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Extension of the ICES CGE model with ecosystems

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SUMMARY This methodological report describes the steps and the modelling developments foreseen to include a more explicit ecosystem dimension inside the recursive-dynamic Intertemporal Computable Equilibrium System (ICES) Computable General Equilibrium (CGE) model. The modelling strategy hinges upon the fact that ecosystems cannot be included in the model directly, but only indirectly, by measuring changes in agents' demand and/or supply induced by changes in the services ecosystems provide to production/consumption activities. Against this background, different paths are suggested for the model implementation of changes in ecosystem provisioning, regulating, cultural/recreational services.

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SUMMARY

1. INTRODUCTION

This methodological report describes the steps and the modelling developments foreseen to include a more explicit ecosystem dimension inside the recursive-dynamic Intertemporal General Equilibrium System (ICES) Computable General Equilibrium (CGE) model. ICES, developed by the CMCC ECIP division[1], has been amply used within the framework of the research developed by the GEMINA project to assess the economic implications of climate change impacts at different scales of investigation (see e.g. Bosello et al. 2013a,b).

As standard in CGE models, ICES represents the functioning of the economic system through observable market exchanges of factors of production, goods and services generated by optimizing households and firms. ICES is a multi-country multi-sector model: accordingly, the recorded flows of demand and supply concern both domestic and international trade. The model is calibrated, that is it represents the (value of) market exchanges as they have been observed in a given year. Currently the calibration point is 2007 (for the model database see Narayanan et al., (2012)). The model also assumes that all the demand and supply claims by its representative agents (households and firms) perfectly match.

This initial situation can be then "perturbed" to perform the most different analyses. Population, primary production factor endowments, technological parameters can be modified to build future social economic scenarios, different taxes can be levied to simulate the effect of trade, public sector or environmental policies, climate change impacts on factor of production (e.g. changes in land, labor stock and productivity) or on consumption patterns (e.g. changes in household demand for heating/cooling) can be implemented to determine their final economic implications for the economies concerned.

As seen, CGE models can, at least in principle, be used to analyze the most diverse perturbations of the initial economic "equilibrium". However, this is possible only if they can be translated into a change in those variables that in the model determine

[1] http://www.cmcc.it/models/ices-intertemporal-computable-equilibrium-system

an effect on the demand or supply behavior of the model representative agents. Ultimately, an observable change in market exchanges has to be determined.

Give this background, ecosystems cannot be included in the ICES (or in any) CGE model directly, but only indirectly, by measuring changes in agents' demand and/or supply induced by changes in the services ecosystems provide to the production/consumption activities.

Typically, ecosystem services are classified into (Haines-Young and Potschin, 2013):

Provisioning: which can be considered to embed "all nutritional, material and energetic outputs from living systems".

Regulating and maintenance: covering all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance. This thus goes from the degradation of wastes and toxic substances by exploiting living processes; to the mediation of flows in solids, liquids and gases that affect people's performance such as carbon sequestration in forest or wetlands, to the prevention of hydro-geological or coastal erosion risk by woodlands or wetlands or algae populations.

Cultural: covering all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people.

In what follows, it is proposed to model provisioning services, through the consolidated "production function approach". According to this view, ecosystems support production activities either providing standard factors of production (natural resources like fish, wood etc.) or a particular, and free of charge, productivity enhancing factor. This implies to work primarily on the supply side of the model i.e. on the factor and/or sector productivity, or on the stock of natural resources. The latter in ICES are primary inputs used by the fishing, forestry, fossil fuels and raw metals country-specific representative industries.

It is worth noting that the provisioning role of ecosystem is already incorporated in the model production function as it is implicit in the industrial performances of the different economic sectors and in the value of natural resources they are demanding, both of which are recorded by the model database. Therefore, if ecosystem quality is preserved at “current levels”, nothing changes in the model structure. The provisioning service of ecosystem becomes apparent as soon as ecosystems are degraded (improved) implying a lower (higher) productivity, availability of the relevant stock of natural resources, demand, and subsequent impacts on the economic activity.

Regulating services summarize the ability of ecosystems to protect from environmental damages or to make production systems more resilient (quicker to recover) after an adverse shock. Although recovering the data to quantify this role is difficult, the modelling part is relatively easy. In practice no modification to the mathematical structure of the model is needed. What has to change is the computation of climate change or other environmental shocks which are typically implemented exogenously. Therefore their treatment is not included in this report.

The representation of cultural ecosystem services in a CGE model is problematic as, especially existence/passive values, cannot be captured directly by market exchanges. Nonetheless, using revealed or stated preference techniques, they can be estimated, and the related losses can be monetized. Here, it is proposed to add passive value losses to market losses from ecosystem disruption with a “virtual accounting approach”. A more sophisticated treatment of passive values will be then explored adding the ecosystem non market component as an argument of the household utility function with a given substitutability with the market one.

To conclude, somewhat in between the provisioning and the cultural services, ecosystems can influence the demand side of the economic system “supporting” consumption activities and as such have market relevance. As stressed by Carbone and Smith (2013), (changes in) ecosystem services can indeed influence the demand for market goods and services. This occurs directly, as there could be substitutability between market and non-market goods and services, and indirectly, as changes in e.g. recreational ecosystem services can influence the choice between labor supply and leisure, and ultimately, consumption patterns. In the ICES model leisure is not a maximand in the household objective function. Nonetheless, a demand shift toward recreational activities with a market dimension can be captured through changes in household demand for tourism services. In this case ecosystems are providing a recreational service whose changes can be recorded, at least partially, by market transactions through the behavior of tourists' demand. In the ICES model this is a variable that can be controlled to mimic responses to higher or lower environmental quality. Furthermore, in the CGE model, changes in tourism demand induce an overall re-composition of the agents' consumption choices, as all markets are linked. Accordingly, all the feedback effects on the overall demand patterns can be captured.

All these dimensions are connected by environmental/ecosystem protection expenditure. It has the multiple effect to decrease the production losses due to ecosystem degradation, to decrease the utility loss linked to the impact on the passive value households attach to ecosystem and finally to safeguard production system resilience. Environmental protection expenditure is also one way to transform the loss of passive value into something observable into the model.

The next sections delineate a modeling strategy for the treatment of these different features, specifically: section 2 offers guidelines to implement provisioning ecosystem services in the ICES model, section 3 that part of recreational ecosystem services that can be captured by market transactions, section 4 the passive value of ecosystems. Section 5 describes how to simulate the evolution of ecosystem capital stock, section 6 the data needs. Conclusions follow.

2. INTRODUCING PROVISIONING ECOSYSTEM SERVICES IN THE ICES MODEL THROUGH THE PRODUCTION FUNCTION APPROACH

Production support from ecosystems in the ICES model are already considered through the role of natural resources which are primary inputs to the fishing, the forestry, the fossil fuel and the raw metals sectors (see also Barbier (2013)). It can be further accommodated via a parameter affecting sector specific productivity.

That is, in the standard CES production function of the CGE model represented by (eq. 1)

$$Q_i = a_i \cdot \left(b_{1,i} \cdot K_i^{\alpha} + b_{2,i} \cdot L_i^{\alpha}\right)^{1/\alpha} \qquad \text{(eq. 1)}$$

where the index i stands for sectors, (for simplicity we omit here the index for regions), Q production and K and L capital and labor respectively. The total sector productivity parameter a_i is:

$$a_i = \bar{a}_i + a_{1,i} \cdot (EK_t - EK_{t-1}) \qquad \text{(eq. 2)}$$

The productivity parameter can be made dependent upon changes in an exogenous technological component as before, $\bar{a}_i$, and upon changes in ecosystem capital stock EK. The ICES sectors that can be benefiting from ecosystem support to productivity are forestry, fisheries and agriculture. In principle, productivity in other sectors can be also improved by higher ecosystem quality, e.g. through a labor productivity enhancing effect, but at the moment information on this are too limited.

3. INTRODUCING THE CULTURAL/RECREATIONAL MARKET ROLE OF ECOSYSTEM IN THE ICES MODEL.

Also tourism can benefit from healthy ecosystems. There, when well preserved, ecosystems are a factor of attraction and, as such, they foster tourism demand. Note that in this case the recreational value of ecosystems is fully “marketable” as it contributes to generate demand for tourism activities whose effects the CGE model can estimate. These can be modeled introducing a shifting factor analogue to what reported in (eq. 2), but modifying the demand equation of tourism services.

Demand in ICES is the linearized FOC of a standard CD function

$$D_i = \alpha \cdot \frac{Y}{P_i} \qquad \text{(eq. 3)}$$

In (eq.3) D is demand of good i (say tourism services), Y is income and P the price of the good. It can be modified adding a shifting factor S to its right hand side accounting for changes in preferences, with S specified as:

$$S_i = s_i \cdot (EK_t - EK_{t-1}) \qquad \text{(eq. 4)}$$

As the FOCs of the household problem have been modified by an external factor, a proper care needs to be paid that the household budget constraint remains satisfied and that the Walrasian properties of the systems are fulfilled. This is accomplished introducing a shifting variable re-balancing the expenditure of other households’ consumption items.

4. INTRODUCING PASSIVE VALUE OF ECOSYSTEMS IN THE ICES MODEL

A further channel for the introduction of ecosystems into the ICES model is through their effect on utility, i.e. considering their ability to originate non-use/passive value.

The first step to their inclusion in ICES is the estimation of the “total household income”. This is composed by the value of the households’ primary factor endowments and the passive value of ecosystems. Once determined, the passive value can be simply added as a virtual component to national income.

In a more simplistic approach, ecosystem capital deterioration induces a loss of “virtual income” that will be subtracted from the total household income, but without affecting that part originated by households’ endowments. Changes in virtual income are thus linked to changes in ecosystem capital stock, can be monetized, but do not originate any direct and observable change in the household behavior. Virtual income losses (or gains) VY in each region r are modeled according to:

$$VY_{r,t} = \varphi_r \cdot \left(EK_{t,r} - EK_{t-1,r}\right) \qquad \text{(eq. 5)}$$

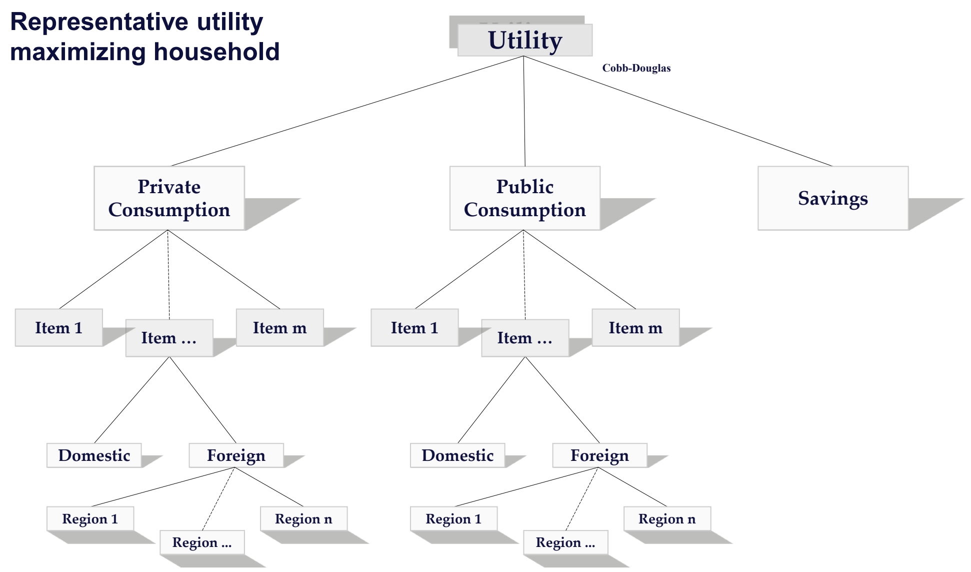
Eq.5 can be easily modified to account for non-linearity in virtual income losses.

Note that this formulation, albeit simple, allows decoupling the market advantages driven by the exploitation of the ecosystem, from the possible non market losses. Think for instance to overfishing. Initially, the fish stock overexploitation does not necessarily translate into lower catches and landings. Therefore, production levels and revenues can be increasing, while passive values can be decreasing. Changes in supply/demand patterns, can then occur when (a) also the ecosystem capital stock declines (e.g. there is “less fish to catch”) implying lower supply, more fishing effort or both or (b) when agents decide to act against ecosystem losses to prevent utility loss. The easiest way to model this is through a tax penalizing those economic activities which generate the externality (fishing activity, deforestation etc.). In this case a negative effect on the economic activity will be recorded, but gains in passive values (and in total income) will be also highlighted.

In addition, environmental protection expenditure can be included into the model. This will add the further possibility to explicitly simulate a public intervention to decreases ecosystem losses, not through a reduction of the harming activities, but via "restoration activities". This can be specified as an exogenous expansion of public expenditure and a contraction in private expenditure items. This will be done adding an exogenous shifting factor to public expenditure and allowing private expenditure to adjust endogenously. This requires re-arranging the equation that in ICES allocates household expenditure preferences across savings, private and public spending reported in (eq. 6), which also represent the first Cobb Douglas "nest" of the ICES consumption tree (Figure 1).

$$ShSum = ShSA + ShPrEX + ShPuEX \quad \text{(eq. 6)}$$

Figure 1: Consumption in the ICES model

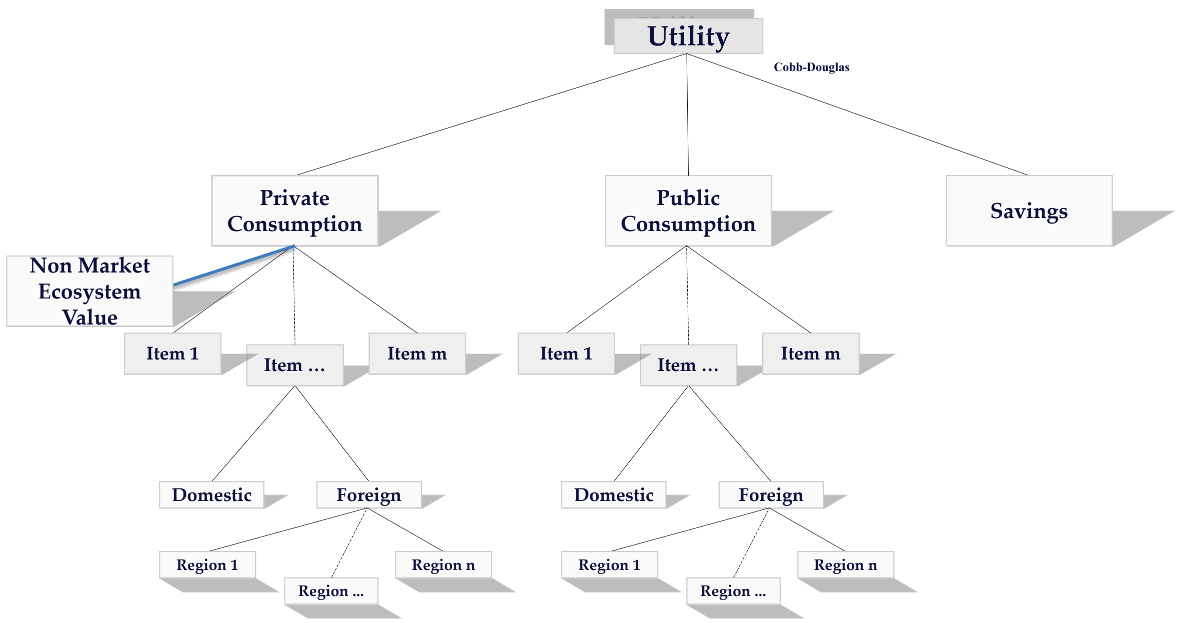


In eq. 8, $ShSA$, $ShPrEX$ and $ShPuEX$ are the shares of expenditure allocated in each region r to savings, private and public consumption respectively. All the three shares are exogenous in ICES, while their sum $ShSum$ (equal to one by construction) is endogenous. Therefore the proposed change amounts to increase exogenously by the desired amount *ShPuEX*, to transform the sum of shares into an exogenous variable itself setting it to 1 and to add an endogenous variable to *ShPrEX* (or transform directly *ShPrEX* into an endogenous variable) that adjusts to fulfill the imposed condition that the sum of shares equals 1.

Environmental taxes and environmental expenditures can then be linked exploring the possibility that the former finance the latter.

In a more sophisticated and interesting approach, passive values will not just contribute to increase virtually national income, but will build a further item in household utility. This amounts to modify the ICES consumption tree in its first node from the representation given in Figure 1 to that on Figure 2.

Figure 2: Consumption with ecosystems in the ICES model



As the Cobb Douglas nest has been changed, the respective shares of the consumption macro categories need to be recomputed to account for the passive value demand, paying attention to preserve the market part perfectly balanced.

The suggested modification allows us to measure, in addition to the virtual income loss, how this could impact the demand of market items. Different degree of substitutability between the market and non-market components will be tested.

5. ECOSYSTEM CAPITAL

Driver of production, consumption changes in the modified ICES model is the change in ecosystem capital stock.

Differentiated ecosystem capital stocks, linked to the different ecosystem categories, will be introduced (due to data availability a good starting point will be the implementation of the role of forest ecosystem).

Then, these ecosystem-specific capital stocks need to start from a given estimated value $EK0$, to evolve, and finally be linked to both market behaviors and passive values (cross effects could be observed in the case of a substitutability/complementarity relation between market and passive values).

The initial market value of (given) ecosystem capital stocks can be retrieved directly from the ICES database which already records the value of primary natural resource purchases by the different firms (fishery, timber, etc.). The initial passive value of ecosystem capital stocks can be estimated with econometric techniques, like e.g. meta-analyses.

Then these stocks will evolve according to exogenous and endogenous dynamics.

For instance, in the case of forest ecosystem capital stock, exogenous dynamic will be related to given scenarios of agricultural land expansion (or deforestation patterns which are both exogenous in the model) net of forest regeneration dynamics. In the model this will originate a positive market effect (more agricultural production and potentially more timber availability), but a loss of passive values with a feedback on tourism and consumption of other market goods. The endogenization of the process has to be related to some indicators of environmental pressure produced by the model. These can be for instance, GHG (Greenhouse Gases) emissions and/or demand of food commodities once these have been linked to land use changes e.g. through the coupling with a land use model.

As anticipated, expenditure in environmental protection is a further component that can influence the dynamics of ecosystem capital stock reducing or halting its losses. Initially environmental expenditure can be an exogenous policy decision.

All these relations are represented compactly by (eq. 7) and (eq. 8) below. There LE, EM and EX stand respectively for: land expansion, GHG emissions and environmental protection expenditure.

$$EK_t = (1+\eta) \cdot EK_{t-1} \qquad \text{(eq. 7)}$$

$$\eta_t = \lambda \cdot LE_t + \varepsilon \cdot EX_t + \gamma \cdot EM_t \quad with\ \lambda, \gamma < 1;\ \varepsilon > 1 \qquad \text{(eq. 8)}$$

Terms in (eq. 8) can easily take non-linear functional forms to introduce convexity in ecosystem losses and concavity (decreasing returns) in environmental protection expenditure.

The introduction of environmental protection expenditure requires a further modification of the model structure: the inclusion of a new sector producing a service that the government can buy together with the "traditional" defense, education and health[2].

[2] In fact the description of the public sector in the majority of CGE models and in ICES is peculiar. Public services are not produced by the government and sold to households. Rather the government which behaves like a standard household demands public services which are produced by representative industries.

6. DATA NEEDS

In terms of data needs, this implies to estimate the following:

- value of total passive value of different types of ecosystems in the calibration year for each region in the model, ($EK0_r$). This step should also allow the estimate of changes in passive values linked to changes in ecosystem capital stocks.
- link between changes in ecosystem capital stock and changes in sector productivity ($a_{1,i}$) and in tourism demand (s_i)
- value of total ecosystem protection expenditure in the calibration year for each region in the model ($EX0_r$). In principle it would be necessary to know also the value of capital and labour needed to produce that environmental protection. But these can be attributed proportionally to the sector share of value added and subtracted from the aggregate “public services”.
- link between ecosystem capital stock and land expansion and/or between ecosystem capital stock and GHG emission (λ and Υ respectively in eq. 8). These are necessary to project the evolution of the ecosystem capital stock.
- Link between ecosystem capital stock and environmental protection expenditure. I.e. effectiveness of environmental protection expenditure (ε in eq. 8). An exogenous component representing the regenerative capacity of ecosystems can be easily included.

7. CONCLUSIONS

This methodological report describes the steps and the modelling developments foreseen to include a more explicit ecosystem dimension inside the recursive-dynamic Intertemporal Computable Equilibrium System (ICES) Computable General Equilibrium (CGE) model. The modelling strategy hinges upon the fact that ecosystems cannot be included in the model directly, but only indirectly, by measuring changes in agents' demand and/or supply induced by changes in the services ecosystems provide to production/consumption activities. Against this background, different paths are suggested to implement changes in ecosystem provisioning, regulating, cultural/recreational services.

Provisioning services, their changes and the related economic implications will be captured through the consolidated "production function approach". It is worth noting that the provisioning role of ecosystem is already incorporated in the model production function as it is implicit in the industrial performances of the different economic sectors and in the value of natural resources they are demanding, both of which are recorded by the model database. Therefore changes in provisioning ecosystem services will entail modification in the supply side of the model i.e. on the factor and/or sector productivity, or on the stock of natural resources.

Changes in non-market, non-use cultural/recreational ecosystem services will be included with a virtual accounting approach. A more sophisticated treatment of passive values will be then explored adding the ecosystem non-market component as an argument of the household utility function with a given substitutability with the market one.

That part of recreational ecosystem services with an use value will be finally modelled through changes in household demand for tourism services.

Policies to limit ecosystem degradation or to restore ecosystem when degraded will be simulated with proper limitations imposed with quota or taxes on the harming activities (e.g. restriction to the fishing activities) and/or creating a new sector in the model producing an environmental protection service whose demand can be increased.

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