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# Advancement report on “Extended economic model post 2050”

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**SUMMARY** The present report describes the advancements related to GEMINA P53 carried out in 2011 under the Work Package 6.2.9 consisting in the extension of the dynamic recursive ICES CGE model to perform economic assessment post 2050.

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# Summary

1. Introduction ........ 3

2. The ICES dynamics ........ 3

2.1 Endogenous Dynamics ........ 4

Capital and debt accumulation processes ........ 4

The Stock of Natural Resources ........ 7

2.2 Exogenous Dynamics ........ 7

3 Extension of the simulation horizon ........ 7

References ........ 9

# 1. Introduction

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.* (2011) on sea-level rise; Bosello *et al.* (2006) on health; Darwin (1999), Ronneberger *et al.* (2009) on agriculture; 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.

In the past research activity of the CMCC the Intertemporal Computable Equilibrium System (ICES) model (Eboli *et al.*, 2010), developed at the CIP division, has been used 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.

One of the research advancements to be accomplished by GEMINA WP 6.2.9 is the extension of the model horizon post 2050. The aim is to allow the model to simulate until 2075, in order to capture stronger climatic and consequently economic signals. Doing this however requires to re-calibrate the specificities of the dynamic equations of the model.

In what follows section 2 describes the dynamics in the ICES model, whereas section 3 reports the results of some preliminary extension experiments.

# 2. The ICES dynamics

Dynamics inside the ICES model are driven essentially by two different sources: one endogenous and one exogenous to the model.

The first involves two components: one, the most important, is the capital and foreign debt evolution processes governed by endogenous investment decisions. The other concerns a peculiar treatment of the evolution of natural resources stock.

The second is defined by a set of assumptions concerning the changes in some key economic - mainly supply-side - parameters and exogenous variables which are imposed to the model in order to reflect their possible evolution that can be tailored to different statistical sources, other modelling exercises and economic scenarios.

## 2.1 Endogenous Dynamics

### Capital and debt accumulation processes

ICES is a recursive dynamic model, this means it presents a sequence of static equilibria which are intertemporally connected by the process of capital accumulation.

Capital growth is standard and follows:

$$Ke_r = I_r + (1-\delta)\cdot Kb_r \qquad (1)$$

Where $Ke_r$ is the "end of period" capital stock, $Kb_r$ is the "beginning of period" capital stock, δ is capital depreciation and $I_r$ is endogenous investment. Once solved the model at a given step t, the value of $Ke_r$ is stored in an external file and used as the "beginning of period" capital stock of the subsequent step t+1.

For the particular syntax of GEMPACK, the language in which ICES is written, all the equations express variables in percentage changes. Accordingly, (1) after differentiation and rearrangement is first transformed into:

$$dKe_r \cdot \frac{I}{Ke} = dI_r \cdot \frac{I_r}{I_r} \cdot \frac{I}{Ke_r} + (1-\delta)\cdot dKb_r \cdot \frac{Kb_r}{Kb_r} \cdot \frac{I}{Ke_r}$$

or

$$ke_r = i_r \cdot \frac{I}{Ke_r} + (1-\delta)\cdot kb_r \cdot \frac{Kb_r}{Ke_r} \qquad (2)$$

where small case letter stand for percentage changes.

Then, defining from (1)

$$(1-\delta)\cdot\frac{Kb_r}{Ke_r}=1-\frac{1}{Ke_r}= 1-INVKER_r$$

and substituting in (2), (1) becomes:

$$Ke_r = INVKER_r \cdot I_r + (1-INVKER_r)\cdot Kb_r \tag{3}$$

Which is in fact the equation appearing in the ICES code.

The hearth of the dynamic is the endogenous determination of investment demand $I_r$ .

Sources of world I are savings from households. Regional households save a given share of their income which is firstly "pooled" by a "world bank" and then redistributed back to each region following:

$$I_r = RGDP_r \cdot \exp\left[\rho_r \cdot (R_r^E - R_W)\right] \tag{4}$$

where RGDP is real GDP, $\rho_r$ is a flexibility parameter, $R_r^E$ and $R^W$ are the expected rate of return to capital in region r and the world rate of return to capital respectively.

Equation (4) says that a region demands (or, said differently, is able to "attract") investment as long as its real GDP rises, or its expected rate of return is higher than the world rate of return $R^W$. Investment demand is negatively correlated to $R^W$ which on its turn is determined by the general equilibrium condition requiring equalization between global savings and investments. The parameter $\rho_r$ reflects the flexibility of capital movement related to changes in the current rate of return. If $\rho_r$ has a small value then it will reduce the effect of the growth of the current rate of return when compared with the growth of the global rate of return; basically it can be assumed to reflect policy restrictions.

$R_r^E$ needs a particular comment: ICES does not generate endogenously the expected rate of return to capital according to a fully rational expectation generation process of a forward looking agent; more simply it is assumed that the expected rate of return to capital coincides with the current observed rate of return to capital. That is:

$$R_r^E = R_r^C \quad (5)$$

Substituting (5) in (4), log-linearizing and expressing (4) in percentage changes it is possible to obtain:

$$i_r = rgdp_r + [\rho_r \cdot (R_r^C \cdot r_r^C - R^W \cdot r^W)] \quad (6)$$

which is actually implemented in the ICES code. Again small cases letters are percentage changes, while capital letters are levels. Equation (6) highlights the myopic nature of investment decisions and of capital formation process. Indeed investment in period t depends only on period t rate of return to capital which has no link with future capital stock. Nevertheless investment decided in period t does determine capital stock in period t+1. What governs investment is only what happens in period t: ultimately changes in demand modifying equilibrium prices.

It can be useful to isolate the term $R^W \cdot r^W$ in (6). This leads trivially to:

$$R^W \cdot r^W = rgdp_r + [\rho_r \cdot (R_r^C \cdot r_r^C - i_r)] \quad (7)$$

This formulation highlights that in ICES it is not the full equalization of rates of returns across regions that drives international investment allocation. What is equalised across regions is the whole right hand side of (6). This means that investment moves responding to the relatively higher rates of returns in one region respect to another, but that they do not have to be necessarily the same across regions. Moreover real GDP also plays a role. It allows investment demand to change even in the case rates of returns were equalised or growing at the same rate across regions.

In the mechanism described, world investment supply (savings) must match world investment demand, but this is not necessarily so at the regional level. Indeed a region can run a foreign debt or credit position as long as $S_r >< I_r$. This will be reflected in an disequilibrium in the trade balance. Foreign debt/credit thus evolves according to:

$$De_r = Db_r + TBAL_r \quad (8)$$

Where $De_r$, $Db_r$and $TBAL_r$ are respectively the debt at the end of period, debt at the beginning of period and trade unbalance during the period.

As with capital, at each simulation step the debt at the end of the period is stored in an external file and then recalled in the next simulation step as debt at the beginning of period.

Finally, debt is serviced at the world rate of return to capital, that is, regional income is increased or reduced by $R^W \cdot Db_r$ .

### The Stock of Natural Resources

A rather specific methodology was adopted to get estimates for the evolution of natural resources' stock for which no reliable data are available. As explained in Hertel and Tsigas (2002), initial calibration values for these variables in the original GTAP data set, and accordingly in ICES, are not obtained from official statistics, but are indirectly estimated, to make the model consistent with some industry supply elasticity values, taken from the literature. Then to represent in ICES availability of additional resources due to new discoveries, the price of natural resources has been fixed exogenously, making it variable over time in line with the GDP deflator, while allowing the model to compute endogenously the stock levels.

## 2.2 Exogenous Dynamics

Capital an natural resources are not the only factors expected to vary over time.

Population stock, labour stock, labour and land productivity change over time because of natural or technological evolutionary processes.

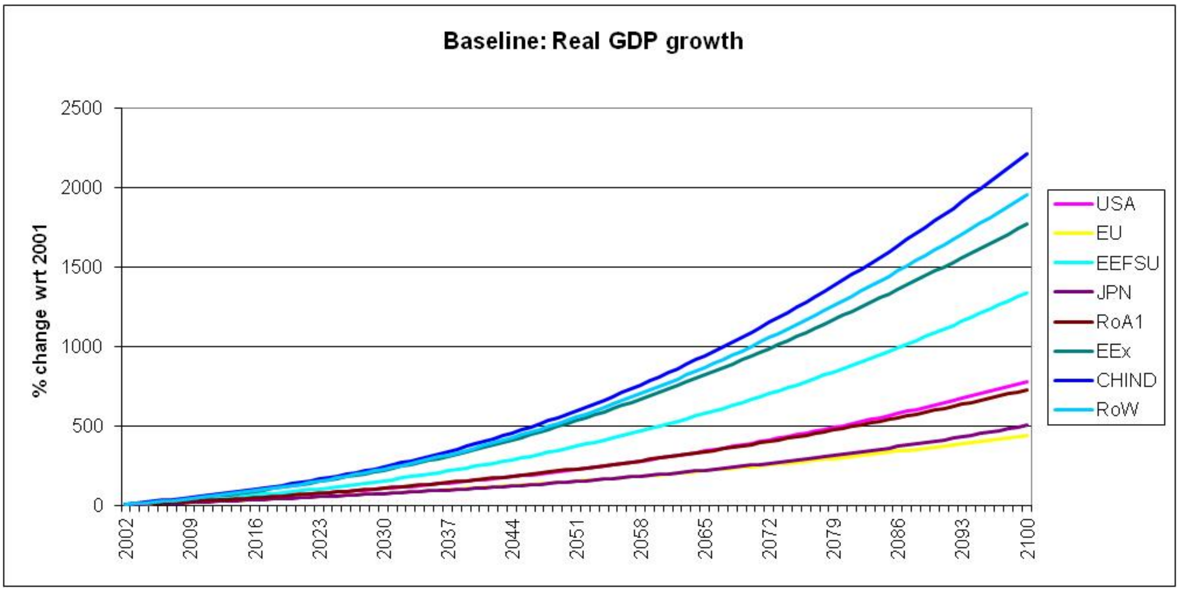
These processes are also taken into account in the baseline. This is done updating exogenously year by year the initial calibration data of all the above mentioned variables according to their expected rates of change derived from different sources.

# 3 Extension of the simulation horizon

At the moment two preliminary exercises have been performed. The first has been to run the model up to 2100, but imposing the regional growth rates that the A2 IPCC scenario expects for 2050. The ICES model is already able to simulate these in 2050. Therefore this experiment which consists in a simple extension of the simulation periods or in a multiplication of the simulation steps is a very basic test to verify if there are weaknesses in the very dynamic structure of the model. The ICES version used for this exercise considers 8 regions and 17 sectors.

As reported in figure 1, the model has no problem in replicating the desired growth rates.

**Figure 1. ICES (8 regions-17 sectors) model runs up to 2100**




In a second experiment we tried to replicate with the ICES model the real post-2050 growth rates as described in the A2 IPCC scenario. We also used a more regionally disaggregated model version (14 regions). In this case the model is able to solve until the 62$^{th}$ step, which is 2063. Afterwards, the rate of returns to capital seems to decline too fast to allow convergence. At present the modeling team is working to adjust this shortcoming.

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10

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