV	E1_AV	RCP
China	0.82%	-0.31%	1.14%	17.2	-6.4	24.0
Japan	-0.50%	-0.29%	-0.54%	-22.5	-12.9	-24.1
India	-5.89%	-2.69%	-6.02%	-42.4	-19.4	-43.4
Canada	0.23%	0.12%	0.29%	2.2	1.2	2.8
USA	-0.18%	-0.09%	-0.20%	-29.7	-15.7	-32.9
Brazil	-0.25%	-0.74%	0.13%	-1.4	-4.1	0.7
EU-15	-0.43%	-0.15%	-0.39%	-41.6	-15.0	-38.3
EU-New Member States	-0.20%	0.00%	-0.04%	-1.1	0.0	-0.2
Australia & New Zealand	-0.05%	0.27%	0.07%	-0.6	3.3	0.9
Norway & Switzerland	0.00%	0.04%	0.07%	0.0	0.2	0.4
Former Soviet Union	0.53%	0.31%	0.76%	2.5	1.5	3.6
Rest of the World	-1.67%	-0.86%	-1.87%	-77.3	-39.8	-86.7
Global Average / TOTAL	-0.46%	-0.25%	-0.45%	-194.7	-107.2	-193.1

Source: authors' own calculations

In absolute terms, we estimate the global loss of welfare at between $100 bn and $200 bn, depending on the scenario. The greatest fall is seen in the Rest of the World, while substantial losses are also seen in India, Japan, USA and EU-15 – although proportionally the loss to India is by the far the greatest.

4.2 Impact on international trade

Agricultural trade

Absolute changes in agricultural exports are shown in Table 7. The main impact of the yield change involves a reduction in net exports by the Rest of the World, and a sharp increase in net exports from China, Canada, Former Soviet Union and Australia & New Zealand. The general pattern is that countries with positive (negative) yield changes export more (less) because their agriculture prices fall, improving their competitiveness.

Table 7. Change in exports in ensembles scenarios

	Agricultural Exports in 2010 bn $2004			
	Reference	A1B_AV	E1_AV	RCP
China	11	14	11	15
Japan	1	1	1	1
India	4	3	3	3
Canada	14	20	17	21
USA	38	36	38	35
Brazil	16	17	15	19
EU-15	19	18	19	18
EU-New Member States	7	8	8	8
Australia & New Zealand	22	26	27	27
Norway & Switzerland	4	5	4	5
Former Soviet Union	7	9	8	9
Rest of the World	73	63	67	60

Source: authors' own calculations

Table 8 shows the proportion of each region's own consumption of agricultural products that is produced domestically, giving a measure of food security (although it should be noted that this sector does not include manufactured food products). Taken together, Table 7 and Table 8 show the increase in import dependency of India and Rest of the World in absolute terms, as well as the dramatic rise (in relative terms) of exports from certain regions. For example, Canada and Australia & New Zealand provide over 20% of global exports in each yield change scenario, compared to under 17% in the Reference scenario.

Table 8. Change in share of agricultural consumption produced domestically, per GEM-E3 region

	% of Agricultural Consumption Produced Domestically [production / (production + imports - exports)]			
	Reference 2010	A1B_AV	E1_AV	RCP
China	96.75%	98.16%	96.92%	98.39%
Japan	85.90%	83.55%	84.57%	83.26%
India	99.86%	98.76%	99.37%	98.75%
Canada	116.09%	129.59%	123.15%	131.78%
USA	102.55%	101.79%	102.36%	101.08%
Brazil	118.22%	120.25%	116.62%	121.89%
EU-15	91.59%	91.08%	91.80%	91.24%
EU-New Member States	99.06%	100.39%	99.82%	100.66%
Australia & New Zealand	111.21%	116.08%	115.94%	117.09%
Norway & Switzerland	94.89%	103.26%	99.45%	104.63%
Former Soviet Union	100.75%	104.69%	102.95%	105.32%
Rest of the World	102.52%	100.40%	101.36%	99.80%

Source: authors' own calculations

Non-agricultural trade

In terms of non-agricultural trade, our results show a number of different regional responses to the yield change (see Table 9). In *Comparative advantage* regions, increases (falls) in yield are accompanied by reductions (increases) in non-agricultural trade as economies alter specialisation into (away from) agriculture. In other regions, yield changes and changes in non-agricultural net trade occur in the same direction, meaning that increases (reductions) in agricultural productivity are accompanied by increases (reductions) in net exports from other sectors.

Comparative advantage regions are able to shift away from agricultural trade as their productivity declines (or into agricultural trade as productivity increases). This suggests that production technologies and consumer preferences are sufficiently flexible to allow the wider economy to adapt to (and partially mitigate) the change in yields.

Japan, USA and EU-15 are able to counteract falls in agricultural yield with increased net exports in other sectors. This is also true of the Rest of the World in some scenarios, though here there are likely to be substantial intra-regional differences given the level of aggregation. Canada, Australia & New Zealand, Norway & Switzerland and the Former Soviet Union respond to yield increases with reductions in non-agricultural net exports, suggesting that these economies increase specialisation in agriculture and/or increase imports of other goods as a result of the productivity increase.

In other regions, by contrast, non-agricultural trade responds in the same direction as the yield change. For India (and in some scenarios China, Brazil and EU-New Member States) a fall in agricultural yields is accompanied by deterioration in other sectors' net trade position. This implies that the income effect (the global GDP fall) outweighs the ability of the economy to alter its specialisation and/or that low per capita incomes reduce the ability of consumers to substitute out of agricultural products in the face of high prices. In the two scenarios where yields increase in China, we also see an improvement in non-agricultural trade performance which may be due to the fall in domestic input prices created by the positive yield shock (Table 5 shows that China is the only region to experience a notable fall in the whole-economy price level following a positive yield shock).

Table 9. Comparison of change in yield and change in non-agricultural trade balance in ensembles scenarios

	A1B_AV		E1_AV		RCP	
	Yield	Non-Ag Trade	Yield	Non-Ag Trade	Yield	Non-Ag Trade
China	+	+	-	-	+	+
Japan	-	+	-	+	-	+
India	-	-	-	-	-	-
Canada	+	-	+	-	+	-
USA	-	+	-	+	-	+
Brazil	-	-	-	-	+	-
EU-15	-	+	-	+	-	+
EU-New Member States	-	-	+	-	+	-
Australia & New Zealand	+	-	+	-	+	-
Norway & Switzerland	+	-	+	-	+	-
Former Soviet Union	+	-	+	-	+	-
Rest of the World	-	-	-	+	-	+

Source: authors' own calculations

4.3 Agriculture damage function

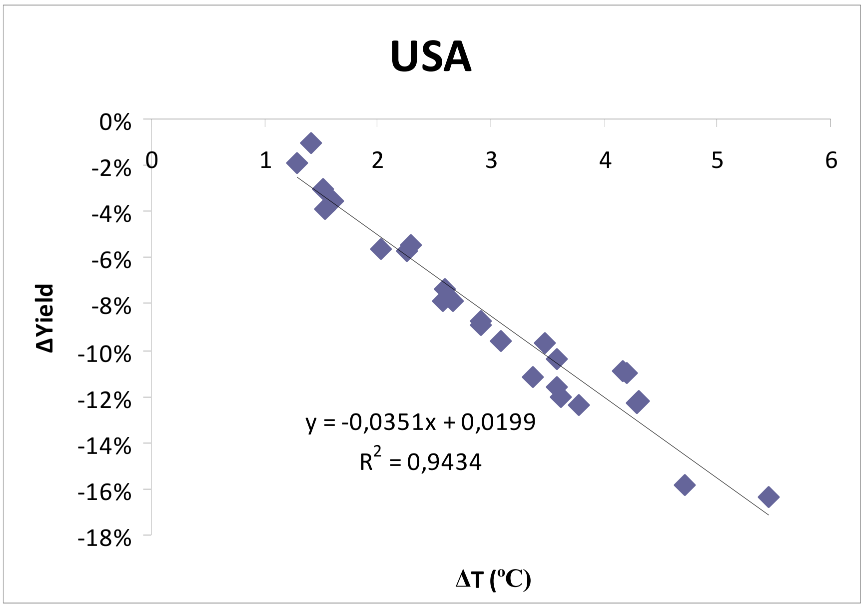
Many researchers are interested in the reduced-form function linking climate variables with climate impacts. In the review of Hitz and Smith (2004) they concluded that the agriculture damage function is parabolic, with growing damages as temperature increases up to a threshold, after which damages fall and even become net benefits.

Simplified integrated assessment models (e.g. the DICE model of Nordhaus, 1994) use the so-called damage function linking temperature change with GDP change. The empirical evidence used in this article allows exploring the shape of that damage function.

Figure 2 presents the relationship between yield changes and temperature change in USA. There appears to be a negative correlation between both variables. Source: authors' own calculations

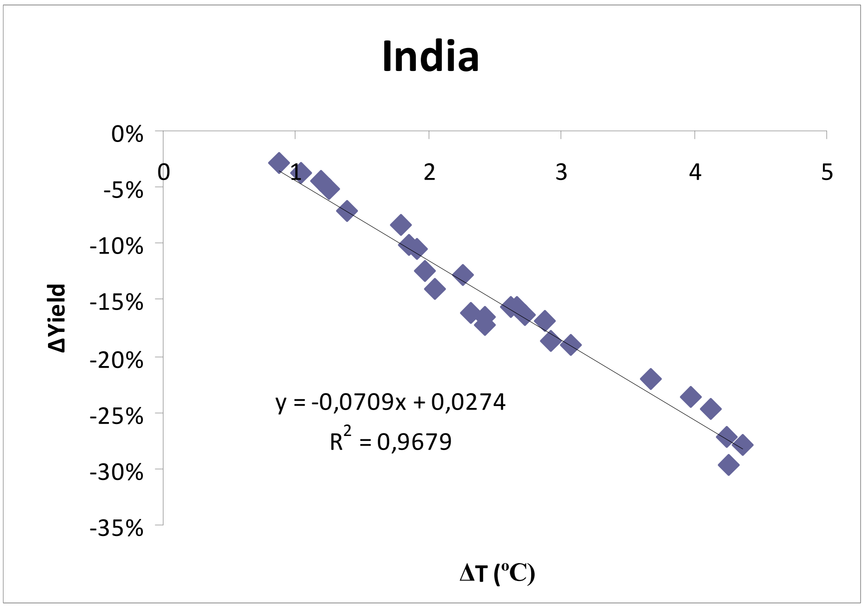
Figure 3 represents the case of India, where the sensitivity of yield changes to temperature change is much higher, approximately twice that of the USA. For the regions for which yield changes are positive, one would expect a positive correlation. That is the case for instance of China (Figure 4).

Figure 2. Agriculture yield changes and temperature changes for the A1B and E1 scenarios in USA



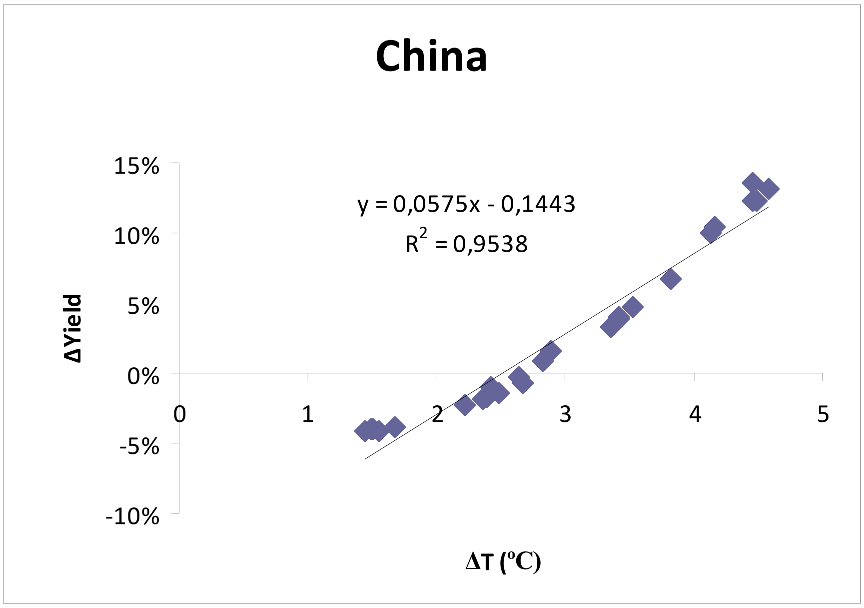
Source: authors' own calculations

Figure 3. Agriculture yield changes and temperature changes for the A1B and E1 scenarios in India



Source: authors' own calculations

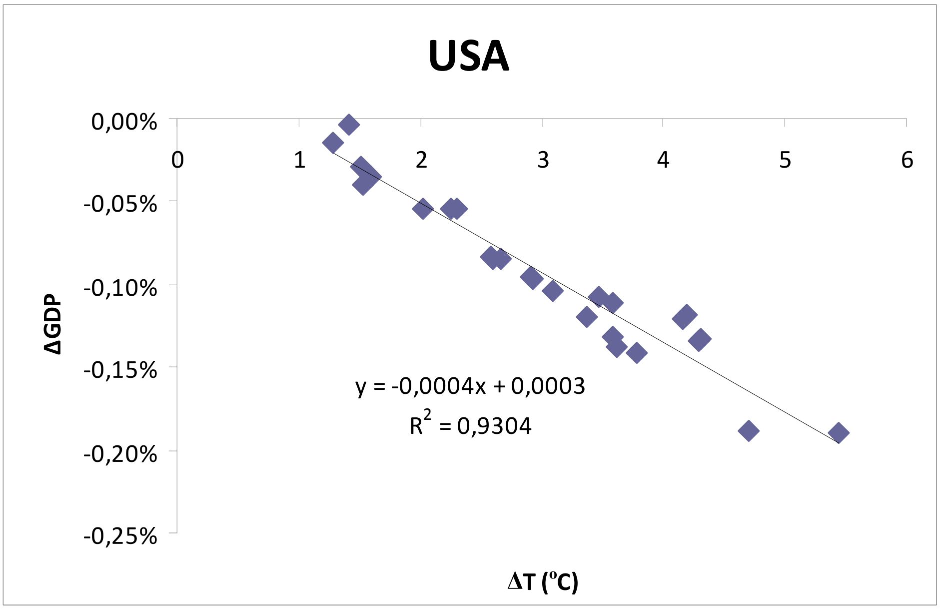
Figure 4. Agriculture yield changes and temperature changes for the A1B and E1 scenarios in China



Source: authors' own calculations

The next step is to relate directly the GDP change against the temperature change. Figure 5represents such first attempt for USA: temperature change in USA (the difference between the average of the 2071-2100 period and the average of the 1961-1990 period) vis-à-vis the GDP change. The figure suggests that there is a positive correlation between temperature change and GDP loss.

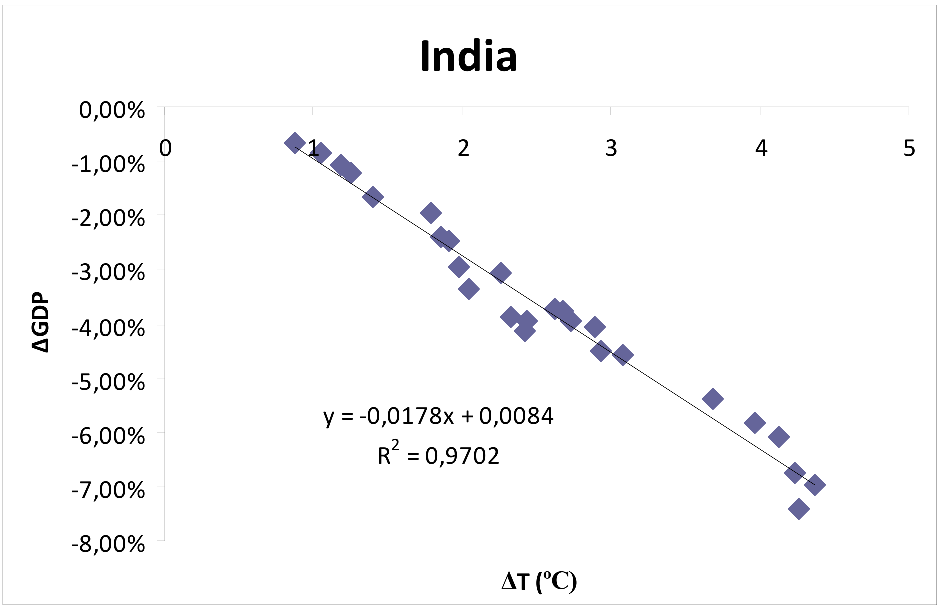
Figure 5. Agriculture damage function for USA



Source: authors' own calculations

For the case of India (Figure 6), due to the noted high share of agriculture in GDP, the elasticity of GDP change to temperature change is approximately four times larger than the USA value. Further econometric work is required to fully analyse those correlations, including also precipitation and CO2 and explanatory variables.

Figure 6. Agriculture damage function for India



Source: authors' own calculations

5 Conclusions

We have integrated agriculture yield changes estimates from a set of 27 climate runs into an economic general equilibrium model. A comparative static framework has been used to estimate the damages if the climate of the 2080s would occur today.

We conclude that the global welfare loss induced by the high emission scenarios (leading to approximately a 4°C global temperature increase) would mean approximately a $200 bn global loss, which would be reduced by half under a 2°C scenario. Regionally, the net welfare damages are directly proportional to the yield change. Regions experiencing positive yield change are able to increase agricultural production and exports, resulting in improved welfare. In China, high positive yield changes improve the competitiveness of the whole economy. Other regions such as Canada and Australia & New Zealand experience welfare improvements as their share in global agricultural exports increases significantly. On the other hand, welfare is reduced in regions suffering yield losses. This is felt most sharply in India where crop production is an important share of GDP and yield losses are most severe. In some scenarios, net export regions such as Brazil and Rest of the World also experience welfare losses as yield losses worsen their competitive position.

Furthermore, this article suggests an approach for estimating agriculture damage functions, which potentially can be fed into integrated assessment models of climate change, such as Nordhaus' DICE model. The approach has the following key features. Firstly, it is based on a set of high-resolution climate data. Secondly, a bottom-up biophysical model is run to estimate the physical impacts. Finally, the physical impacts are integrated into a CGE model. The first and third characteristics reinforce the spatial consistency of the analysis, improving the credibility of the damage functions.

As further work the authors are planning to explore an alternative specification of the agriculture productivity change, modifying directly land productivity. Adaptation will be also considered in the analysis, with a particular emphasis on their costs to the agriculture sector. The richness of climate runs would also allow making a stochastic analysis of the impacts of climate change on the world economy, accounting for other sources of uncertainty as well. Expanding the sectoral and regional disaggregation of the model would improve the richness of the analysis. Finally, a panel data econometric analysis of the agriculture damage functions could provide a new set of regional agriculture damage functions, which would have the novelty of being derived from the same coherent global framework.

Acknowledgements

Authors acknowledge the financial contribution from the FP7 ClimateCost research project. The ENSEMBLES climate data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged. We thank the Max-Planck Institute for Meteorology, the Danish Meteorological Institute and the

Centre National de Recherches Météorologiques for making their simulation data available for the project.

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Annex 1

Table 1. Climate centres, models, scenarios and file names of the climate runs

Centre	Model	Emissions scenario	Files	Number of runs	Runs code
BCCR	BCM2.0	A1B	BCM2	1	A1B_1
CNRM	CM3	A1B	CNCM3	1	A1B_2
FUB	EGMAM2006	A1B	EGMAM	3	A1B_4 to A1B_6
INGV	SXG2005	A1B	INGVSX	1	A1B_8
IPSL	CM4_v1	A1B	IPCM4	1	A1B_9
MPI	ECHAM5	A1B	MPEH5	3	A1B_10 to A1B_12
DMI	ECHAM5	A1B	DMIEH5	1	A1B_3
UKMO	HadGEM1	A1B	HADGEM	1	A1B_7
UKMO	HadGEM2	E1	HADGEM	1	E1_7
CNRM	CM3.3	E1	CNCM33	1	E1_1
FUB	EGMAM2006	E1	EGMAM2	2	E1_4 to E1_5
INGV	C-ESM2007	E1	INGVCE	1	E1_8
IPSL	CM4_v2	E1	IPCM4v2	3	E1_9 to E1_11
MPI	ECHAM5.4	E1	MPEH5C	3	E1_12 to E1_14
DMI	CM3.3	E1	DMICM3	2	E1_2 to E1_3
UKMO	HadCM3C	E1	HADCM3C	1	E1_6

Source: ClimateCost project, ENSEMBLES project (Christensen et al. 2011)