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CLIMATE CHANGE FEEDBACK ON ECONOMIC GROWTH: EXPLORATIONS WITH A DYNAMIC GEM

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SUMMARY Human-generated greenhouse gases depend on the level of economic activity. Therefore, most climate change studies are based on models and scenarios of economic growth. Economic growth itself, however, is likely to be affected by climate change impacts. These impacts affect the economy in multiple and complex ways: changes in productivity, resource endowments, production and consumption patterns. We use a new dynamic, multi-regional Computable General Equilibrium (CGE) model of the world economy to answer the following questions: Will climate change impacts significantly affect growth and wealth distribution in the world? Should forecasts of human induced greenhouse gases emissions be revised, once climate change impacts are taken into account? We found that, even though economic growth and emission paths do not change significantly at the global level, relevant differences exist at the regional and sectoral level. In particular, developing countries appear to suffer the most from climate change impacts.

Keywords: Computable General Equilibrium Models, Climate Change, Economic Growth

JEL: C68, E27, O12, Q54, Q56

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1. Introduction

Climate change is affected by the concentration of greenhouse gases (GHG) in the atmosphere, which depends on human and natural emissions. In particular, the anthropogenic contribution to this phenomenon is widely recognized as the main driver of climate change (IPCC, 2007).

Very little is known, however, about the reverse causation, by which climate change would affect economic growth, both quantitatively and qualitatively. Understanding how climate change will influence the global economy is obviously very important. This allows assessing the intrinsic auto-adjustment system capability, identifying income and wealth distribution effects and verifying the robustness of socio-economic scenarios.

Unfortunately, the issue is very complex, because there are many diverse economic impacts of climate change, operating at various levels. Some previous studies (Berritella *et al*., 2006; Bosello *et al*., 2006; Bosello *et al*., 2007; Bosello and Zhang, 2006) have used CGE models to assess sectoral impacts, using a comparative static approach. This paper builds upon these studies, but innovates by considering many climate change impacts simultaneously and, most importantly, by considering dynamic impacts in a specially designed dynamic CGE model of the world economy (ICES).

Using a dynamic model allows us to investigate the increasing influence of climate change on the global economic growth. This influence is twofold: on one hand, the magnitude of physical and economic impacts will rise over time and, on the other hand, endogenous growth dynamics is affected by changes in income levels, savings, actual and expected returns on capital.

We typically find that climate change is associated with significant distributional effects, for a number of reasons. First, not all impacts of climate change are negative. For example, milder climate attracts tourists in some regions, reduced need for warming in winter times saves energy, incidence of cold-related diseases is diminished, etc. Second, changes in relative competitiveness and terms of trade may allow some regions and industries to benefit, even from a globally negative shock. Third, higher (relative) returns on capital, possibly due to changes in demand structure and resource endowments, could foster investments and growth. All these effects can hardly be captured by a stylized macroeconomic model, and require instead a disaggregated model with explicit representation of trade links between industries and regions.

Our work complements a recent paper by Dell *et al*. (2008), who use annual variation in temperature and precipitation over the past 50 years to examine the impact of climatic changes on economic activity throughout the world. Their main finding is that higher temperatures substantially reduce economic growth in poor countries but have little effect in rich countries. This result is obtained by estimating coefficients of an aggregate econometric model, in which growth and level effects of climate change on GDP are separately considered. The drawback of this approach is that the various causal mechanisms which could lead to the aggregate result are not identified, whereas the model used in this paper allow to analyze different impacts and effects. Furthermore, it allow explaining why different climatic conditions may affect investments and growth, through induced changes in the capital rate of return.

The paper is organised as follows. Section 2 presents the ICES model structure and explains how a baseline scenario is built. Climate change impacts are analysed in Section 3. Section 4 illustrates the simulation results, assessing how climate change impacts will affect regional economic growth in the world. The last section draws some conclusions.

Sectors		
Food Industries	***Heavy Industries***	***Light Industries***
Rice Wheat Other Cereal Crops Vegetable Fruits Animals Fishing	Coal Oil Gas Oil Products Electricity Energy Intensive industries	Water Other industries Market Services Non-Market Services Forestry

Regions	
Code	***Description***
USA	United States
EU	European Union - 15
EEFSU	Eastern Europe and Former Soviet Union
JPN	Japan
RoA1	Other Annex 1 countries
EEx	Net Energy Exporters
CHIND	China & India
RoW	Rest of the World

Table 1: Model sectoral and regional disaggregation

2. The ICES Model

ICES (Inter-temporal Computable Equilibrium System) is a dynamic, multi-regional CGE model of the world economy, derived from a static CGE model named GTAP-EF (Roson, 2003; Bigano et al., 2006).[1] The latter is a modified version of the GTAP-E model (Burniaux and Troung, 2002), which in turn is an extension of the basic GTAP model (Hertel, 1997).

ICES is a recursive model, generating a sequence of static equilibria under myopic expectations, linked by capital and international debt accumulation. Although its regional and industrial disaggregation may vary, the results presented here refer to 8 macro-regions and 17 industries, listed in Table 1.

Growth is driven by changes in primary resources (capital, labour, land and natural resources),

from 2001 (calibration year of GTAP 6 database)[2] onward. Dynamics is endogenous for capital and exogenous for others primary factors.

Population forecasts are taken from the World Bank,[3] while labour stocks are changed year by year, according to the International Labour Organization (ILO) annual growth rates estimates[4]. Estimates of labour productivity (by region and industry) are obtained from the G-Cubed model (McKibbin and Wilcoxen, 1998). Land productivity is estimated from the IMAGE model (IMAGE, 2001).

Since natural resources are treated in GTAP in a rather peculiar way (Hertel and Tsigas, 2006), these factor stocks are endogenously estimated in the ICES model, by fixing their prices during the baseline calibration stage, while for further simulations those estimated stocks become an exogenous input in the model. For fossil fuels (oil, coal and gas), we use EIA forecasts (EIA, 2007), whereas for other industries (forestry, fishing) its resource price is changed in line with the GDP deflator.

Regional investments and capital stocks are determined as follows. Savings are a constant fraction of regional income.[5] All savings are pooled by a virtual world bank, and allocated to regional investments, on the basis of the following relationship:

$$\frac{I_r}{Y_r} = \phi_r \exp[\rho_r (r_r - r_w)] \qquad (1)$$

where: I_r is regional annual investment, Y_r is regional income, r_i is regional and world returns on capital, ϕ_r, ρ_r are given parameters.

The rationale of (1), which has been adopted from the ABARE GTEM model (Pant, 2002), is that whenever returns on capital (that is, the price of capital services) do not differ from those in the

[1] Detailed information on the model can be found at the ICES web site: http://www.feem-web.it/ices.
[2] Dimaranan (2006).
[3] Available at http://devdata.worldbank.org/hnpstats/. Population does not directly affect labour supply, but affects household consumption, which depends on per capita income.
[4] Available at http://laborsta.ilo.org/. The annual percentage growth rate in the period 2001-2020 has been applied to the longer period 2001-2050.
[5] Therefore, the upper level of the utility function for the representative consumer is Cobb-Douglas. Intertemporal utility maximization is implicit.

rest of the world, investments are proportional to regional income, like savings are. In this case, current returns are considered as proxies of future returns. If returns are higher (lower) than the world average, then investments are higher (lower) too.

Investments affect the evolution of capital stock, on the basis of a standard relationship with constant depreciation over time:

$$K_r^{t+1} = I_r^t + (1-\delta) \cdot K_r^t \qquad (2)$$

Equation (1) does not ensure the equalization of regional investments and savings, and any region can be creditor or debtor vis-à-vis the rest of the world. Because of accounting identities, any excess of savings over investments always equals the regional trade balance (*TB*), so there is a dynamics of the debt stock, similar to (2), but without depreciation:

$$D_r^{t+1} = TB_r^t + D_r^t \qquad (3)$$

Foreign debt is initially zero for all regions, then it evolves according to (3). Foreign debt service is paid in every period on the basis of the world interest rate r_w .[6]

Consider now how an external shock, like those associated with climate change impacts, affects economic growth through capital and debt accumulation.

If the shock is a negative one, a decrease in regional GDP proportionally lowers both savings and investments. Any difference between these two variables, which amounts to a change in foreign debt stock and trade balance, must then be associated with changing relative returns on capital, according to (1). Most (but not all) negative effects of climate change (losses of capital, land, natural resources, or lower labour productivity) imply an higher relative scarcity of capital, thereby increasing returns. In this case, the shock is partially absorbed by running a foreign debt, which must eventually be repaid.

If the negative shock would last one or few periods, this mechanism amounts to spreading the negative shock over a longer interval, allowing a smoother adjustment in the regional economy. Since the shocks we apply in the model rise in magnitude over time, if an economy starts attracting foreign investments, it will continue to do so over all the subsequent years, and vice versa. Therefore, the capital accumulation process tends to make this economy growing at higher rates, in comparison with the baseline, in which climate change impacts are absent. A comparison of growth paths for this economy, with and without climate change, would then highlight (non-linearly) divergent paths.

This dynamic effect overlaps with the direct impacts of climate change. The direct impacts would make each regional economy growing faster or lower. If direct and indirect effects work to the same direction, macroeconomic variables (like GDP) will progressively diverge (positively or negatively). On the other hand, if the two effects are opposite, the direct effect would prevail at first, then the capital accumulation

[6] This is set in the model by equating global savings and investments.

will eventually drive the economic growth, possibly inverting the sign of the total effects.

Dell *et al*. (2008) find evidence that changes in temperature have a long lasting impact on economic growth, particularly for poor countries, but do not provide a convincing explanation for this effect.[7] In the ICES model, instead, we are able to analyze how the various climate change impacts may affect the capital rate of return, thereby influencing the allocation of international investments.

3. Modelling Climate Change Impacts

Earlier studies (Berritella *et al*., 2006; Bosello *et al*., 2006; Bosello *et al*., 2007; Bosello and Zhang, 2006) have used CGE models to assess the economic implications of climate change impacts. Simulations are performed by identifying the relevant economic variables, and imposing changes in some model parameters, like:

- *Variations in endowments of primary resources*. For example, effects of sea level rise can be simulated by reducing stocks of land and capital (infrastructure).
- *Variations in productivity*. Effects of climate change on human health can be simulated through changes in labour productivity. Effects on agriculture can be simulated through changes in crop productivity.
- *Variation in the structure of demand*. Although demand is typically endogenous in a general equilibrium model, shifting factors can capture changes in demand not induced by variations in income or prices. In this way, it is possible to simulate: changing energy demand for heating and cooling, changing expenditure on medical services, changing demand for services generated by tourists, etc.

Comparative static CGE models can usefully highlight the structural adjustments triggered by climate change impacts, by comparing a baseline equilibrium, at some reference year, with a counterfactual one, obtained by shocking a set of parameters. In a dynamic model like ICES, parameters are varied in a similar way, but in each period of the sequence of temporary equilibria.

We run the model at yearly time steps, from 2002 to 2050. In each period, the model solves for a general equilibrium state, in which capital and debt stocks are "inherited" from the previous period, and exogenous dynamics is introduced through changes in primary resources and population. Then, impacts are simulated by "spreading" the climate change effects over the whole interval 2002-2050. For example, changes in crop productivity are related to changes in temperature and precipitation. As temperature progressively rise over time, wider variations are imposed to the model productivity parameters.

[7] They found some evidence of temperature impacts on political instability, suggesting that this could be one possible explanation for falling investments in a region. Our model cannot capture political economy aspects, but provides an alternative explanation, in terms of rates of returns.

In this way, the model generate two sets of results: a baseline growth path for the world economy, in which climate change impacts are ignored, and a counterfactual scenario, in which climate change impacts are simulated. The latter scenario differs from the basic one, not only because of the climate shocks, but also because exogenous and endogenous dynamics interact, and climate change ultimately affect capital and foreign debt accumulation.

All shocks have been computed by considering an increase in global average temperature of 1.5º C for 2050, with respect to 1980-1999, which is in line with IPCC estimates (Table 2).

Table 2 – Projected global mean warming (℃) wrt 19 80-1999

IPCC scenarios	***2011-2030***	***2046-2065***	***2080-2099***
A1B	0.69	1.75	2.65
A2	0.64	1.65	3.13
B1	0.66	1.29	1.79

Source: IPCC (2007)

We consider here five climate change impacts, related to: agriculture, energy demand, human health, tourism and sea level rise. In all cases, we adapt for the dynamic model some input data previously used in static CGE models.

Agricultural impact estimates are based on Tol (2002a, 2002b), who extrapolated changes in specific yields for some scenarios of climate change and temperature increase. This impact has been modelled in ICES through exogenous changes in the productivity of land, devoted to different crops.

To evaluate how energy demand reacts to changing temperatures, we use demand elasticities from De Cian *et al.* (2007). This study investigates the effect of climate change on households' demand for different energy commodities. The effects of variations in residential energy demand are reflected through exogenous shifts in the households' demand.

Two impacts related to human health are considered: variation in working hours, reflecting changes in mortality and morbidity modelled through productivity changes, and variation in the expenditure for health care services, undertaken by public administrations and private households (Bosello *et al.,* 2006). Health impacts related to six classes of climate related diseases (malaria, dengue, schistosomiasis, diarrhoea, cardiovascular and respiratory) are included in the model, through labour productivity variations and shifts in the demand for public and private health services.

Coastal land loss due to sea level rise (SLR) was estimated by elaborating results from the Global Vulnerability

Assessment (Hoozemans *et al.*, 1993), integrated with data from Bijlsma *et al.* (1996), Nicholls and Leatherman (1995), Nicholls *et al.* (1995) and Beniston *et al.* (1998). The methodology and some results are illustrated in Bosello *et al.* (2006). The inclusion of SLR in ICES is simulated by exogenously reducing the amount of the primary factor "land" in all regions.

Finally, climate change impacts on tourism are obtained from the Hamburg Tourism Model (HTM) (Bigano *et al.*, 2005), which is an econometric model, estimating tourism flows on the basis of average temperature, coastal length, population, prices and income. Changes in tourism flows are accommodated in the CGE model in two ways. First, as in the case of energy and health impacts, a shifting factor induces exogenous variations in the households' demand for domestic market services, at constant prices and income. The exogenous change amounts to the estimated variation in expenditure by tourists. Secondly, national incomes are adjusted, to account for the purchasing power of foreign tourists.

Table 3 summarizes the exogenous shocks introduced in the model to simulate the climate change impacts.

Net Energy Exporters (EEx) and the Rest of the World (RoW) are negatively affected by a reduction of labour productivity and an increase in medical expenditure, while other regions appear to benefit from climate change impacts related to human health (see also Bosello et al., 2008, for further discussion). For agriculture, except the case of wheat in the Rest of Annex 1 countries (RoA1), land productivity is reduced by climate change. EEx and RoW experience the strongest reduction in tourism demand, since countries in these regions will have quite hot climates. Tourists would then prefer milder locations, like Japan.

Table 3 – 2001-2050 % parameters' variation in the climate change scenario

Sectors		
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Estimates for residential energy demand show a general reduction in natural gas and oil demand (for heating), while impacts on electricity demand are not very relevant, except for EEx and China and India (CHIND), where a substantial increase is estimated (for cooling). In the case of sea level rise, all regions suffer some land losses, although the share of lost land is relatively small.

4. Simulation Results

We present here the simulation results, by focusing on the differences between the baseline and the climate change impact scenarios. Our aim is twofold: assessing the economic consequences of climate change on growth and income distribution in the world, and verifying whether considering the climate change feedback on economic scenarios brings about significant variations in estimates of emissions of greenhouse gases.

Let us first consider each of the five impacts separately, by looking at the differences generated between the two scenarios in the regional GDP. Figure 1 presents differences in GDP in the period 2002-2050, due to the effects of climate change on agriculture, obtained by simulating a progressive change in land productivity.

The general reduction in land productivity hits more severely some agriculture-based and relatively poorer economies, while developed regions get some benefits, primarily because of positive changes in the terms of trade.

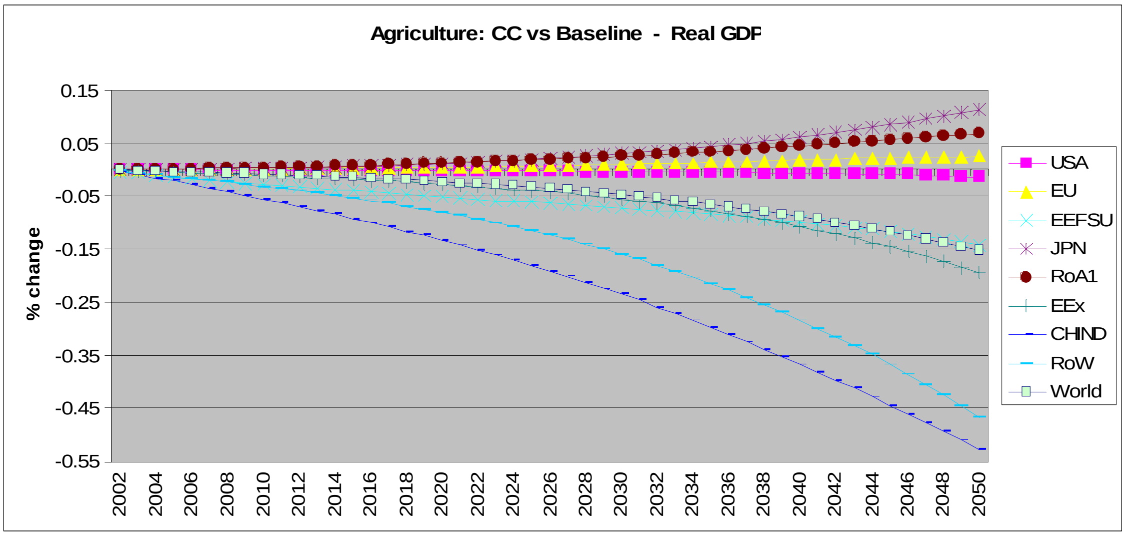

Figure 1 – Agriculture impacts – Differences in regional GDP

Figure 2 shows a similar picture, referred to climate change impacts on energy demand.

Here we have a more differentiated picture: some regions lose, some other gains, whereas the world average is about the same. This should be expected, because of the nature of the shock, which modifies the structure of demand without affecting the endowments of primary resources.

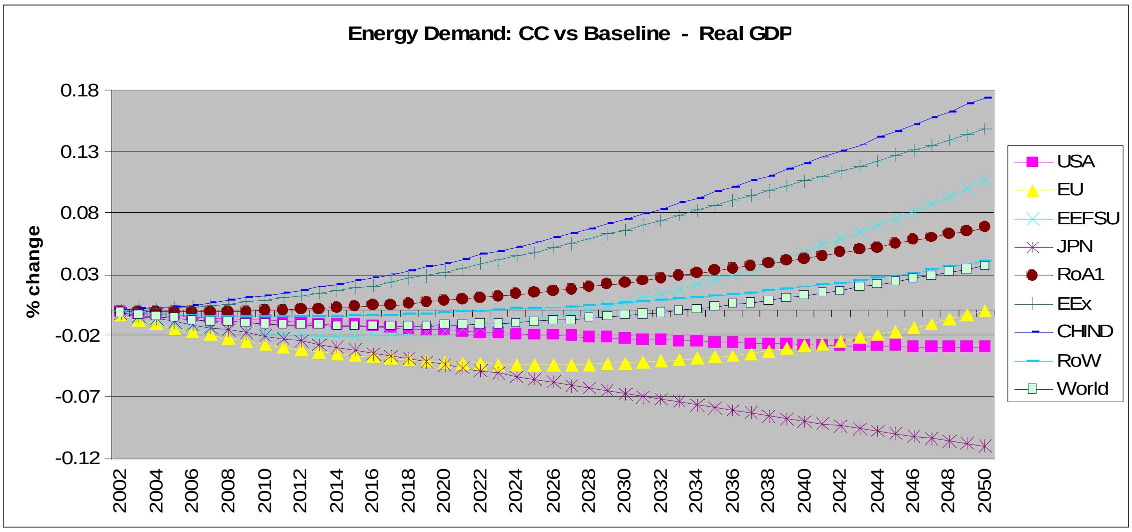

Figure 2 – Energy demand impacts – Differences in regional GDP

To better understand the results of the energy demand shock, it is necessary to take into account the role of the terms of trade. Consider, for example, the case of Energy Exporting Countries (EEx). This region suffers from an adverse shock in the terms of trade. This means that more exports are needed to pay for imports: real GDP increases, but nominal GDP (and welfare) decrease.

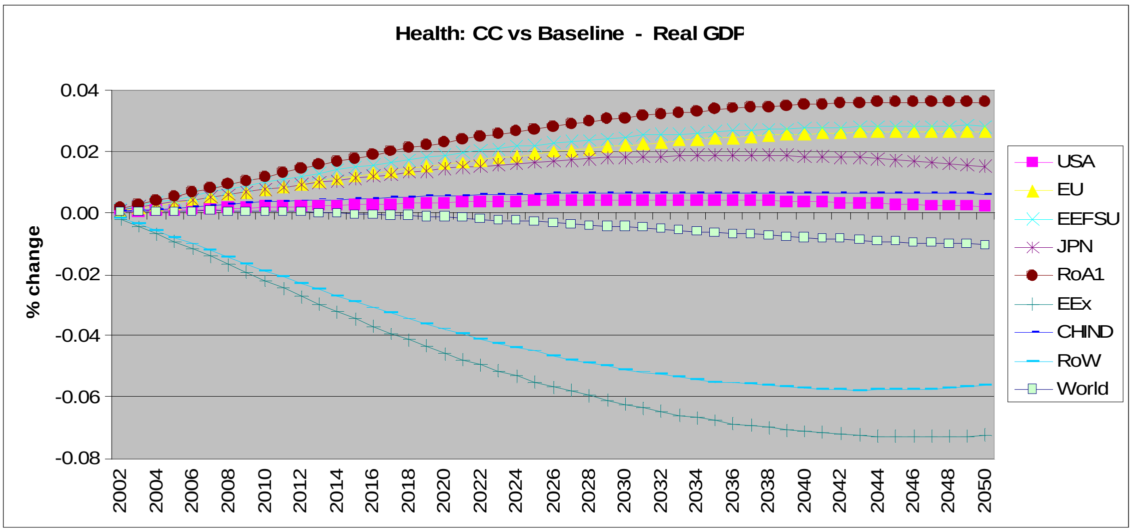

Figure 3 – Human health impacts – Differences in regional GDP

Figure 3 illustrates the dynamic effect of climate change impacts on labour productivity and health services expenditure. Two regions, which are the poorest in the world, experience losses, whereas the remaining regions get small benefits. The magnitude of the GDP variations is small, but we are considering here only monetary costs/gains of health impacts, disregarding the possible existence of catastrophic events.

Notice the shape of the curves. This suggests that direct impacts of climate change and the indirect impacts of capital accumulation are opposite.

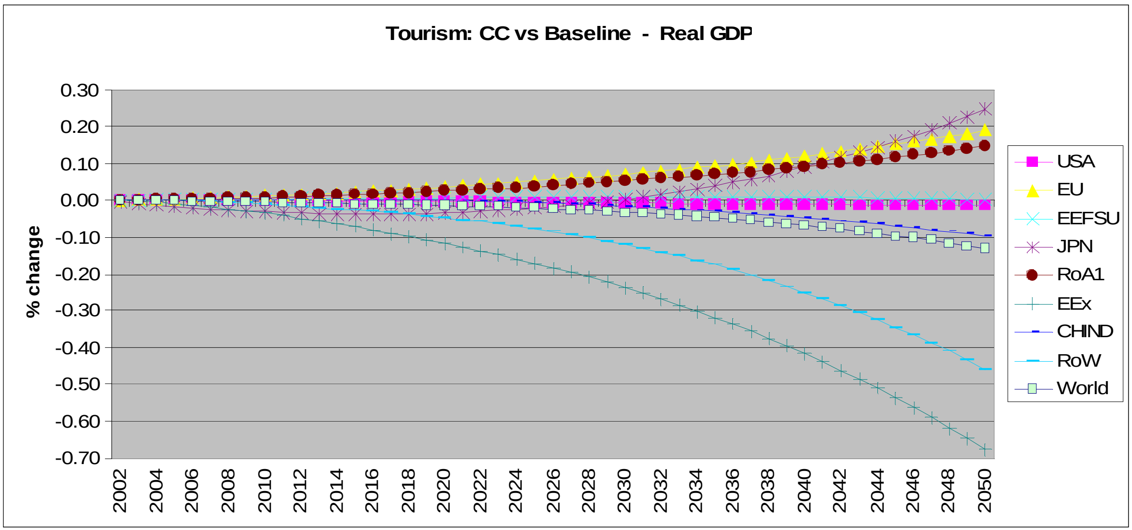

Figure 4 – Tourism impacts – Differences in regional GDP

Figure 4 illustrates tourism impacts. Although the shape of the curves is different from the one in Figure 3, the regional distribution of gains and losses is quite similar. This suggests that most factors making a region unhealthy also make the same region less attractive as a tourist destination. However, the absolute value of impacts on GDP is much larger here, particularly in poor regions, where tourism is a sizeable industry.

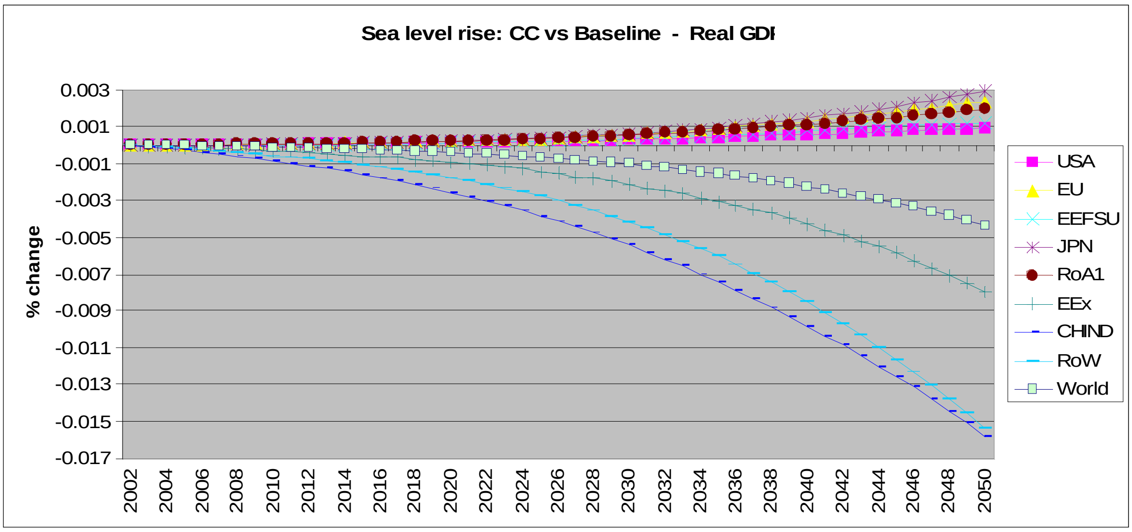

Figure 5 – Sea level rise impacts – Differences in regional GDP

Figure 5 shows the impact of sea level rise, generating losses of agricultural land, in the absence of any protective investment.

Variations are quite limited, as land losses are quite small in the aggregate. Again, poorer regions are the ones which experience the most significant reductions in GDP.

Figure 6 presents percentage variations in GDP generated by the joint action of all the impacts together. Notice that the total effect is not just the sum of all individual effects, as the various impacts interact and affect the endogenous growth mechanism.

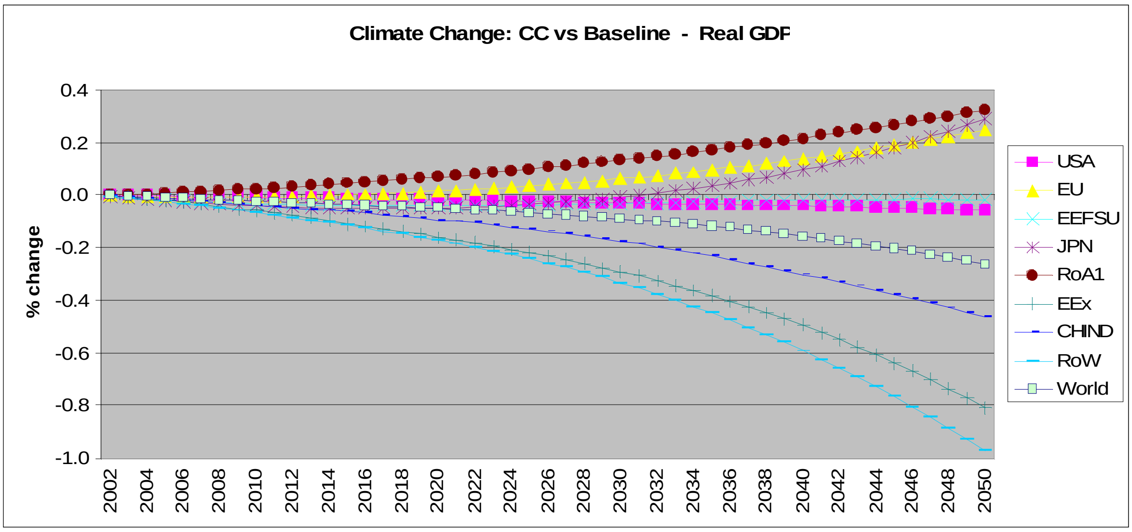

Figure 6 – Joint impacts – Differences in regional GDP

We can see that the overall impact is fairly large, and the distributional consequences are significant, making the poorest countries worse off. In other words, climate change works against equity and income convergence in the world.

The next two figures show the industrial effects. Figure 7 presents the percentage deviations in the physical output of the various industries, whereas Figure 8 presents the corresponding variations in prices.

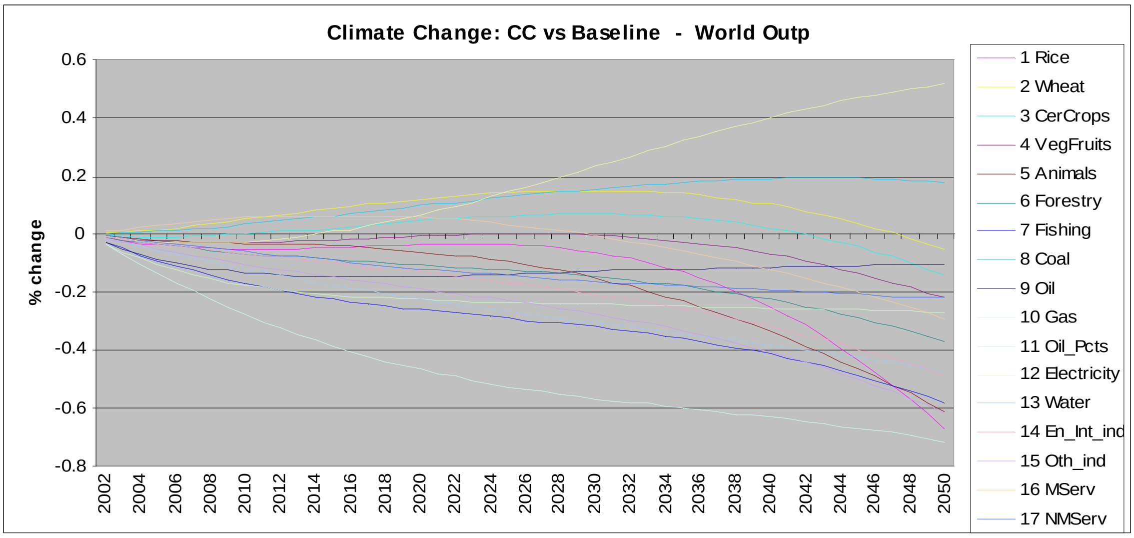

Figure 7 – Differences in industrial output

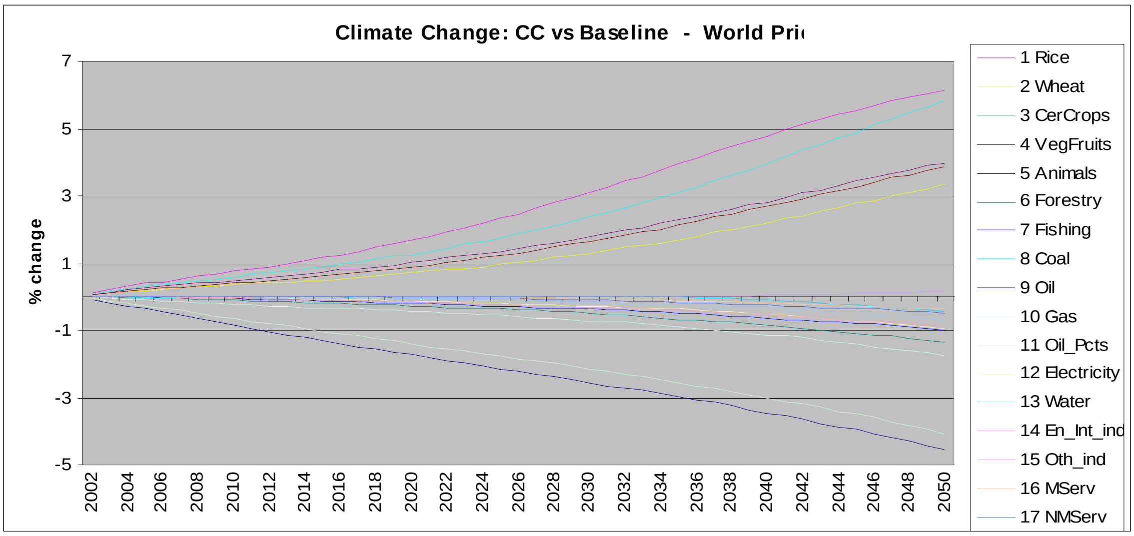

Figure 8 – Differences in industrial prices

In quantity terms, Electricity is the largest growing industry (relative to the baseline), whereas wheat production first increases, then declines. Significant reductions are observed in the Fishing, Gas, Rice and Other Industries. Prices increases in most agricultural industries, particularly in Rice and Cereals, whereas prices are lower in the energy sector, most notably for Oil, Oil Products and Gas.

An interesting question is whether emissions of greenhouse gases are affected by the changing growth of the world economy. ICES produces estimates of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Figure 9 illustrate the percentage changes for these three GHGs between the two scenarios.

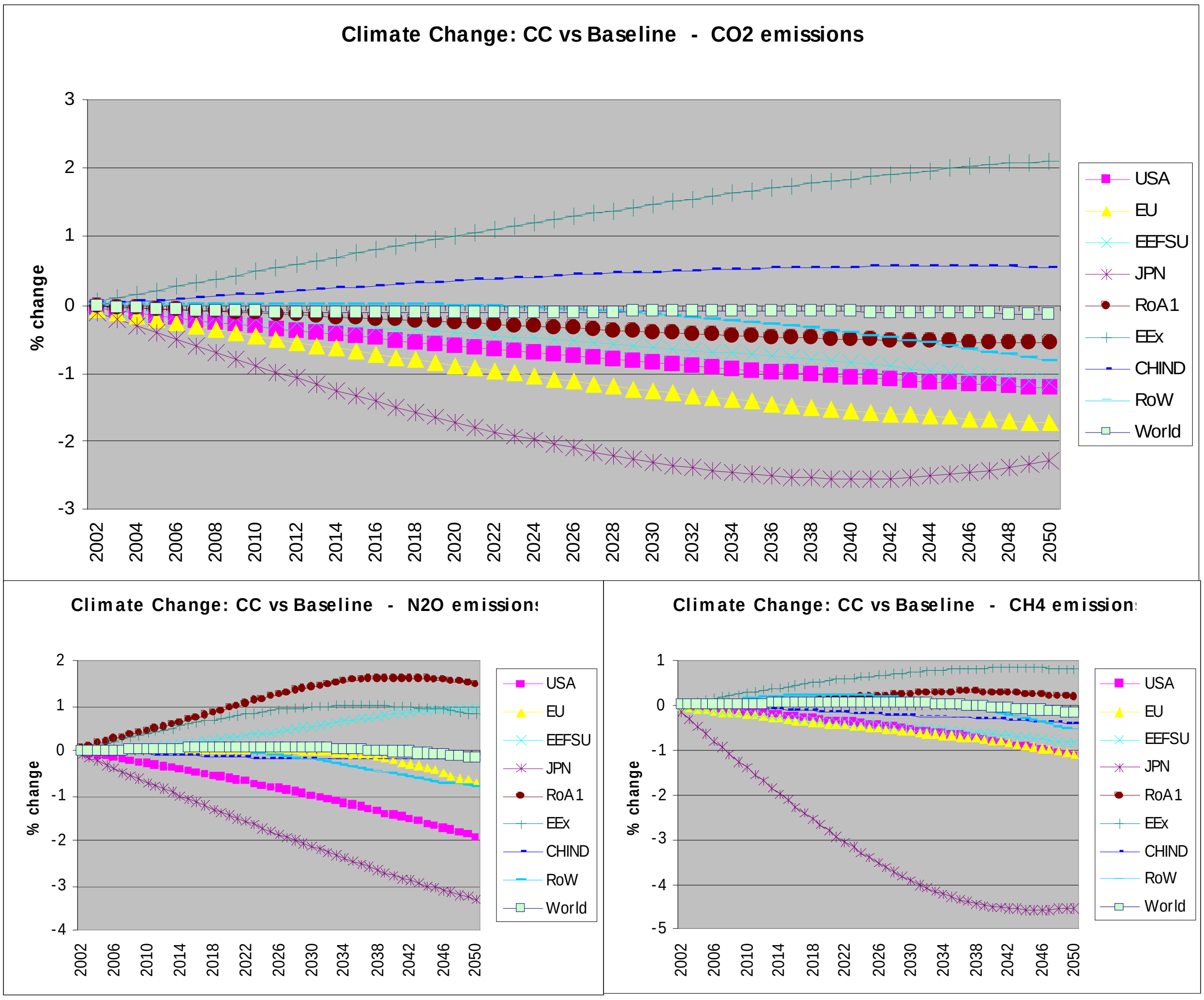

Figure 9 – Differences in CO_2, N_2O and CH_4 emissions

Although emissions increase in some countries and decrease in some other countries, there are quite small global variations, and this is good news for climatologists, who adopt fixed socio-economic scenarios for their analyses. They would not need to revise their assumptions about anthropogenic emissions.

More precisely, considering the different size and baseline volume of emissions, total emissions of greenhouse gases turn out to be slightly smaller, once the climate change feedback on the economy is taken into account.

Table 4 provides a summary of all impacts on regional GDP, analysed separately and jointly. The aggregate effect of climate change is negative, but some regions are expected to gain.

Carbon dioxide emissions increase in developing regions, despite reductions in the GDP. The opposite occurs for developed countries, where a higher GDP is associated with a reduction in carbon emissions.

Some of them, notably Japan and European Union, experience negative impacts at first, which are turned to positive by the end of the period.

Table 4 - Summary of Impacts on Regional Real GDP

Effect	RoA1	JPN	EU	EEFSU	USA	CHIND	EEx	RoW	World
Agriculture	+	+	+	-	-	-	-	-	-
Energy Demand	+	-	-	+ (*)	-	+	+	+ (*)	+ (*)
Health Care	+	+	+	+	+	+	-	-	-
Tourism Flows	+	+ (*)	+	+	-	-	-	-	-
Sea Level Rise	+	+	+	+	+	-	-	-	-
Joint impact	+	+ (*)	+ (*)	-	-	-	-	-	-

(*) negative at the beginning of the period   [grey] *Significant positive impact*   [red] *Significant negative impact*

5. Conclusions

Climate change affects the world economy in many different ways. Using a dynamic general equilibrium model, we have been able to analyze the second-order, system-wide effects of climate change impacts and their consequences on growth. This is an important innovation, because previous studies have ignored the potentially important interaction between exogenous shocks on the economic system, due to climate change, and endogenous capital and foreign debt accumulation processes.

We found that macroeconomic effects are sizeable but, most importantly, that there are significant distributional effects at the regional and industrial level. In particular, we found that climate change works against equity and income convergence in the world. This result is perfectly consistent with Dell *et al*. (2008), using a completely different methodology. In this paper, however, we have been able to identify a number of potential causal mechanisms.

The interaction between endogenous and exogenous dynamics generates non-linear deviations of growth paths from the baseline. Also, endogenous dynamics may amplify exogenous shocks, or counteracts them, possibly reversing the sign of the effects (e.g., on regional GDP) on the long run.

On the other hand, global emissions of greenhouse gases are only a little diminished when the climate change feedback is considered. Therefore, constancy of human-generated emissions appears to be a reasonable approximation for most physical climate models, since climate change is a global externality and only global GHG emissions and concentrations matter when predicting future climate.

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