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Advancement report on "Updated assessment of the economic impacts of climate change"

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SUMMARY The present report describes the first step of the GEMINA research conducted in WP 6.2.9 aiming to perform climate change integrated impact assessment exercise, whose economic evaluation is based on a CGE approach and modelling effort. The first (still ongoing) phase consists in a revised assessment of climatic change impacts, per region and type, based on the most recent available impact literature.

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1. Introduction

A key challenge today's policy makers are facing, concerns the reduction of greenhouse gases emissions, the major cause of climate change. If emissions continue to grow as they did over the last century, the consequences on the ecologic and human systems could be daunting. This is the economic reasoning that underlines the search for economic efficient climate policies. More precisely, policy makers should base the choice of environmental regulations on analyses allowing reliable and robust comparisons of the costs and the benefits of a given policy.

In the context of climate change, this is very demanding. It means, preliminarly, to give a monetary value to actual and expected consequences of present and future climate change in different locations worldwide, all affected, but in differentiated ways. Coupling climatic, environmental and economic models can help to provide this type of information.

This report describes the advancements in the first phase of the wider GEMINA research plan aiming to estimate an updated region-specific, reduced-form, climate change damage function. It introduces updated estimates of physical and economic consequences of climate change impacts based on recent results produced by the FP7 project CLIMATECOST and describes how these are translated into appropriate input for the ICES CGE model developed at the CMCC. This work will be completed in month 18 of the GEMINA project.

The logical steps of the whole research effort are summarized in Figure 1 and described below:

- Identification and estimation of a wide set of climate change impacts through impact-specific bottom-up partial equilibrium studies;
- Joint macro-economic assessment of these climate change impacts. The assessment is done by means of a top-down recursive-dynamic computable general equilibrium (CGE) model, ICES (Intertemporal General Equilibrium System). The aim is to capture the role of market driven mechanisms able to smooth or amplify the initial climate shocks to the economic system.
- Extrapolation, starting from these outputs, of a reduced-form damage function accounting for autonomous market adaptation. .
- The updated damage function is embedded in an Integrated Assessment model WITCH (World Induced Technical Change model)
- The assessment of the social cost of carbon under different policy scenarios is performed using the augmented version of the WITCH model.

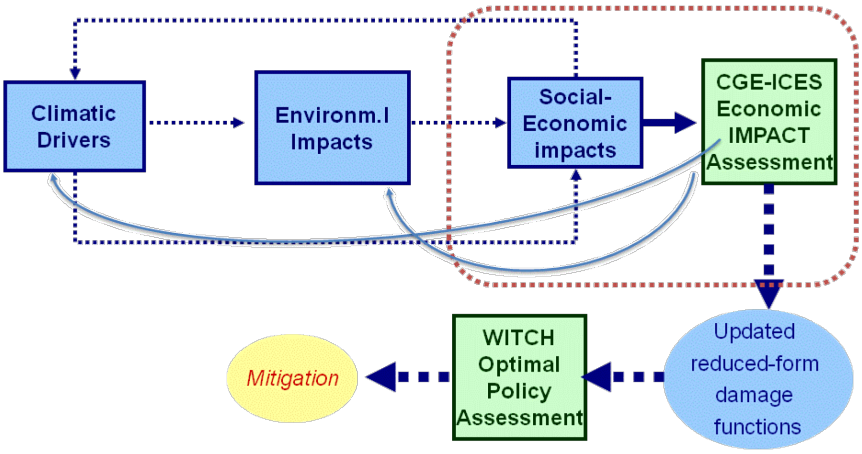

Figure 1. The structure of the economic assessment exercise

In what follows, section 2 introduces the ICES CGE model and benchmark calibration. This is the model that will be used for the subsequent impact assessment exercise. Section 3 briefly describes the impacts assessment provided by bottom-up studies analyzed so far; section 4 details the process of including impacts into the CGE model.

2. The ICES model and the baseline scenario

Computable General Equilibrium (CGE) models are increasingly used to assess costs and benefits associated with climate change impacts (for a partial list, see e.g. Deke *et al.* (2002), Darwin and Tol (2001), Bosello *et al.* (2007) on sea-level rise; Bosello *et al.* (2006) on health; Darwin (1999), Ronneberger *et al.* (2009) on agriculture; Berrittella *et al.* (2007), Calzadilla *et al.* (2008) on water scarcity; Bosello *et al.* (2009) on sea-level rise, agriculture, health, energy demand, tourism, forestry; Aaheim and Wey (2009) on sea-level rise, agriculture, health, energy demand, tourism, forestry, fisheries, extreme events, energy supply; Ciscar, (2009) on sea-level rise, agriculture, tourism, river floods).

The appeal of such tools is the explicit modelling of market interactions between sectors and regions (inter industry and international trade flows are accounted for by databases relying upon input output Social Accounting Matrices). This allows tracing adjustment mechanisms in the whole economic system triggered by a “shock” concerning initially just one part of it (region or sector). Putting it differently, not only direct costs but higher-order effects as well can be determined.

Following this approach, we shall use the Intertemporal Computable Equilibrium System (ICES) model (Eboli *et al.*, 2010) to assess the economic consequences of a wide set of climate change impacts. ICES is a recursive-dynamic model improving upon the static structure of the GTAP-E model (Burniaux and Troung, 2002). The calibration year is 2001, data come from the GTAP6 database (Dimaranan, 2006) and the simulation time is 2001-2050.

Table 1 reports regional and sector aggregation for this study. A detailed description of the model can be found in Appendix I

Table 1 - Regional and sector disaggregation of the ICES model

REGIONAL DISAGGREGATION OF THE ICES MODEL	
USA:	United States
MEUR:	Mediterranean Europe
NEUR:	Northern Europe
EEUR:	Eastern Europe
FSU:	Former Soviet Union
KOSAU:	Korea, S. Africa, Australia
CAJANZ:	Canada, Japan, New Zealand
NAF:	North Africa
MDE:	Middle East
SSA:	Sub Saharan Africa
SASIA:	India and South Asia
CHINA:	China
EASIA:	East Asia
LACA:	Latin and Central America
SECTORAL DISAGGREGATION OF THE ICES MODEL	
Rice	Gas
Wheat	Oil Products
Other Cereal Crops	Electricity
Vegetable Fruits	Industry
Animals	Transport
Forestry	Residential
Fishing	Market Services
Coal	Public Services
Oil	

To be consistent with the majority of bottom-up impact studies available in the literature, the economic benchmark of the model replicates the A1B IPCC SRES scenario whose GDP growth rates are reported by Figure 2.

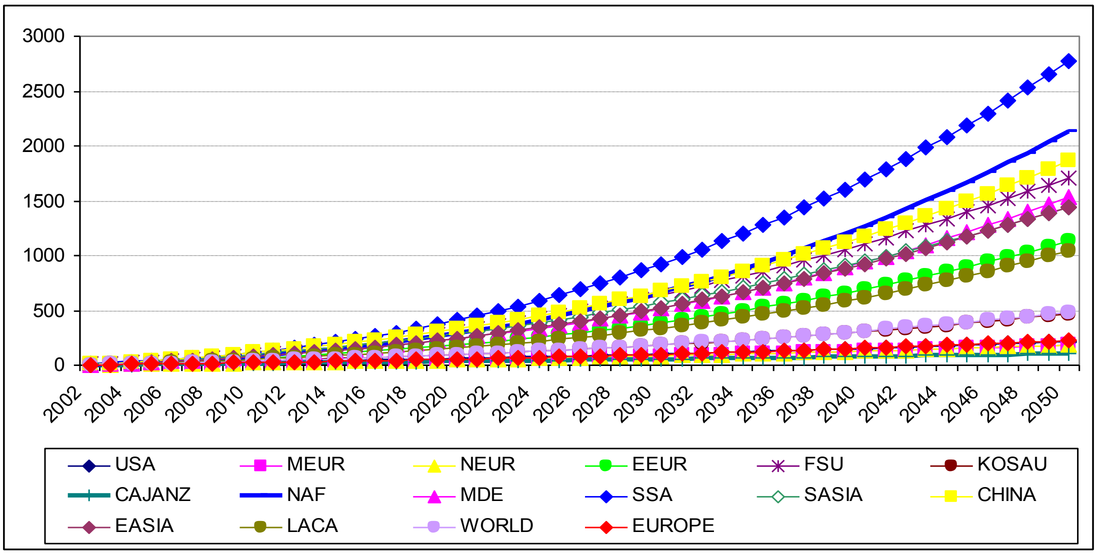

Figure 2 - GDP growth rates by region (% change 2001-2050)

The next sections reports the impacts' categories considered and how they have been translated into suitable input to the ICES model.

3. Assessing climate change impacts by category

As anticipated, part of the initial inputs to the CGE exercise derive from the results of a set of bottom-up partial-equilibrium exercises performed within the ClimateCost project (see Table 2).

These allow to physically quantifying climate change consequences on sea-level rise, energy demand, agricultural productivity, tourism flows, net primary productivity of forests, floods, reduced work capacity because of thermal discomfort ("health"). All the studies, except those on floods and health, have a global coverage. The last two focus on the EU. The majority of them is based on a geographic information system . When this is the case, results have been aggregated to match the geographical resolution of the CGE exercise.

The major characteristics of the individual studies are summarized below, while for detailed description the interested reader is directly addressed to the specific impact studies.

Estimates of coastal land loss due to *sea-level rise*, are based upon the DIVA model outputs (Vafeidis *et al.*, 2008). DIVA (Dynamic Integrated Vulnerability Assessment) is an engineering model designed to address the vulnerability of coastal areas to sea-level rise. The model is based on a world database of natural system and socioeconomic factors for world coastal areas reported with a spatial resolution of 5°. The temporal resolution is 5-year time steps until 2100 and 100-year time steps from 2100 to 2500. Changes in natural as well as socio-economic conditions of possible future scenarios are implemented through a set of impact-adaptation algorithms. Impacts are then assessed both in physical (i.e. sq. Km of land lost) and economic (i.e. value of land lost and adaptation costs) terms.

Changes in *tourism flows* induced by climate change are derived from simulations based on the Hamburg Tourism Model (HTM) (Bigano *et al.*, 2007). HTM is an econometric simulation model, estimating the number of domestic and international tourists by country, the share of international tourists in total tourists and tourism flows between countries. The model runs in time steps of 5 years. First, it estimates the total tourists in each country, depending on the size of the population and of average income per capita; then it divides tourists between those that travel abroad and those that stay within the country of origin. In this way, the model provides the total number of holidays as well as the trade-off between holidays at home and abroad. The share of domestic tourists in total tourism depends on the climate in the home country and on per capita income. International tourists are finally allocated to all other countries based on a general attractiveness index, climate, per capita income in the destination countries, and the distance between origin and destination.

Changes in average *crops' productivity* per world region derive from the ClimateCrop model (Iglesias *et al.*, 2009; Iglesias *et al.*, 2010). Crop response depends on temperature, CO_2 fertilisation and extremes. Water management practices are also taken into account. Integrating spatially all these elements the model estimates climate change impacts and the effect of the implementation of different adaptation strategies.

Responses of *residential energy demand* to increasing temperatures derive from the POLES model (Criqui, 2001; Criqui *et al.*, 2009). It is a bottom-up partial-equilibrium model of the world energy system extended within ClimateCost to include information on water resource availability and adaptation measures. It determines future energy demand and supply according to energy prices trend, technological innovation, climate impacts and alternative mitigation policy schemes. The present version of the model considers both heating and cooling degree-days in order to determine the evolution of demand for different energy sources (coal, oil, natural gas, electricity) over the time-horizon considered.

Data on changes in *forest net primary productivity (NPP)* are provided by the LPJmL Dynamic Global Vegetation Model developed at the PIK – (Boundeau *et al.*, 2007; Tietjen *et al.*, 2009). The LPJ model, endogenously determines spatially explicit transient vegetation composition and the associated carbon and water budgets for different land-uses including forestry. It estimates the effects of climate change on forest (NPP) for all world countries in the world, with or without carbon fertilization effect on vegetation and the role of forest fires.

Data on climate change impacts on *river floods* are based on results from the LISFLOOD model (Van der Knijff *et al.*, 2009; Feyen, 2009). This is a spatially distributed hydrological model embedded within a GIS environment. It simulates river discharges in drainage basins as a function of spatial information on topography, soils, land cover and precipitation. This model has been developed for operational flood forecasting at European scale and it is a combination of a grid-based water balance model and a 1-dimensional hydrodynamic channel flow routing model. The LISFLOOD model can assess the economic loss in the EU27 countries per different macro-sectors: residential, agriculture, industry, transport and commerce together with the number of people affected. The role of climate change, and of economic growth in determining the final losses can be disentangled. Differently from other impact studies, LISFLOOD is an EU model, thus the Non-EU regions remain outside the scope of its investigation.

Finally, climate change impacts on *"on the job performance" in Europe* are derived from Kovats and Lloyd (2011). They assess the change in working conditions due to heat stress produced by the increase in temperature and their effects on labour productivity. By linking climate data, a combined measure of heat and humidity (the "Wet Bulbe Globe Temperature") and effects on the human body (Kjellstrom *et al.*, 2009), they are able to estimate the expected decrease in labour productivity for four European macro-regions (Western, Eastern, Northern and Southern). Authors also consider sectoral impacts taking into account future changes in distribution of labour force across sectors.

Table 2 Impact specific assessments and models within CLIMATECOST.

IMPACT	**MODEL**	**Geographical Scope**	**Reference**
sea-level rise	DIVA (Dynamic Integrated Vulnerability Assessment)	Global	Vafeidis *et al.*, 2008
tourism flows	Hamburg Tourism Model	Global	Bigano *et al.*, 2007
crops' productivity	ClimateCrop	Global	Iglesias *et al.*, 2009; Iglesias *et al.*, 2010
residential energy demand	POLES	Global	Criqui, 2001; Criqui *et al.*, 2009
forest net primary productivity	LPJmL Dynamic Global Vegetation Model	Global	Boundeau *et al.*, 2007; Tietjen *et al.*, 2009
river floods	LISFLOOD	EU27	Van der Knijff *et al.*, 2009; Feyen, 2009
job performance	n.a.	Europe	Kjellstrom *et al.*, 2009, Kovats and Lloyd (2011)

4. Implementing climate change impacts in the ICES CGE model

To determine with a CGE model the economic consequences of the different impacts assessed, these need to be firstly translated into changes in economic variables existing in the model.

In the following we discuss the procedure adopted.

Land losses to sea-level rise has been modelled as percent decreases in the stock of productive land and capital by region. Both modifications concern variables, land and capital stocks, which are exogenous to the model and therefore can be straightforwardly implemented. As information on capital losses are not available, we assume that they exactly match land losses[1].

Changes in regional *households' demand for oil, gas and electricity* are modelled as changes in households' demand for the output of the respective industries.

Changes in *tourists' flows* are modelled as changes in (re-scaled) households' demand addressing the market services sector, which includes recreational services. In addition, changes in monetary flows due to variations in tourism demand are simulated through a direct correction of the regional incomes.

Impacts on *agriculture* are modelled through exogenous changes in land productivity. Due to the nature of source data, land productivity varies by region, but is uniform across all crop types present in ICES.

Climate change impacts on *forest NPP* are implemented in ICES via an exogenous change in the productivity of the natural resource endowment of the timber sector, assuming that the available stock of forest for commercial purposes remains constant with respect to the baseline scenario.

With reference to *river floods*, to account for economic damages affecting the agricultural sector we impose an equal-value reduction in regional land stock, while, when other sectors are involved, an equal-value reduction in sectoral capital productivity. With regard to people affected, this is accommodated in the model by reduction in labour productivity. This is computed relating people affected to the total regional population and assuming that the average loss of working days is one week.

Reduction in work productivity is also the channel to account for *on the job performance effects of temperature increases*. Figures derived from Kovats and Lloyd (2011) are directly used to modify ICES sector-specific labour productivity.

As can be noted, two broad categories of impacts can be distinguished in the abovementioned list. The first relates to the supply-side of the economic system, affects exogenous variables in the model - stock or productivity of primary factors - and thus can be easily accommodated. Impacts on sea-level rise, agriculture, forestry, but also on floods and human health belong to this category and they do not require any substantial change in the basic structure of the model to be implemented.

The second affects changes in the demand side. Impacts on tourism and on energy consumption are of this kind. This implies to intervene on variables which are endogenous to the model. The technicality involved is more complex than in the case of exogenous variables and the following procedure has been adopted. The computed percentage variations in the demands have been imposed as exogenous shifts in the respective demand equations. The implicit assumption is that the starting information refers to partial equilibrium

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[1] We could have avoided including capital losses, however they are an important part of sea-level rise costs therefore we prefer to have a rough even though arbitrary estimation of this component rather than none. We are not including displacement costs.

assessment thus with *all prices and income levels constant*. The model is then left free to determine the *final* demand adjustments. Modification in demand structure imposes however to comply with the budget constraint, so we compensated the changed consumption of energy and tourism services with opposite changes in expenditure for all the other commodities.

Table 3 summarizes the results of all this procedure presenting the computed inputs for the ICES CGE model necessary to run the climate-change simulation.

The computations refer to year 2050 and are consistent with the A1B IPCC SRES emission scenario or a temperature increase of roughly +1.9°C with respect to preindustrial levels (Christensen *et al.*, 2010).

Table 3 - Climate change impacts: inputs for the ICES model (% change wrt baseline, reference year 2050, A1B IPCC SRES Scenario)

	Demand-side Impacts				
	Energy			*Tourism*	
	Gas	*Oil Products*	*Electricity*	*Mserv Demand*	*Regional Income**
USA	0.83	1.78	7.25	2.99	0.067
MEUR	0.15	0.79	6.91	-1.18	-0.008
NEUR	-0.55	0.15	0.33	1.57	0.012
EEUR	0.41	1.30	0.15	0.13	0.0007
FSU	0.17	2.18	-2.94	5.15	0.061
KOSAU	0.80	1.63	3.60	0.20	0.004
CAJANZ	0.43	1.10	8.05	8.29	0.038
NAF	-0.26	0.77	7.38	-3.78	-0.018
MDE	1.00	2.66	5.86	-2.71	-0.001
SSA	-0.14	0.91	4.53	-2.93	-0.002
SASIA	1.94	3.06	9.46	0.01	0.0002
CHINA	-0.59	0.96	5.22	-3.32	-0.005
EASIA	-1.25	0.29	12.68	-3.28	-0.027
LACA	-0.54	0.23	11.95	-2.28	-0.122

* Trillion $

	Supply-side Impacts (1)			
	SLR	*Forestry*	*Agriculture*	*Health*
	Land and K Stock	*NPP*	*Land productivity*	*Labour productivity*
USA	-0.082	-10.73	-7.54	*n.a. -> 0*
MEUR	-0.008	-17.78	-12.60	-0.31
NEUR	-0.258	-10.71	11.41	-0.004
EEUR	-0.003	-9.88	-0.94	-0.14
FSU	-0.080	0.31	4.17	*n.a. -> 0*
KOSAU	-0.013	-15.72	-4.01	*n.a. -> 0*
CAJANZ	-0.332	0.29	5.30	*n.a. -> 0*
NAF	-0.005	28.57	-21.63	*n.a. -> 0*
MDE	-0.272	-20.29	-6.53	*n.a. -> 0*
SSA	-0.034	-13.30	-8.60	*n.a. -> 0*
SASIA	-0.660	-10.07	-14.22	*n.a. -> 0*
CHINA	-0.0004	-5.87	4.07	*n.a. -> 0*
EASIA	-0.140	-14.37	-16.03	*n.a. -> 0*
LACA	-0.027	-13.87	-3.23	*n.a. -> 0*

n.a.: not available

	Supply-side Impacts (2)					
	Floodings					
	Lab Prod.	*Agriculture (land stock)*	*Industry (K prod.)*	*Transport (K prod.)*	*Residential (K prod.)*	*Commerce (K prod.)*
USA	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
MEUR	-0.0003	-0.014	-0.004	-0.003	-0.044	-0.001
NEUR	-0.0004	-0.013	-0.008	-0.006	-0.115	-0.002
EEUR	-0.0004	-0.008	-0.010	-0.010	-0.697	-0.004
FSU	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
KOSAU	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
CAJANZ	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
NAF	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
MDE	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
SSA	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
SASIA	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
CHINA	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
EASIA	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*
LACA	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*	*n.a. -> 0*

n.a.: not available

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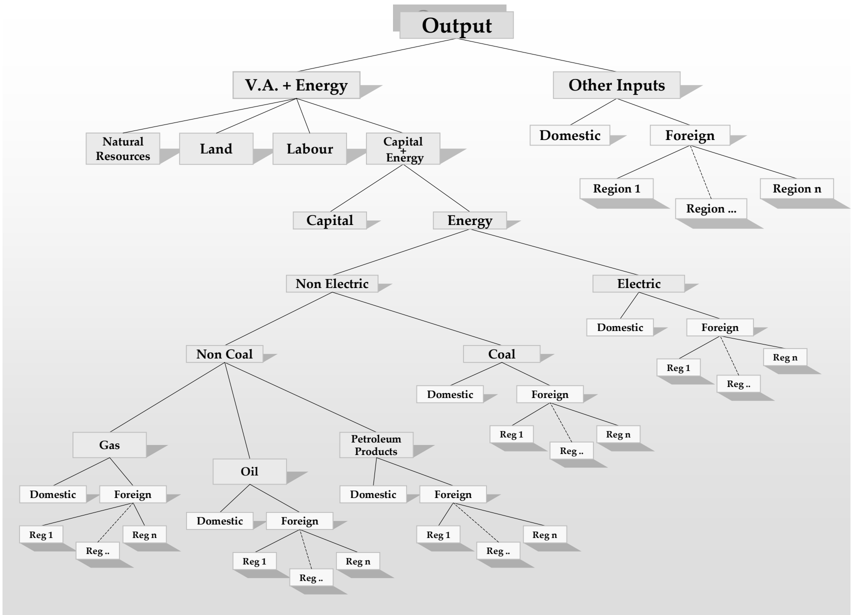
Appendix. The ICES model

As in all CGE models, ICES makes use of the Walrasian perfect competition paradigm to simulate market adjustment processes, although the inclusion of some elements of imperfect competition is also possible. Industries are modelled through a representative firm, minimizing costs while taking prices as given. In turn, output prices are given by average production costs. The production functions are specified via a series of nested CES functions. Domestic and foreign inputs are not perfect substitutes, according to the so-called "Armington" assumption (Figure A1).

Figure A1. Nested tree structure for industrial production processes of the ICES model

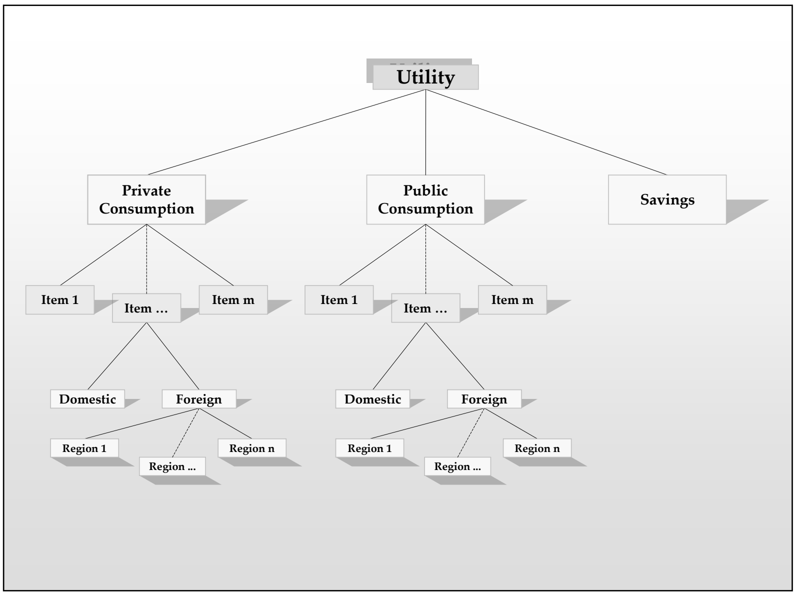


A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labour, capital). Capital and labour are perfectly mobile domestically but immobile internationally. Land and natural resources, on the other hand, are industry-specific. This income is used to finance three classes of expenditure: aggregate household consumption, public consumption and savings. The expenditure shares are generally fixed, which amounts to saying that the top-level utility function has a Cobb-Douglas specification.

Public consumption is split in a series of alternative consumption items, again according to a Cobb-Douglas specification. However, almost all expenditure is actually concentrated in one specific industry: non-market services.

Private consumption is analogously split in a series of alternative composite Armington aggregates. However, the functional specification used at this level is the Constant Difference in Elasticities form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods (Figure A2).

Figure A2. Nested tree structure for final demand of the ICES model



Investment is internationally mobile: savings from all regions are pooled and then investment is allocated so as to achieve equality of expected rates of return to capital.

In this way, savings and investments are equalized at the world, but not at the regional level. Because of accounting identities, any financial imbalance mirrors a trade deficit or surplus in each region.

The recursive-dynamic engine for the model can replicate dynamic economic growths based on endogenous investment decisions. As standard in the CGE literature the dynamic is recursive. It consists of a sequence of static equilibria (one for each simulation period which in the present exercise is the year) linked by the process of capital accumulation. As investment decisions which build regional capital stocks are taken one year to the other, i.e. not taking into account the whole simulation period, the planning procedure is "myopic". Two factors drive endogenously investment and its international allocation: the equalization of expected rate of return to capital and the international GDP differentials. In other words, a country can attract more investment and increase the rate of growth of its capital stock when its GDP and its rate of return to capital are relatively higher than those of its competitors.

CMCC Research Papers

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Centro Euro-Mediterraneo sui Cambiamenti Climatici

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