MODELLING THE ECONOMIC IMPACT OF CLIMATE CHANGE

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1. Introduction

Evaluating the economic consequences of the climate change, as well as assessing the environmental economic policies associated with it, requires a good understanding of both natural and socio-economic processes. Specific models, named Integrated Assessment Models, are used to this purpose. The idea behind the IAM models is relatively straightforward (in theory): climatologic sub-models get information about human-induced greenhouse gas emissions from economic sub-models, simulating levels of economic activity, whereas information about climate and temperature changes are used as an input in the determination of economic scenarios.

As a matter of fact, the economic side of currently available IAM models suffer from two main drawbacks. First, the description of the world economic structure is often too simplistic: limited number of industries (sometimes only one good, available for both consumption and investment), poor or absent description of international trade and capital flows (Manne et al. (1995), Nordhaus and Yang (1996)). Second, the multi-dimensional nature of the impact of the climate change on the economic systems is disregarded. This is usually accommodated by specific ad-hoc relationships, making a certain fraction of potential income "melting away" as temperature increases. Not surprisingly, key parameters for these equations are often estimated in rather mysterious ways.

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On the other hand, conventional CGE models have been extensively used for the assessment of environmental economic policies. Typical simulation experiments in this field are: introduction of carbon or green taxes, tax swaps, domestic and international emissions trading systems, etc. Whereas the use of CGE models provides a more accurate, realistic and consistent picture of the economic systems, their range of applicability is limited by two elements. First, most CGE analyses are conducted within a short-medium term horizon, whereas the climate change is a long-term phenomenon. Second, the environmental dimension is not really present in the models, as it is often a matter of interpretation. For example, if carbon emissions are associated with energy consumption, carbon taxes are equivalent to some type of energy consumption taxes. In addition, computation of welfare measures, like the equivalent variation, typically disregard changes in the environmental quality.

Very few attempts have been made at using CGE models on a longer time horizon, to evaluate the various economic shocks induced by the climate change[1]. This paper describes the methodology and some early results obtained by the GPCC modelling team of the Fondazione Eni Enrico Mattei, working in collaboration with the Universities of Hamburg and Oldenburg.

Our approach is based on a two-stages procedure. Counterfactual equilibria of the world economy are generated first; by means of a method we named “pseudo-calibration”, which is fully described in the next section. Subsequently, conventional comparative-static analysis is conducted, by simulating a certain number of shocks. “Impact modules”, analysing the implications of climate change in different dimensions (health, land use and fertility, energy demand, and others), are used to estimate variations in parameters for these experiments. The third section of this paper illustrates how these modules and the world CGE model are interfaced, and provides some preliminary simulation results. A concluding section summarizes the main findings, discusses the limitation of our modelling approach and the prospects for future research.

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[1] A few studies considered a limited number of impacts: e.g., Darwin and Tol (2001), Deke et al. (2001).

2. The “pseudo-calibrations”

In the CGE jargon, “calibration” refers to a standard procedure for the estimation of structural parameters of the model, based on available information on prices and quantities, normally obtained from a Social Accounting Matrix (SAM).

The process of collecting and assembling data for a complete SAM requires a considerable amount of time, so that statistical offices normally produce these tables with a time lag of at least five years. However, CGE models need not be entirely based on “old” databases, because more updated statistical information is usually available, although not with the level of disaggregation required for a full-scale model calibration.

Dixon and Rimmer (2002) suggest that, after a standard SAM-based calibration, a CGE model can be used to update the initial data set, by forcing it (trough an appropriate swapping between endogenous and exogenous variables) to reproduce observed values for variables like the main national accounting aggregates, international trade flows, or employment levels.

In the same vein, forecasted values for some key economic variables could be “plugged in”, to identify a hypothetical general equilibrium state at some future time. This equilibrium would then be fully described in terms of a counterfactual SAM, which is an output of the model, combining the forecasts with the structural information obtained from the initial model calibration.

We followed this approach to get baseline SAM matrices, and model calibrations, at some given future years (2010, 2030, 2050). The idea is to project the structure of the world economy in the absence of any major exogenous shock, including changes in the climate.

Since we are working on the medium-long term, we have focused primarily on the supply side sources of growth: changes in the national endowments of labour, capital, land, natural resources, as well as variations in factor-specific and multi-factor productivity.

Most of these variables are “naturally exogenous” in standard CGE models. For example, static CGE models usually take the national labour force as a given, and allocate the labour endogenously among the various industries. In this case, we simply shock the exogenous variable “labour stock”, changing its level from that of the initial calibration year (1997) to some future forecast year (e.g., 2030). Along with changes in other primary resources (and productivity), this shock induces variations in relative prices and a structural adjustment for the entire world economy. The result is a picture of the global economic system at the year of interest.

In other cases, we start from forecasts for variables, which are normally endogenous in the model. For example, suppose that estimates are available for industry-specific employment levels. Before running a simulation, then, one should define these variables as exogenous, by making endogenous an equal number of previously exogenous variables. One possibility, for instance, is to make endogenous the share parameters of labour in the value added composite.

Following this route, other variables for which reliable estimates may exist, in addition to primary resources, could be updated in the model: changes in the structure of final or intermediate demand (technology), propensity to saving relative to national income, level and structure of public expenditure, and so on.

We performed this exercise using a variant of the GTAP model. GTAP (Global Trade Analysis Project) is an extensive database of the world economy, associated with a static CGE model (described in Hertel (1996)). GTAP-E is a variant of this model, developed by Burniaux and Truong (2002), which provides a different treatment of the energy sector[2] and includes carbon emissions in the data. We developed further the GTAP-E model version (GTAP-EX), by augmenting the industrial disaggregation, especially in the agricultural sector.

We obtained estimates of the regional labour and capital stocks by running the G-Cubed model (McKibbin and Wilcoxen (1998)). This is a rather sophisticated dynamic CGE model of the world economy, with a number of notable features, like: rational expectations intertemporal adjustment, international capital flows based on portfolio selection (with non-neutrality of money and home bias in the investments), sticky wages, endogenous economic policies, public debt management. We couple this model with GTAP, rather than using it directly, primarily because the latter turned out to be much

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[2] To model energy substitution, energy factors are taken out of the set of intermediate inputs, and put in an aggregate composite which combines with capital, within the value added nest. Inside the energy aggregate, there is substitution between electric and non-electric factors. Inside the non-electric aggregate, there is substitution between coal and a composite of other inputs.

easier to adapt to our purposes, in terms of disaggregation scale and changes in the model equations.

The G-Cubed model can be used to carry out short-term dynamic policy analysis, or to produce baseline forecasts, as we did here. In this case, the model itself relies on some exogenously given forecasts, most notably about the labour-augmenting productivity. These trends are obtained from a side program, which assumes a progressive convergence of country-specific productivity growth rates to U.S. values.

We got estimates of land endowments and agricultural land productivity from the IMAGE model version 2.2 (IMAGE (2001)). IMAGE is an IAM model, with a particular focus on the land use, reporting information on seven crop yields in 13 world regions, from 1970 to 2100. We ran this model by adopting the most conservative scenario about the climate (IPCC B1), implying minimal temperature changes.

A rather specific methodology was adopted to get estimates for the natural resources stock variables. These are a special type of primary resources, used in a few industries, like forestry and fishing. As explained in Hertel and Tsigas (2002), values for these variables in the original GTAP data set were not obtained from official statistics, but were indirectly estimated, to make the model consistent with some industry supply elasticity values, taken from the literature.

However we discovered, by running the model, that these elasticities cannot be assumed in the long-term. Indeed, by significantly increasing the endowments for all primary resources, except the natural ones, the model simulates huge and unrealistic increases in the relative prices of natural resources stocks, and related industries. For this reason, we preferred to fix exogenously the price of the natural resources, making it variable over time in line with the GDP deflator, while allowing the model to compute endogenously the stock levels.

The results obtained by simultaneously shocking in the model: land, labour, capital and natural resources endowments, as well as land and labour productivity, are summarized in Table I. The model output describes the hypothetical structure of the world economy, which is implied by the selected assumptions of growth in primary factors. Although these results may be of some interest on their own, we would like to stress that all subsequent simulation experiments depend only marginally from them, as the climate change effects will be considered only in terms of deviation from the baseline.

Table I - Baseline: Selected Indicators (2010-2030-2050)

(Percentage variation from 1997 values)

REGIONS	USA	EU	EEFSU	JPN	RoA1	EEx	CHIND	RoW
Popul. (*) 10	11.29	1.11	-2.27	-0.9	10.19	25.54	13.89	24.48
Population 30	22.28	-0.83	-2.81	-5.78	15.33	56.87	26.58	53.6
Population 50	30.4	-3.71	-2.7	-11.6	17.17	86.24	35.36	79.74
GDP (°) 10	35.77	35.41	51.69	24.71	36.46	61.18	48.21	58.02
GDP 30	113.42	110.42	157.57	95.20	111.53	161.95	158.41	167.54
GDP 50	212.57	198.80	298.95	197.72	210.07	303.48	315.96	317.26
CO_2 Em. (°) 10	48.16	36.58	47.16	49.10	44.95	72.54	76.71	63.06
CO_2 Emiss. 30	161.06	132.33	170.37	147.56	150.86	238.80	297.60	230.91
CO2 Emiss 50	336.05	268.83	396.32	303.68	296.53	508.73	681.76	515.80
Endowments (*)								
Labour 10	35.74	39.92	34.83	20.17	40.69	72.47	42.32	74.04
Labour 30	116.36	125.56	117.89	91.57	124.43	163.02	123.75	180.43
Labour 50	249.63	266.58	257.02	214.47	263.68	324.16	254.43	352.43
Capital 10	42.19	22.79	33.88	53.68	32.33	51.82	47.05	36.46
Capital 30	132.86	88.2	118.03	114.6	106.7	181.78	205.87	153.79
Capital 50	253.66	163.95	266.4	177.5	185.62	373.73	500.81	353.48
Nat. Res.(°) 10	56.46	31.58	45.02	51.17	53.62	67.19	83.88	76.51
Natur. Res. 30	186.46	108.18	170.14	134.40	172.41	235.95	325.05	273.04
Natur. Res. 50	397.01	219.12	406.71	267.37	323.25	501.49	765.82	627.80
Labour Productivity (*)								
Agricult.(§) 10	23.18	27.64	46.45	26.06	26.06	46.45	56.17	56.17
Agriculture 30	63.45	74.83	122.32	70.84	70.84	122.32	146.38	146.38
Agriculture 50	120.14	140.79	227.25	133.59	133.59	227.25	271.01	271.01
Energy ($) 10	0	3.63	18.9	0	2.34	18.9	26.78	26.78
Energy 30	0	6.96	36.02	0	4.52	36.02	50.74	50.74
Energy 50	0	9.38	48.65	0	6.11	48.65	68.53	68.53
Electricity 10	14.95	19.12	36.67	17.64	17.64	36.67	45.73	45.73
Electricity 30	38.87	48.54	88.89	45.15	45.15	88.89	109.33	109.33
Electricity 50	69.45	85.34	151.89	79.8	79.8	151.89	185.57	185.57
Water 10	29.52	32.24	51.6	29.86	28.96	51.65	62.1	62.35
Water 30	84.27	90.44	141.19	83.58	80.79	141.92	169.73	170.54
Water 50	167.56	177.2	273.55	163.07	157.02	276.15	330.91	332.62
En_Int_ind 10	23.18	27.64	46.45	26.06	26.06	46.45	56.17	56.17
En_Int_ind 30	63.45	74.83	122.32	70.84	70.84	122.32	146.38	146.38
En_Int_ind 50	120.14	140.79	227.25	133.59	133.59	227.25	271.01	271.01
Oth_ind 10	29.52	32.24	51.6	29.86	28.96	51.65	62.1	62.35
Oth_ind 30	84.27	90.44	141.19	83.58	80.79	141.92	169.73	170.54
Oth_ind 50	167.56	177.2	273.55	163.07	157.02	276.15	330.91	332.62
Mserv 10	29.52	32.24	51.6	29.86	28.96	51.65	62.1	62.35
Mserv 30	84.27	90.44	141.19	83.58	80.79	141.92	169.73	170.54
Mserv 50	167.56	177.2	273.55	163.07	157.02	276.15	330.91	332.62
Nmserv 10	29.52	32.24	51.6	29.86	28.96	51.65	62.1	62.35
Nmserv 30	84.27	90.44	141.19	83.58	80.79	141.92	169.73	170.54
Nmserv 50	167.56	177.2	273.55	163.07	157.02	276.15	330.91	332.62
Land Productivity (**)								
2010	78.24	44.66	117.7	106.41	135.5	203.93	206.25	203.93
2030	97.46	49.6	184.52	129.39	190.11	280.62	259.69	280.62
2050	114.03	52.75	267.25	162.45	225.54	379.87	339.51	379.87

(*) source: G-Cubed model.
(**) source: IMAGE model.
(°) source: GTAP-EX model.
(§) includes: Rice, Wheat, Cereals, Vegetables and Fruits, Animals, Forestry, Fishing.
($) includes: Coal, Oil, Gas, Oil Products.

3. Modelling the impacts

The economic valuation of the various impacts of the climate change is a difficult task. It requires interdisciplinary knowledge from many fields, other than economics: agronomy, geology, meteorology, demography, medicine, political science, biology, engineering, physics. Tol (2002a,b) reviews the available studies for impacts on human health, productivity in agriculture and forestry, losses of species and ecosystems, sea level rise, energy consumption and water resources. He discusses methodological issues and provides a meta-analysis, obtaining "best-guesses" for the valuation of the various impacts.

The modelling project we are undertaking draws heavily on this work, but also aims at improving the analysis by moving from "local" impacts to system-wide effects, propagated inside the world economy by means of trade and income flows.

Figure 1 illustrates how impact studies and the CGE model are interfaced.

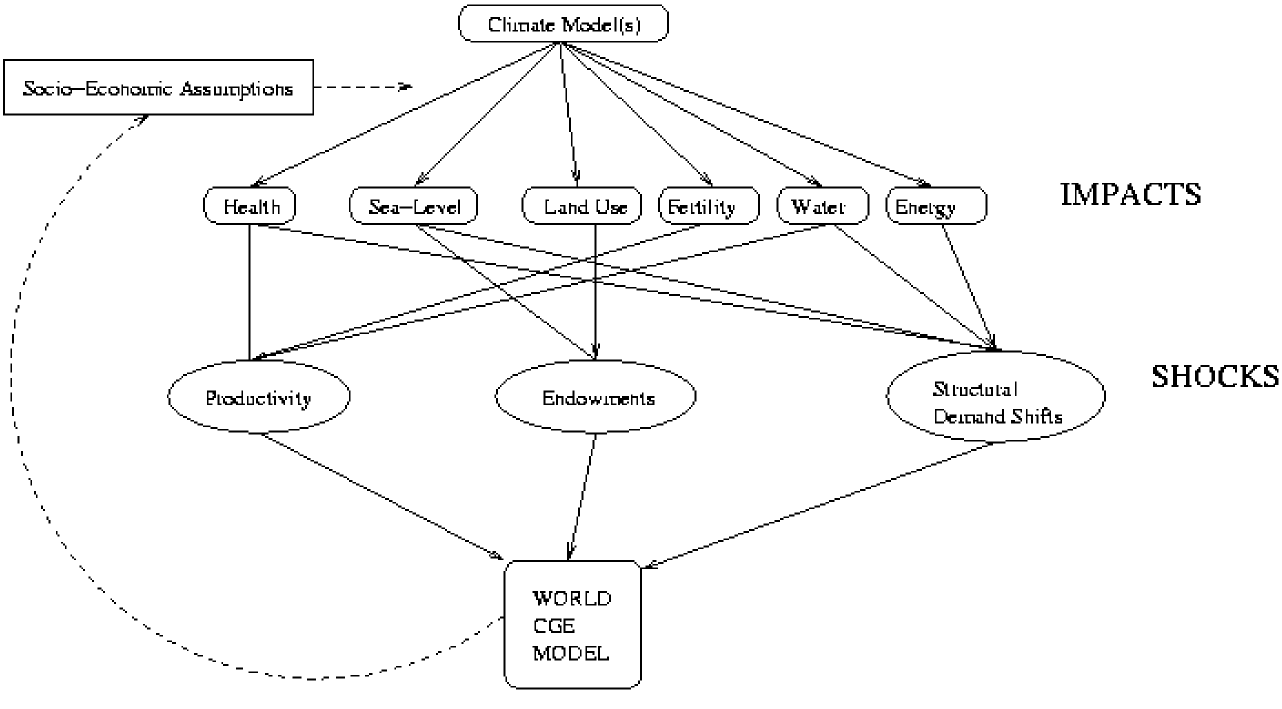

Figure 1.

The impact modules are independent studies, each one considering a specific aspect of the climate change. They are based on one or more climatologic models (GCM), as well as on a number of socio-economic assumptions regarding, for instance, the adaptation capabilities, or the technological progress.

The typical output of an impact study is not suited for direct use in a CGE simulation, because of differences in the spatial and sectoral detail, in the units of measure, and in the reference points (e.g., degrees of temperature increase, rather than years)[3]. The results of the impact modules, therefore, need to be translated in terms of variations of exogenous parameters in the CGE model.

There are three main categories of parameters that are affected by this process. Productivity shift parameters modify the productivity of a specific factor, or of a composite aggregate. For example, additional diseases, as estimated by the health module, imply a reduction of working hours, and a consequent decrease in the labour productivity. Land fertility is directly linked to the productivity of land for the various crops. A reduction of water availability harms the overall productivity of some agricultural industries, even when water resources are not a marketed good[4].

Resource endowments are another important category. Land, and possibly capital, resources are lost because of the sea level rise. Climate change may alter the patterns of land use, with more or less land available for the various industries.

Finally, many impacts imply some structural demand shifts. By this, we mean changes in the structure of final and intermediate demand, not induced by changes in relative prices. For example: more expenditure on health services by the public sector or the households, forced investment for coastal protection, purchases of air conditioning systems.

Remember that the demand for specific goods and services is endogenously computed in a general equilibrium model. Therefore, before running it, the model has to be partially

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[3] The typical impact study is not suitable for use in a CGE also because it estimates economic and welfare losses. These are an output, not an input, in a general equilibrium model.

[4] The water services industries only delivers to households and firms; agricultural water is apparently hidden in land productivity.

"recalibrated". This is obtained by forcing a change in some demand quantities, while keeping the associated prices unchanged[5].

We are currently working on some test simulations, considering first the effects of climate change on health and sea level. We report here some preliminary results, which should only be regarded as an illustration.

Tol (2002a,b) estimates the impacts of climate change on human mortality through six pathways: malaria, schistosomiasis, dengue fever, cold-related cardiovascular diseases, heat-related cardiovascular diseases, and heat-related respiratory disorders, based on several different sources. The change in labour productivity per year equals the ratio of the total number of life years diseased *because of climate change* and the total number of years. This assumes that climate change affects the working population as much as the non-working population.

The impacts of climate change on coastal zones are as described in Tol (2002a,b). The land loss due to sea level rise is divided by the total land area of a region to derive the proportional change in the land endowment in GTAP-EX.

In both cases, only the effects on endowments, or productivity, of primary resources are considered, whereas the expenditure effects for coastal protection and health services are disregarded.

Results are summarized in Tables II and III. Table II shows the impact of the two separate shocks (health and sea level), in terms of income equivalent variation[6]. The two shocks can be applied simultaneously in the model, but we found the results to be (approximately) the sum of the results obtained in the two simulations reported here.

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[5] In practice, this amounts to swapping the price variables (normally endogenous) with the specific share parameters (normally exogenous).

[6] The equivalent variation (EV) is an estimate of the hypothetical variation in the household income, which would have produced the same change in the utility of the representative consumer, at fixed prices. A negative EV signals a worsening of consumer's utility and purchasing power.

Table II – Health and Sea Level Effects of Climate Change
measured in terms of income equivalent variations
(millions of 1997 US$)

HEALTH	**2010**	**2030**	**2050**
USA	0.663518	191.8071	848.296
EU	3.354671	952.384	3539.161
East Europe FSU	0.290912	89.24757	359.0927
Japan	-0.03802	-9.53093	-66.7773
Rest of Annex I	0.588743	167.5813	600.8062
Energy Exporters	-3.6002	-1063.25	-3986.77
China India	-1.39503	-423.291	-1313.98
Rest of the World	-3.5194	-1092.27	-4124.34

SEA LEVEL RISE	**2010**	**2030**	**2050**
USA	-1.048711	-41.9225	-1609.62
EU	-1.431420	-43.8268	-1277.25
East Europe FSU	-0.401172	-8.73332	-203.624
Japan	-0.428043	-2.39755	150.337
Rest of Annex I	-0.038618	3.909041	285.1913
Energy Exporters	-7.260132	-134.392	-1352.67
China India	-2.648810	-83.4139	-1296.33
Rest of the World	-4.153444	-97.0129	-1349.96

Table III – Simultaneous Health and Sea Level shock in 2050
percentage variation of industrial output, relative to the baseline

	USA	**EU**	**EEFSU**	**JPN**	**RoA1**	**EEx**	**CHIND**	**RoW**
Rice	-0.02626	0.014227	-0.00325	-0.01974	0.052383	-0.11594	-0.0457	-0.09566
Wheat	-0.04945	-0.01908	0.010583	-0.26349	0.031489	-0.09474	-0.04188	-0.087
CerCrops	-0.02395	0.026631	0.050131	-0.08275	0.086026	-0.118	-0.02821	-0.08257
VegFruits	-0.035	0.01751	0.025481	-0.08674	0.069181	-0.13843	-0.06026	-0.08766
Animals	-0.02308	-0.00802	0.022196	-0.03781	0.026819	-0.11061	-0.08262	-0.09214
Forestry	-0.0425	-0.02175	-0.02453	-0.03092	-0.01851	-0.03961	-0.02897	-0.03375
Fishing	-0.00561	-0.00441	-0.00822	-0.01645	-0.02509	-0.03711	-0.05746	-0.03347
Coal	-0.00663	-0.00583	-0.00232	-0.07439	-0.04929	0.004317	-0.02125	-0.01873
Oil	-0.01025	-0.02584	-0.00778	-0.05823	-0.031	0.007878	0.005501	-0.00455
Gas	0.003996	-0.02271	0.000418	-0.03199	-0.03949	0.013137	-0.01435	-0.02467
Oil_Pcts	0.014982	0.018181	0.011589	0.016072	0.028717	-0.01348	-0.04324	-0.02029
Electricity	0.002083	-0.00218	0.007924	-0.00853	-0.01523	-0.02896	-0.0416	-0.02409
Water	0.002592	0.013017	0.015567	0.000448	0.021304	-0.03452	-0.02842	-0.03649
En_Int_ind	-0.00723	0.003987	0.005455	-0.03322	-0.03015	-0.04587	-0.04765	-0.0461
Oth_ind	-0.01657	-0.0029	-0.00714	-0.00996	0.008968	-0.11423	-0.05817	-0.09678
MServ	0.006196	0.016568	0.011467	0.003953	0.017221	-0.04217	-0.06647	-0.03192
NMserv	0.006709	0.022368	0.01797	0.002285	0.026226	-0.05622	0.001992	-0.04322
CGDS	0.006229	0.01576	-0.00589	0.024285	0.02831	-0.10205	-0.1573	-0.06452

Some points are worth to be stressed here. First, the impact of both shocks appears to be highly non-linear; they are barely felt in 2010, but in 2050 they become significant[7]. The health impacts depend on the geographic position of the regions, with large regions exhibiting average results (which are likely to hidden quite different local impacts).

In assessing the distributional consequences of the shocks, it is important to underline that human and material resources are valued much more in the developed countries, than in the third world. Therefore, the economic valuation of, say, a human life in the USA is much larger than a human life in Kenya. On the other hand, if the impacts are measured relative to the wealth, or to the GDP (not shown here), then they may turn out to be larger in the developing countries.

Another interesting characteristic can be noted in the results of the sea level shock, for example in 2050. Although the shock is unambiguously negative[8], some countries (Japan, Rest of Annex I[9]) actually gain. This outcome highlights the difference between a general equilibrium analysis, based on relative competitiveness, and a local impact analysis which, by construction, rules out (possibly positive) second order effects.

The same type of outcome can be noticed in Table III, displaying changes in industrial production, as a consequence of a simultaneous shock on health and sea level in 2050. Here again there are slight reductions in the output of most industries, but some industries in some countries experience a growth. Generally speaking, the industries and countries most negatively affected by the shocks are those having labour-intensive, or land-intensive, production processes.

4. Concluding Remarks

In this paper, we have illustrated the overall approach and some preliminary results of a project, aimed at modelling the economic consequences of the climate change. The adoption of a general equilibrium methodology allows tracing the propagation

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[7] The relatively large geographical aggregation may shadow some dramatic effects on specific locations (e.g., small island disappearing because of the sea level rise).

[8] The impact on health, on the other hand, could be positive because of, say, reduction of cold-related illness.

[9] Annex I is an addendum of the Kyoto Protocol, listing all signatory countries (mainly developed countries).

mechanism of shocks to resources, productivity, and demand structure, throughout the world economy. We believe this is a rather unexplored theme in the environmental economics literature, although some studies (e.g. Böringer and Rutherford (1999)) have already shown that trade-related second order effects are essential in the assessment of environmental policies.

Nonetheless, it is clear that our approach has its own limitations. Perhaps the most evident one is the choice of modelling the climate change as a one-time event. In reality, climate change occurs progressively over time, and natural systems interact dynamically with human systems.

In principle, this would call for a fully dynamic Integrated Assessment Model. The actual implementation of such a model, at a sufficient level of disaggregation, would however be overwhelmingly complex.

On the environmental side, the climate change has its own dynamics, due to the adaptation processes of natural and human systems to the changing environment (see Tol (2002b)). On the economic side, the static CGE model would have to be transformed in a dynamic general equilibrium model, and this entails solving a number of difficult issues, like modelling investment behaviour and expectations, capital flows, migrations, intertemporal budgets. Furthermore, it is not clear how reliable such a model would be in the medium-long term[10], and if sufficient information is available.

For all these reasons, although we will continue working on the model dynamics, in the near future we plan to focus on enlarging the spectrum of climate change effects in the comparative static analysis. New and unexplored impacts, like changes in the demand for insurance services induced by greater weather variability, will be taken into account.

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[10] We developed and tested a recursive dynamic version of the GTAP-E model (GTAP-ER). This variant tends to produce divergent (and sometimes unrealistic, especially in the long run) growth paths for the different economies. The model could be used, with some amendments, as a substitute of the G-Cubed model for the determination of the baseline scenarios. This would possibly improve the model internal consistency, but it is not clear whether this would also improve its realism and usefulness.

References

Böringer, C., Rutherford, C.F., (1999) *Decomposing General Equilibrium Effects of Policy Intervention in Multi-Regional Trade Models - Method and Sample Application*, ZEW Discussion Paper n. 36.99.

Burniaux J-M., Truong, T.P., (2002) *GTAP-E: An Energy-Environmental Version of the GTAP Model*, GTAP Technical Paper n.16 (www.gtap.org).

Darwin, R.F., Tol, R.S.J., (2001), 'Estimates of the Economic Effects of Sea Level Rise', *Environmental and Resource Economics*, vol.19 (2), pp.113-129.

Deke, O., Hooss, K.G., Kasten, C., Klepper, G., Springer, K., (2001) *Economic Impact of Climate Change: Simulations with a Regionalized Climate-Economy Model*, Kiel Working Paper No. 1065, Kiel Institute of World Economics.

Dixon, P., Rimmer, M., (2002) *Dynamic General Equilibrium Modeling for Forecasting and Policy*, North Holland.

Hertel, T.W., (1996) *Global Trade Analysis: Modeling and applications*, Cambridge University Press.

Hertel, T.W., Tsigas, M. (2002), GTAP Data Base Documentation, Chapter 18.c "Primary Factors Shares" (www.gtap.org).

IMAGE (2001), *The IMAGE 2.2 Implementation of the SRES Scenarios*, RIVM CD-ROM Publication 481508018, Bilthoven, The Netherlands.

Manne, A., Mendelsohn, R., Richels, R., (1995) MERGE- A model for evaluating regional and global effects of GHG reduction policies, *Energy Policy*, vol. 23, pp. 235-274.

McKibbin, W.J, Wilcoxen, P.J., (1998) The Theoretical and Empirical Structure of the G-Cubed Model, *Economic Modelling*, vol. 16(1), pp. 123–48.

Nordhaus, W.D.,Yang Z., (1996) A Regional Dynamic General Equilibrium Model of Alternative Climate-Change Strategies, *American Economic Review*, vol. 86(4), pp. 741-765.

Tol, R.S.J., (2002a) Estimates of the Damage Costs of Climate Change - Part I: Benchmark Estimates, *Environmental and Resource Economics*, vol. 21, pp. 47–73.

Tol, R.S.J., (2002b) Estimates of the Damage Costs of Climate Change - Part II: Dynamic Estimates, *Environmental and Resource Economics*, vol. 21, pp. 135-160.