

Land transformation analysis and application

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Abstract

This study presents an internal modification of a dynamic computable general equilibrium model, ICES, employing inputs from a partial equilibrium model for agricultural sector, VALUE. The aim is to quantify and analyze the medium-term socio-economic consequences of projected climate change. The methodology is innovative as it combines state-of-the-art knowledge from economic and biophysical sources. Initially, to this end, the VALUE model is applied to two Mediterranean countries: Israel and Italy. The information from VALUE model was incorporated in the economic model ICES to improve the agricultural production structure. The new land allocation method takes into account the variation of substitutability between different types of land use. It captures agronomic features included in the VALUE model. This modification gives a better representation of heterogeneous information of land productivity to the economic framework. Climate impacts and policy evaluation with ICES become reinforced due to the more refined system of land allocation. The originality of this exercise is our ability to base the analysis on empirically estimated parameters, which in other similar studies are mainly assumed or guessed. Notably, we suggest diverse land Constant Elasticity of Transformation (CET) frontiers to two main ecological regions in the Mediterranean basin, for more accurate representation of agronomic characteristics. With the modified ICES model we present an evaluation of climate change impact on agricultural production in the Mediterranean.

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JEL Classification: C68, D58, Q10, Q24, Q51, Q54

1. Introduction

Computable general equilibrium (CGE) “top-down” modelling is widely used for appraisal of the economic effects of climate change and to assess the efficacy of climate policies. CGE enables to evaluate the net impact of climate change as it simultaneously affects various economic sectors as well as terms of trade. Among the specification parameters affecting the quantitative and qualitative results of CGE models, transformation elasticities of land as a production factor for various agricultural uses have a major influence. Excessively high (low) elasticities may result in substantial under- (over-)estimation of the impact of climate change. Critics to CGE argue that such parameters need more solid econometric foundations and that current CGE models fail to capture many important characteristics of the agricultural economy.

In light of this criticism there is an increasing development of top-down models with agriculture-energy-economy capabilities. Adding a capability for terrestrial mitigation and adaptation options to existing energy-economy models presents challenges in both conceptual development and data requirements. Two main modeling alternatives are possible: (i) to develop an integrated assessment model (IAM), i.e., to couple a top-down CGE model with a bottom-up agricultural land-use model; (ii) to improve the relevant functional structure inside the CGE model itself. Constant Elasticity of Transformation (CET) of land is one of the key functions in CGE models which determine how an aggregate endowment of land is transformed across alternative uses, subject to various transformation parameters. CET mirrors the responsiveness of land supply to changes in relative yields and reflects factors that limit land mobility, such as costs of conversion, managerial inertia, and unmeasured benefits from crop rotation. CET is, for instance, the key parameter in CGE models that reflects the ability of a farmer to change land uses in response to profit variations. Each of the two options has relative advantages and drawbacks in terms of data requirements, computational practices and accuracy of representation.

Palatnik and Roson (2009) produced a survey of various approaches taken to describe, model and measure the complex relationships of climate change, agriculture and land use. They conclude that even though coupling top-down with bottom-up models benefits from the strength of partial equilibrium (PE) – which can capture in detail agriculture and land use aspects – in the economy-wide, comprehensive framework of the CGE model, it encounters major difficulties due to data incomparability, computational limitations and the need for sophisticated programming. In addition, establishing the link may demand substantial compromises on the theoretical or empirical quality of the analysis.

By contrast, internal extension of a CGE model, through the introduction of new structural relations and corresponding parameters, seems a more feasible and reliable method. For example, The Global Trade Analysis Project, Energy - Land model (GTAPE-L) (Burniaux 2002; Burniaux and Lee 2003) extends the standard GTAP model to track inter-sectoral land transitions to estimate emissions Greenhouse gas emissions (GHGs). Keeney and Hertel (2005) offer another special-purpose version of the GTAP model for agriculture, called GTAP-AGR. The study modifies both the factor supply and derived demand equations. The authors also amend the specification of consumer demand, assuming separability of food from non-food commodities. Finally, they introduce substitution possibilities amongst feedstuffs used in the livestock industry (see Palatnik and Roson (2009) and Hertel et al. (2009) for a comprehensive review of this topic.) Despite the achievements and individual strengths of existing modeling approaches, core problems of global land-use modeling are yet unresolved. Even though some studies were conducted to develop internal representation of land in the CGE models, there are only a few recent attempts to evaluate land CET. Most of these studies use own return elasticities of land quantity for each use, to calibrate corresponding CET function (see for example Ahmed et al. 2008; Huang et al. 2004). The range of applicability of global land-use modeling is still limited by the way land is represented, as the latter is frequently treated as homogeneous and space-less, with disregard of biophysical characteristics and spatial interactions

This paper presents an effort to improve the characterization of the agricultural sector in a dynamic general equilibrium model, ICES (Inter-temporal Computable Equilibrium System) by creating a loose link to a partial equilibrium agricultural model. We investigate the most appropriate nested structure of land transformation between uses, in order to improve the accuracy of analysis of climate change impacts on agriculture as they affect farmers' land allocation decisions. First, employing a regional scale positive mathematical programming (PMP) model (VALUE, Vegetative Agricultural Land Use Economic model) we examine adaptation of vegetative agriculture to various exogenous shocks through reallocation of land and water sources among crops. Running VALUE for a range of exogenous shocks we create an artificial database of land reallocation and corresponding land profitability. This database is used to estimate the CET function of land. The land supply structure in ICES is modified accordingly. Second, we demonstrate the applicability of the model to climate change impacts on agriculture in the Mediterranean via a modified version of ICES ([ICESValue](#)). We argue that the link between the PE model VALUE and the CGE model ICES allows for a detailed representation of the agricultural sector while keeping the computations and modeling modifications in CGE feasible. The potential of the developed framework is

demonstrated in application to the agricultural sector of two Mediterranean countries, Israel and Italy.

The paper is organized as follows. Section 2 motivates the need to enhance the CET frontier in the ICES model. Section 3 outlines the main characteristics of the VALUE model and the construction of an artificial database of changes in land allocation for agricultural crops. Section 4 describes the new nested CET function and compares its structure to other CET frontiers in the literature. Section 5 validates the modified ICES model and presents an evaluation of climate change impact on Mediterranean agricultural output. Section 6 concludes.

2. Motivation: ICES-The Point of Departure

In order to assess the systemic general equilibrium effects of climate change on agriculture and land use, we employ a dynamic multi-regional CGE model of the world economy called ICES. ICES is a recursive model that generates a sequence of static equilibria under myopic expectations, linked by capital and international debt accumulation. Eboli et al. (2010) present a detailed description of the model. To keep this work self-contained, the details of the model are not presented here with exception of the land supply structure, which is essential for the discussion.

Land supply in ICES follows the standard one level CET assumption incorporated in the GTAP model structure as shown in Figure 1. Land adjusts sluggishly according to relative rents obtained in respective activities. All countries have a common cost structure with constant elasticity of transformation σ_l equal to -1.

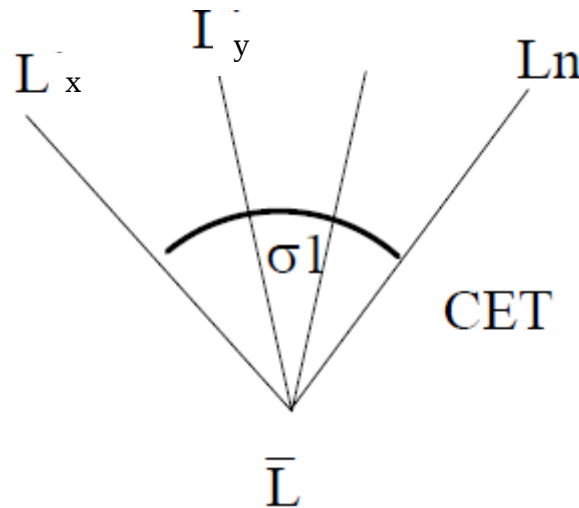


Figure 1: Land Allocation Tree for Standard GTAP

This CET function means that land input is exogenously fixed at the regional level; it is imperfectly substitutable among different crops or land uses. Indeed a transformation function

distributes land among 9 land-using sectors¹ in ICES in response to changes in relative rental rates. This structure is over-simplified for analyses focusing on the agricultural sector, as it assumes land to be equally easily transformable between different crops (e.g., rice, grassland, cotton and vegetables). A model operating under such assumptions overstates the potential for heterogeneous land to move across uses. This study estimates a more accurate CET frontier.

Palatnik and Roson (2009) define a CET for land use transformation as:

$$TL^{\frac{1-\sigma}{\sigma}} = \sum_x \lambda_x L_x^{\frac{1-\sigma}{\sigma}} \quad (1)$$

Where: TL stands for total available land, L for land assigned to crop/industry x , λ_x are share parameters and σ is the (constant) elasticity of transformation.

Maximization of the total value of land, i.e., the sum of products of industry land L_x by price (rent) P_x , subject to (1), gives rise to first-order conditions like:

$$\frac{L_x}{L_y} = \left(\frac{\lambda_y P_y}{\lambda_x P_x} \right)^{\sigma} \quad (2)$$

When there are n industries, parameters λ_x, λ_y can be calibrated by taking as given the elasticity of substitution σ , and solving the $n-1$ conditions (2) and the (1), on the basis of observed crop-specific land L_x , total land TL and prices P_x ².

Hence, in order to evaluate land CET function, information on land profitability in various uses and corresponding land allocation should be available. To overcome the limitations of previous models, we utilize VALUE to assess per-hectare yield's responses to both the quantity and salinity of the water applied and produce an econometric estimation of CET structure.

3. The Vegetative Agricultural Land Use Economic model (VALUE)

VALUE is a regional scale PMP model. It examines adaptation of vegetative agriculture to changes in various exogenous variables through reallocation of land and water sources among crops. Such changes can influence both agricultural revenues and costs. For the costs, VALUE adopts the quadratic function commonly used by PMP modelers to incorporate farmers' land-allocation considerations (e.g., Howitt 1995; Röhm and Dabbert, 2003). But the strength of VALUE mainly stems from the properties of the revenues side. VALUE employs a nonlinear production function,

¹ Annex A presents sectoral and regional disaggregation in ICES for the current study.

² For more details on the CET, please see Shumway and Powell (1984).

which reflects per-hectare yield's responses to both the quantity and salinity of water applications. Following Kan et al. (2002), a sigmoid field-level function describing responses of evapotranspiration (ET) to water's quantity and salinity is estimated based on outputs of a production model (Shani et al., 2007), which simulates equilibrium in plant-soil-water relations. Then, the ET levels are transformed into output units using a linear function, the parameters of which constitute instruments for calibrating the model so as to reproduce observed water applications in a base period. Such meta-analytical approach has been applied in field-level (Letey and Dinar, 1986; Plessner and Feinerman, 1995; Kan, 2008) and regional-scale (Kan, 2003; Schwabe et al., 2006) analyses though without calibration. By integrating decisions on land allocation and per-hectare water applications to crops, VALUE enables a trade off among both the intensive (field level water application) and extensive (regional scale land allocation) margins. Various strategies of mixing waters with different salinities can be analyzed. Moreover, the reliance on outputs of agronomic models enables VALUE to reliably simulate large shocks in exogenous production variables (e.g., in rainfall and water salinity levels), even outside of their range of variation in the base period.

3.1. VALUE model formulation

Consider an area divided into J regions, where each region j , $j = 1, \dots, J$, is characterized by a total agricultural land, X_j , and K types of irrigation water quality, where S_{kj} (in cubic-meter/year) denotes the availability of irrigation water of type k , $k = 1, \dots, K$ in region j . A specific salinity level c_{kj} pertains to each quality type and is measured in electrical conductivity units of deci-Siemens/meter (dS/m). Potentially, I crops may be grown in each region. The term p_i (in \$/ton), $i = 1, \dots, I$, denotes the market price of crop i , and p_{kj} is the region's price of water of quality k (in \$/m³).

The vectors $\mathbf{x}_j$ and $\mathbf{s}_j$ are the set of endogenously determined decision variables in our analysis: x_{ij} (in hectares) denotes the land devoted to crop i in region j ; s_{kij} (in m³/ha/year) is the amount of irrigation water of type k applied to crop i in region j . Farmers may respond to exogenous changes – such as pricing policies or climatic changes – by varying the land allocated to different crops, denoted by the vector $\mathbf{x}_j$, $\mathbf{x}_j \equiv (x_{1j}, \dots, x_{Ij})$, and the application of the water quantities and qualities to the I crops, represented by the vector $\mathbf{s}_j$, $\mathbf{s}_j \equiv ((s_{11j}, \dots, s_{1Ij}), \dots, (s_{K1j}, \dots, s_{KIj}))$.

Let $w_{ij} = s_{ij} + \mu_{ij}r_j$ be the annual amount of water available to crop i in region j , where $s_{ij} = \sum_{k=1}^K s_{kij}$ is the sum of the applied K irrigation waters, and r_j (cubic-meter/hectare-year) is region- j 's annual rainfall. While the infiltration rate of irrigation water is assumed to be 1, the infiltration of rainfall may vary with the type of soil. The parameter μ_{ij} , $0 \leq \mu_{ij} \leq 1$, denotes the infiltration rate of rain falling at region j during crop- i 's growing season. The average salinity of the water available to the crop is $c_{ij} = (s_{ij} + \mu_{ij}r_j)^{-1} \sum_{k=1}^K s_{kij}c_{kj}$ (dS/m), where the salinity of the rain is assumed negligible. Changes in water quantity and salinity affect outputs through the production function $y_{ij}(w_{ij}, c_{ij})$ (ton/ha/year), which may vary among crops due to differences in water productivity and sensitivity to salinity. These functions also vary across regions because of differences in the type of soil and in climate conditions, such as the potential ET. VALUE adopts the composite production function developed by Kan et al. (2002):

$$y_{ij}(w_{ij}, c_{ij}) = \phi_{ij} + \theta_{ij} \cdot e_{ij}(w_{ij}, c_{ij}), \quad (3)$$

where ϕ_{ij} and θ_{ij} are parameters, and $e_{ij}(w_{ij}, c_{ij})$ (cubic-meter/ha/year) is a sigmoid function relating ET to water application and salinity:

$$e_{ij}(w_{ij}, c_{ij}) = \frac{\bar{e}_{ij}}{1 + \alpha_{1ij} [\alpha_{2ij} c_{ij} + \alpha_{3ij} w_{ij}^{\alpha_{4ij}}]^{\alpha_{5ij}}}. \quad (4)$$

Here $\bar{e}_{ij}$ is crop- i 's potential ET at region j , and $\alpha_{1ij} - \alpha_{5ij}$ are estimated parameters. The production function is estimated and calibrated by a four-stage procedure. First, a plant-level agronomic model (Shani, 2007) is used to generate a dataset in which ET values are calculated for various combinations of annual water application and salinity. These plant-level data are translated into field-level amounts by assuming a lognormal spatial distribution of water infiltration (Knapp, 1992). The mean value of this distribution equals 1 for mass balance, and the standard deviation is calculated to fit the Christiansen Uniformity Coefficient (CUC) typical to the irrigation system used for each crop, where CUC=80 and CUC=90 for sprinklers and drip systems, respectively. Secondly, the produced dataset is used for estimating the parameters $\alpha_{1ij} - \alpha_{5ij}$ of the ET function (4) by running a non-linear regression. In the third stage the parameter θ_{ij} is calibrated based on the first-order condition, which requires equality between the irrigation-water's value of marginal production and the water's price:

$$p_{ij} \theta_{ij} \frac{\partial e_{ij}(\hat{w}_{ij}, \hat{c}_{ij})}{\partial s_{kij}} = p_{kj}, \quad (5)$$

where $\hat{w}_{ij}$ and $\hat{c}_{ij}$ are, respectively, the water and salinity observed in the base year. Finally, the base-year yield, $\hat{y}_{ij}$, is used for calibrating ϕ_{ij} by the use of Equation (3).

The objective is to set $\mathbf{x}_j$ and $\mathbf{s}_j$ so as to maximize the regional profit, π_j (\$/year):

$$\pi_j = \sum_{i=1}^I x_{ij} \left[p_i y_{ij}(w_{ij}, c_{ij}) - \sum_{k=1}^K p_{kj} s_{kij} - \left(\gamma_{ij} + \frac{1}{2} \delta_{ij} x_{ij} \right) \right]. \quad (6)$$

subject to the land constraints, $\sum_{i=1}^I x_{ij} \leq X_j$, and the K water constraints $\sum_{i=1}^I x_{ij} s_{kij} \leq S_{kj}$. The term $\gamma_{ij} + \frac{1}{2} \delta_{ij} x_{ij}$ (\$/ha/year) in Equation (6) represents the per-hectare non-water production cost, which is expressed as a linear function of crop- i 's parcel, x_{ij} . This dependency is used to indirectly reflect the impact of a collection of unobserved factors considered by farmers while contemplating their land allocation among crops, including spatial variability of soil quality, marketing and agronomic risks. This formulates the total non-water cost as a quadratic function of x_{ij} , and thereby the PMP model enables the optimal land allocation to be smoothly altered in response to exogenous shocks, like changes in precipitations, price, and salinities. The parameters γ_{ij} and δ_{ij} are calibrated by the two-stage procedure developed by Howitt (1995).

The programming model is built on an Excel worksheet and run by the Premium Solver Platform V8.0 instrument to locate global optimum using the Multistart Search strategy. The solving procedure applies a quasi-Newton method based on quadratic extrapolation, where central differencing is used to estimate partial derivatives.

3.2. Calibration of VALUE in Israel and Italy

The VALUE regional model has been calibrated for Israel and Italy, which are considered as two examples of Mediterranean climatic zones and land management variability.

Just 22,000 km² in size, Israel makes up for its small size with a varied topography and climate. Arid zones comprise 45% of the area of the country. The rest is made up of plains and valleys (25%), mountain ranges (16%), the Jordan Rift Valley (9%) and the coastal strip (5%). Israel lies in a transition zone between the hot and arid southern part of West Asia and the relatively cooler and wet northern Mediterranean region. As a result, there is a wide range of spatial and temporal variation in temperature and rainfall. The climate of much of the northwestern part of the area is typically Mediterranean, with mild rainy winters, hot, dry summers and short transitional seasons. The southern and eastern parts are much drier, with semi-arid to arid climate. Throughout the area, summers are completely dry, requiring irrigation for crop production (INCCC, 2010).

Italy is characterized by great climatic variation as well. The country can be divided into seven main climatic zones. Because of the considerable length of the peninsula, there is a variation between the climate of the north, influenced by the European continent, and that of the south, surrounded by the Mediterranean. The Alps act as a partial barrier against westerly and northerly winds, while both the Apennines and the great plain of northern Italy produce special climatic variations. Sardinia is subject to Atlantic winds and Sicily to African winds. In general, four meteorological situations dominate the Italian climate: the Mediterranean winter cyclone, with a corresponding summer anticyclone; the Alpine summer cyclone, with a consequent winter anticyclone.

To calibrate the model for Israel, we utilize regional-scale aggregated data on land allocation among 45 crops as obtained from the Israeli Central Bureau of Statistics (ICBS, 2004), based on a common allocation of the country into 21 ecological regions³. Table B1 in Annex B presents the classification of the 45 crops based on the agricultural categories of ICES.

The model is calibrated for each ecological region separately. Given that current regulations in Israel prohibit blending of fresh and treated wastewater, it was assumed that only one type of water source is used for irrigating each crop. With the lack of detailed information on water usage by each crop, a hierarchical procedure was developed for allocating the water sources to the various crops. Treated wastewater is first distributed according to the specifications of wastewater use regulations (Halperin, 1999), then brackish water is allocated to the most saline tolerant crops using the tolerance classification of Maas and Hofmann (1977), and finally the remaining crops are assumed irrigated by freshwater. The base-year per-hectare water applications were calculated for each crop based on doses mentioned in sample cost analyses (Ministry of Agriculture and Rural Development, 2000, 2003), which were factorized such that the computed regional consumptions of each water source match the observed consumption in 2002.

For the case of Italy, a simplified version of VALUE was implemented, which does not explicitly account for variability in irrigation water quantity and quality in the production function. Unlike the case of Israel, irrigation with brackish and desalinated water is marginal in the Italian context. Although wastewater reuse in agriculture is regulated at national level by the Ministry of Environment with Decree 185/2003 and by separate regulation in several regions, the total volume of treated wastewater reuse in Italy in 2005 including industrial, urban non-potable and agricultural applications accounted for less than 1.5% of the total agricultural yearly water use (Angelakis and Durham, 2008). Moreover, the lack of information on irrigation quantities suggests that freshwater

³ Partitioning of Israel into ecological (agricultural) regions is produced by the Ministry of Agriculture.

availability is not the limiting factor in most contexts. The model is applied to the 21 administrative regions of Italy (i.e., at NUTS-2 level according to the EU classification of the economic territory) to reproduce the land allocation among 34 crop types in baseline year 2004. Table B2 in Annex B presents the classification of the 34 crops based on the agricultural categories of ICES.

Information on the total surface and, where applicable, the actually producing surface for each crop type and Italian region was obtained from the database of agriculture and zootechny maintained by the Italian Institute of Statistics (ISTAT; <http://agri.istat.it/>). The profit associated with growing the i crops in region j was determined based on the Standard Gross Margin (SGM) values calculated by the National Institute of Agricultural Economics (<http://www1.inea.it/rica/index.html>). SGM is used to determine the income of agricultural holdings net of the costs for seeds, purchased fertilizers, pesticides, irrigation water, heating, drying, commercialization, processing, insurance, and other specific costs while accounting for compensatory payment, subsidies and by-products value. To avoid bias caused by fluctuations, e.g., in production due to bad weather, or in input/output prices, the average SGM values for the period 2003-5 were assumed.

3.3. *Data generation*

Although VALUE can be used independently from a CGE model to provide PE high resolution assessments of climate change on agriculture, we report here about the use of VALUE to produce estimates of elasticities of transformation, as inputs to ICES.

The elasticities of transformation are estimated based on a dataset produced by VALUE. This dataset is obtained running VALUE while introducing shocks in the current conditions, and evaluating the reallocation of the overall regional land – and water, in the case of Israel – for each of the crop categories in ICES. The resulting per-hectare profit for each crop is calculated and used as a proxy for the land rent in ICES for each use. Here, we report the model output when the variable that is subject to a shock is the output crop price. In the scenario analysis, the price output of each of the 8 ICES crop categories and in each of the regions independently was shocked with a variation between -90% and +90%, in 10% intervals. The consequent reallocation of land use among crops was estimated with the parameters of the calibrated model and by assuming optimal reallocation (i.e., profit maximization). The change in the per-hectare profitability of land following the price variation was also estimated.

Figure 2 shows as an example the predicted changes in land allocation, total water use, and crop yields for the ICES categories as resulting from a change in the output price of vegetables and fruits in the South regions of Israel. As expected, when cultivation of vegetables and fruits becomes

more profitable due to increases in output price, more land would be allocated to it. For a 90% price increase, a 268% larger land allocation is predicted. Since the total available land is an exogenous constraint, however, to an increase in the area cultivated with vegetables and fruits must correspond a reduction in the area cultivated with other crops. The crop categories that would be most affected by such change are cereals and cotton, whose surface would reduce respectively to 11% and 14% of its current value. The fluctuation in the total water allocated to each group is a result of the substitution between the various water sources (not shown).

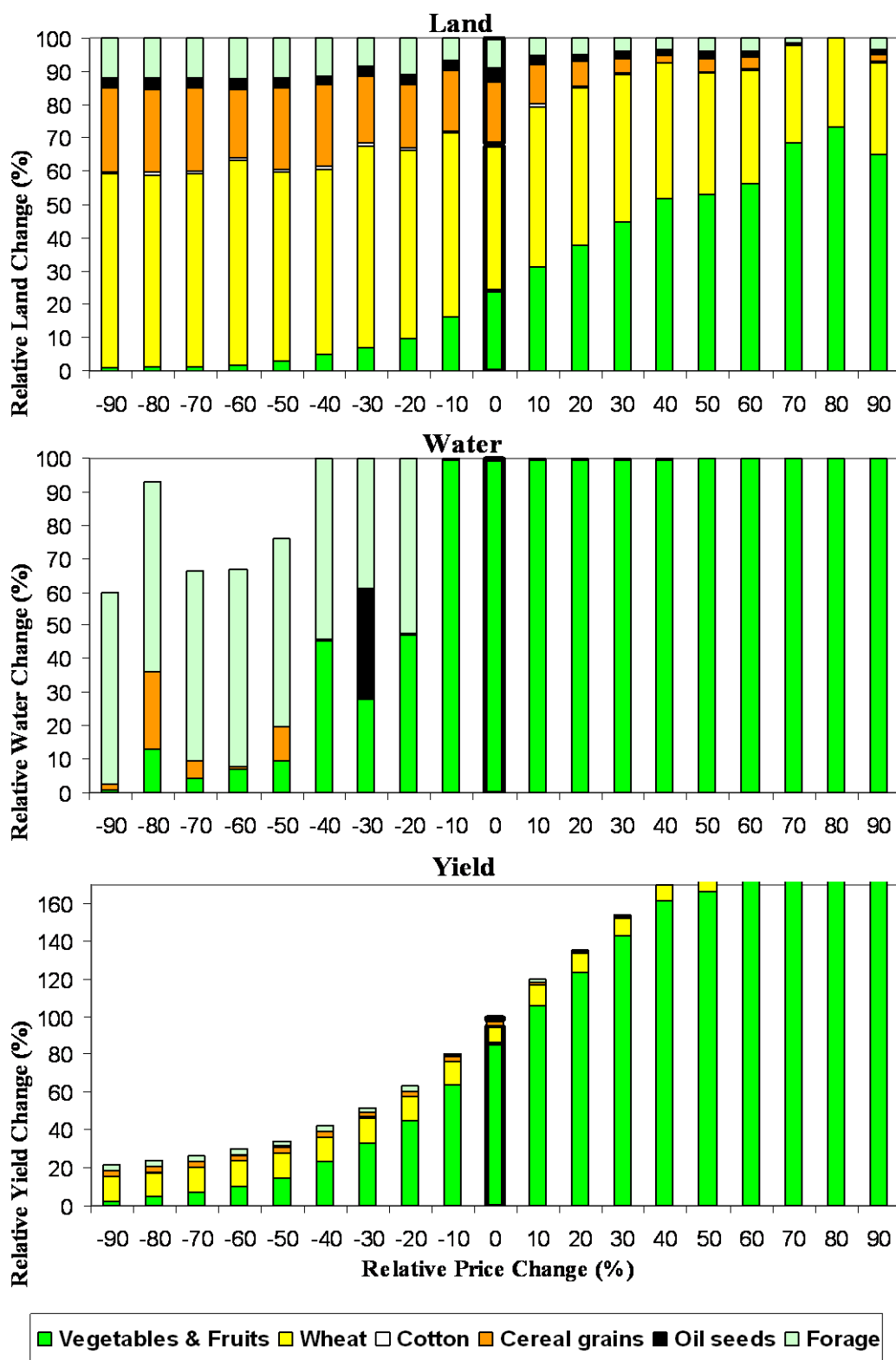


Figure 2. Forecast changes in land allocation, water use and yield from changes in the output price of vegetables & fruits

As an example of changes in the profitability of crop cultivation, Figure 3 shows the predicted changes in the Veneto region of Italy as derived from a 50% shock in the output price of the crops that are cultivated in the region.

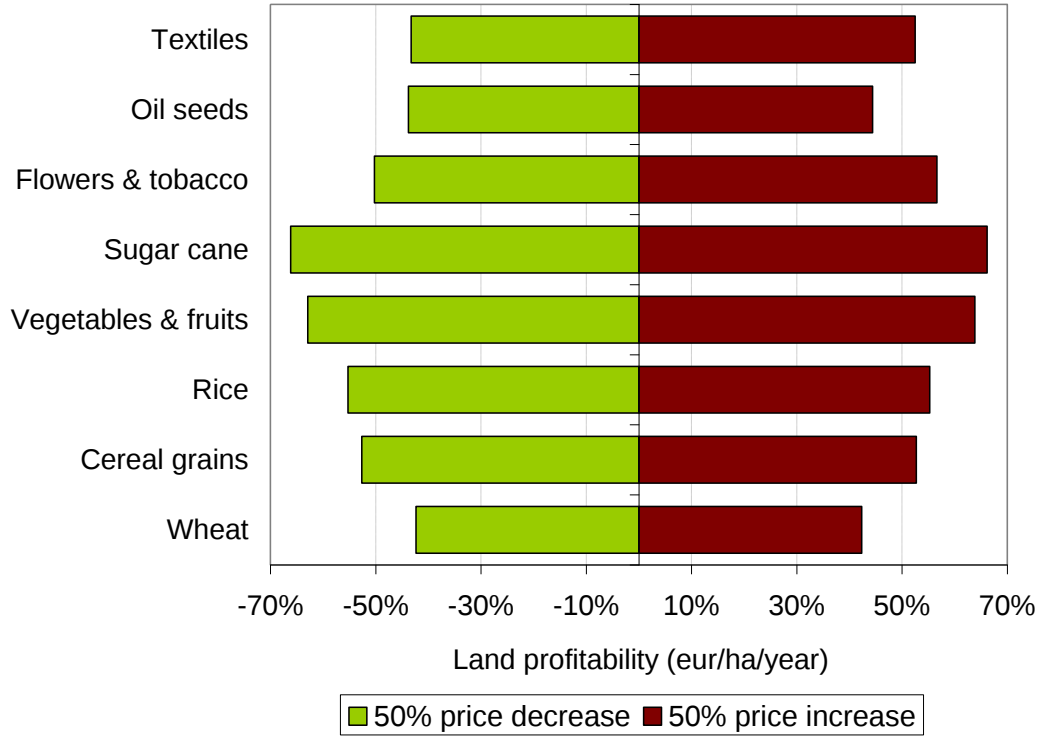


Figure 3. Forecast changes in the profitability of various crops in the Veneto region of Italy following a 50% shock in output price

Due to the different production costs among crops, the change in price affects the profitability of the crops in different ways. The most affected by a change in price is sugar cane, vegetables and fruits for which a 50% increase (decrease) in the price results in a profitability increase (decrease) of more than 60%. The least affected crop is wheat.

4. Estimation of land transformation elasticities

This section outlines VALUE-based estimation of land transformation elasticities, for further incorporation in ICES. In other words, this section aims to evaluate σ in equation (2).

Equation (2) shows that when an elasticity of transformation equals unity, the transformation function involved reduces to a Cobb-Douglas function with the share parameters λ_i as reallocation elasticities. If CET is constant for all uses, then the nested function is one-level where land is equally easy to transform from one use to another. Alternatively, if two land uses are not in the

same nest, then the elasticity of land transformation between them is determined by the two CET elasticities and the cost-share of the composite. In general, different values for the transformation elasticities imply nested CET structure.

Taking logarithm of equation (2) we derive Equation (7):

$$\ln\left(\frac{L_x}{L_y}\right) = \sigma \ln\left(\frac{\lambda_y}{\lambda_x}\right) + \sigma \ln\left(\frac{P_y}{P_x}\right) \quad (7)$$

We econometrically estimate parameters in Equation (7) employing VALUE-based dataset from the following model:

$$\ln\left(\frac{L_x}{L_y}\right)_i = \beta + \sigma \ln\left(\frac{P_y}{P_x}\right)_i + u_i \quad (8)$$

$$\text{Where } \beta = \sigma \ln\left(\frac{\lambda_y}{\lambda_x}\right).$$

We start with the estimation of the parameters at the top of the nesting form. Using the estimation results in the upper stages, we calculate the unit price of composite land types to estimate the parameters of the lower nests.

The exhaustive regional allocation of the dataset for both Israel and Italy allows examining the differences in CET frontier for northern and southern regions, so as to better reflect land management in North and South Mediterranean countries. Significant differences in land CET tree are indeed found for South and North regions, but no significant disparity between the general CET structure for Italy and Israel. Supporting the analysis by datasets from two distinct countries offers an opportunity to overcome the limitations of each of the individual databases on the one hand, and guaranteeing higher validity of the results on the other. The limitation of the dataset for Israel is the absence of two agricultural sectors, rice and sugar cane, that appear in GTAP database. These crops are not cultivated in Israel. However we bridge this gap by estimations from Italian data. The land transformation structure for agricultural sectors that are common to both countries appears to be highly related. Figure 4a and Figure 4b present the resulting land allocation tree for South and North Mediterranean, respectively.

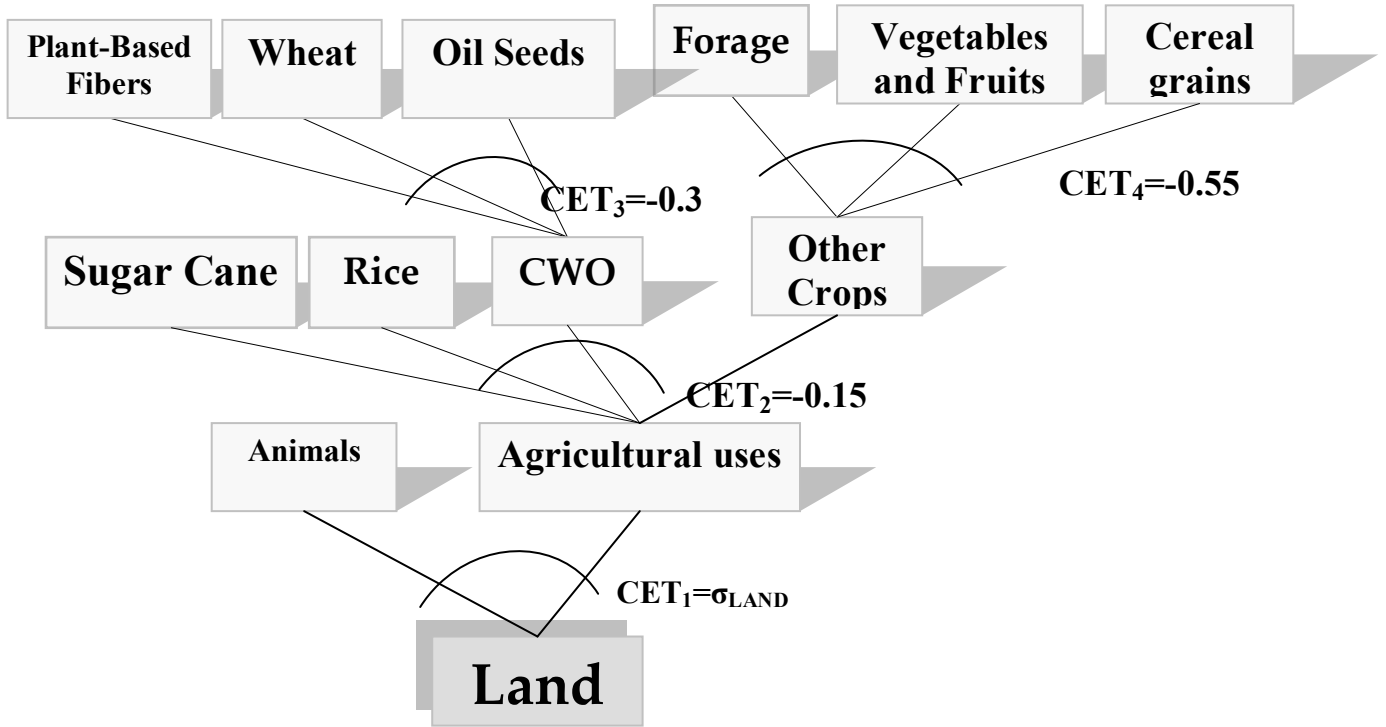


Figure 4a: CET frontier for South Mediterranean

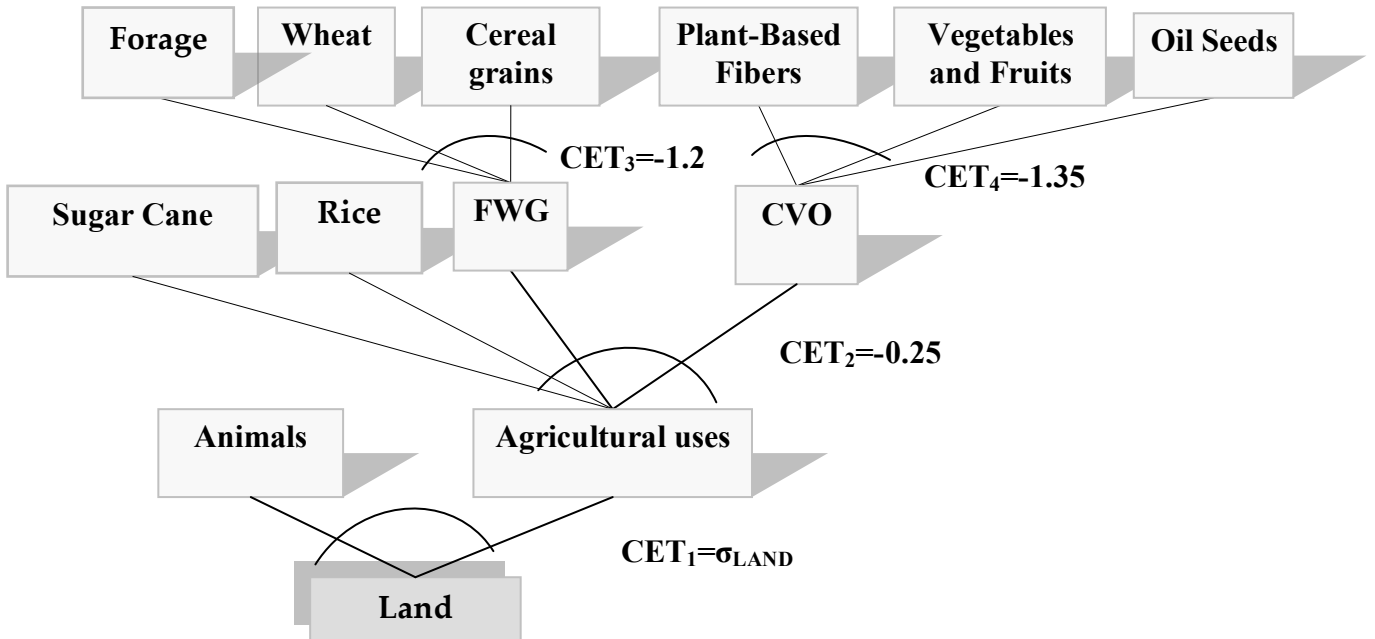


Figure 4b: CET frontier for North Mediterranean

The results refer to a three level CET function, where the degree of transformation of land varies between the nests. The lowest level is similar for North and South Mediterranean. As VALUE operates solely on vegetative agricultural land uses, we preserve the land transformation between ruminant livestock and other agricultural uses at the lowest nest. Therefore, land owners first decide whether the land will be allocated to ruminant livestock production or vegetative

agriculture so as to maximize the total returns from land. The transformation is governed by CET_1 that accepts standard GTAP value for land elasticity of transformation.

At the second level of the nested structure, the landowner decides on the allocation between types of activities based on composite return to land in rice, sugar cane, and FWG (forages, wheat and cereal grains) relative to CVO (vegetables & fruits, oil seeds and plant-based fibres). Here the elasticity of transformation is CET_2 , which is estimated to be equal -0.25 for North Mediterranean and -0.15 for South Mediterranean countries.

The third level of the nested CET appears to reflect most of the divergence between southern and northern regions. In the North, the transformation of land between wheat, forages and cereal grains, is modelled with an elasticity CET_3 equal to -1.2. A change in the price of wheat will bring an adjustment of land for wheat within not only its nest, but between nests as well. The transformation of land between vegetables & fruits, oil seeds and plant-based fibres, is modelled with elasticity CET_4 equal to -1.35. The hypothesis that CET_3 and CET_4 are statistically equivalent and the crops can be grouped in one nest, is rejected.

In the South, not only the values of upper CET nests differ, but also types of crops that form each of the nests. The transformation of land between wheat, plant-based fibres and oil seeds, is modelled with an elasticity CET_3 equal to -0.3. The transformation of land between vegetables & fruits, forages and cereal grains, is modelled with elasticity CET_4 equal to -0.55. Here too, the hypothesis that CET_3 and CET_4 are statistically equivalent and the crops can be grouped in one nest is rejected. Predictably, elasticity values for South are lower than for North reflecting grater rigidity of land transformation due to stricter water constraints and land structure.

In general, at each stage of the decision making process, the CET parameter increases, reflecting the greater sensitivity to relative returns amongst crops. This means that it is relatively easier to change the allocation of land within upper nests, while it is more difficult to move land out of the group into a lower nest, such as into sugar cane and rice. Similarly to Huang et al. (2004), we note that sugar cane production competes with a limited number of crops.

Our CET structure is comparable with estimates obtained in previous studies. An econometric analysis from Choi (2004) suggests transformation elasticities at each level, for the US, being equal to -0.25 for CET nest of agriculture and forest lands, -0.5 for CET nest between crops and livestock, and -1.0 for CET nest of crops. Lubowski et al. (2005) indicate a value of -0.11 for the lower level of the nest whereas Ahmed et al. (2008) suggest a value of -0.22. Keeney and Hertel (2009) propose a model incorporating land, yield, and trade responses to the biofuel expansion. Aggregate land supply in their study is fixed but land can move across uses according to relative returns. Land supply follows a CET structure as described in Figure 5a.

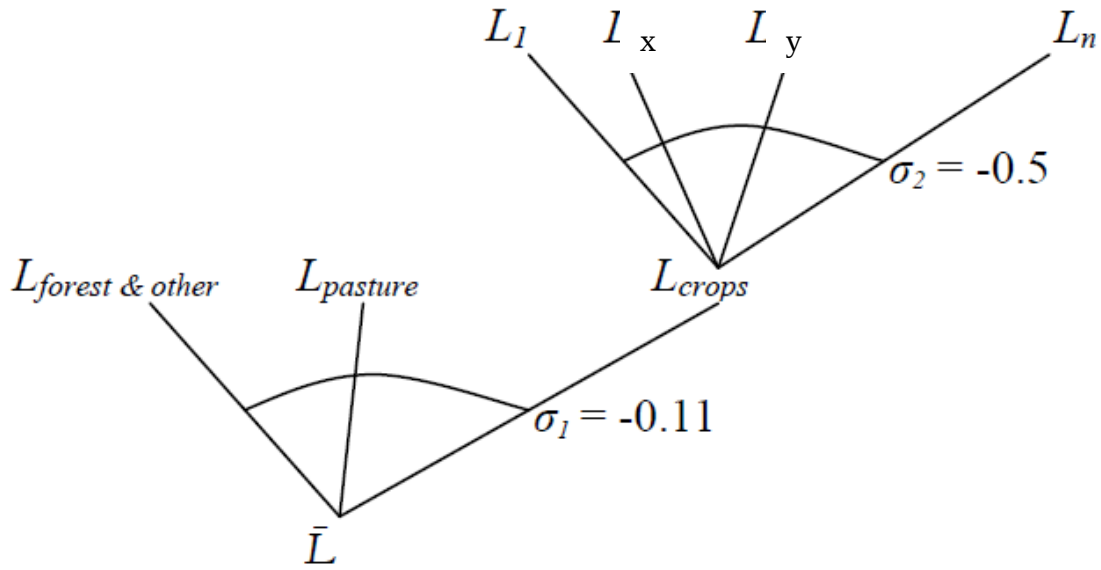


Figure 5a: Land allocation in Keeney and Hertel (2009).

Birur et al. (2008) use the GTAP database developed by Lee et al. (2005) and (2008) to analyze the impact of biofuel production on global agricultural markets. Composite land supply is made of land in the 18 agro-ecological zones (AEZs), which are treated as highly substitutable (with an elasticity of substitution of 20). Within any AEZ, land shifts between forest, pasture, and crops with some CET value of -0.11. Within crops, land shifts moving with a CET elasticity of -0.5. Landowners maximize returns on land by choosing an optimum allocation across uses according to relative returns. Figure 5b describes the nested CET tree structure of land supply. This approach essentially parallels Keeney and Hertel within each AEZ.

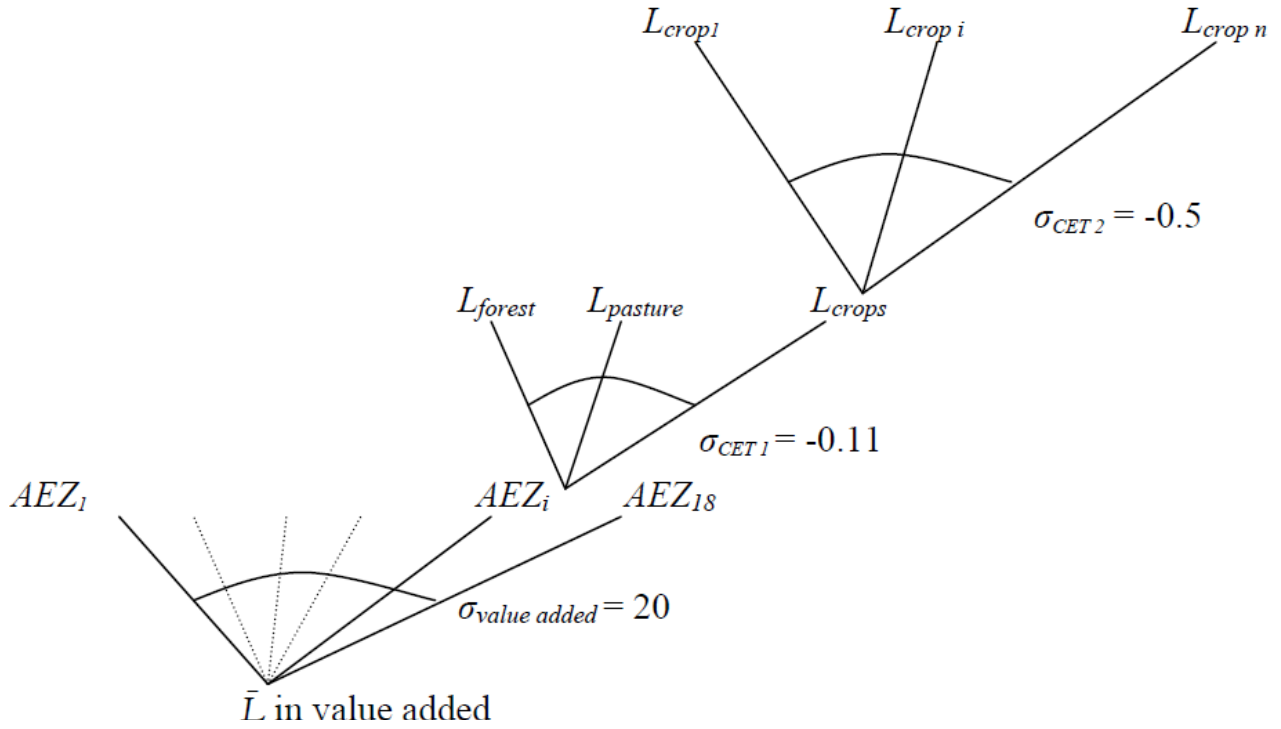


Figure 5b: Land allocation in Birur et al. (2008)

The land allocation structure offered in the present paper acquires analogous structure of CET nested frontier with comparable range of values. The uniqueness of our approach is in decomposing land transformation within agricultural crops, based on actual behavior of landowners as reflected in VALUE model. In addition we define a variation in CET frontier to reflect better land transformation constraints in South versus North regions. Thus, our results resemble the GTAPEM structure suggested in Huang et al. (2004) (see Figure 5c) and Banse et al. (2008a). Their nested structure allows for different CET elasticities for subsets of agricultural activities and crops. For each country⁴, a specific CET tree is designed to capture various and distinct subsets of crops competing for the same agricultural land with a higher elasticity of transformation within nests and lower ones between crop nests.

⁴ Huang et al. (2004) calibrated elasticities of transformation for 8 world regions: Australia/New Zealand, Canada, EU15, Japan, Mexico, Turkey, USA, and rest of OECD.

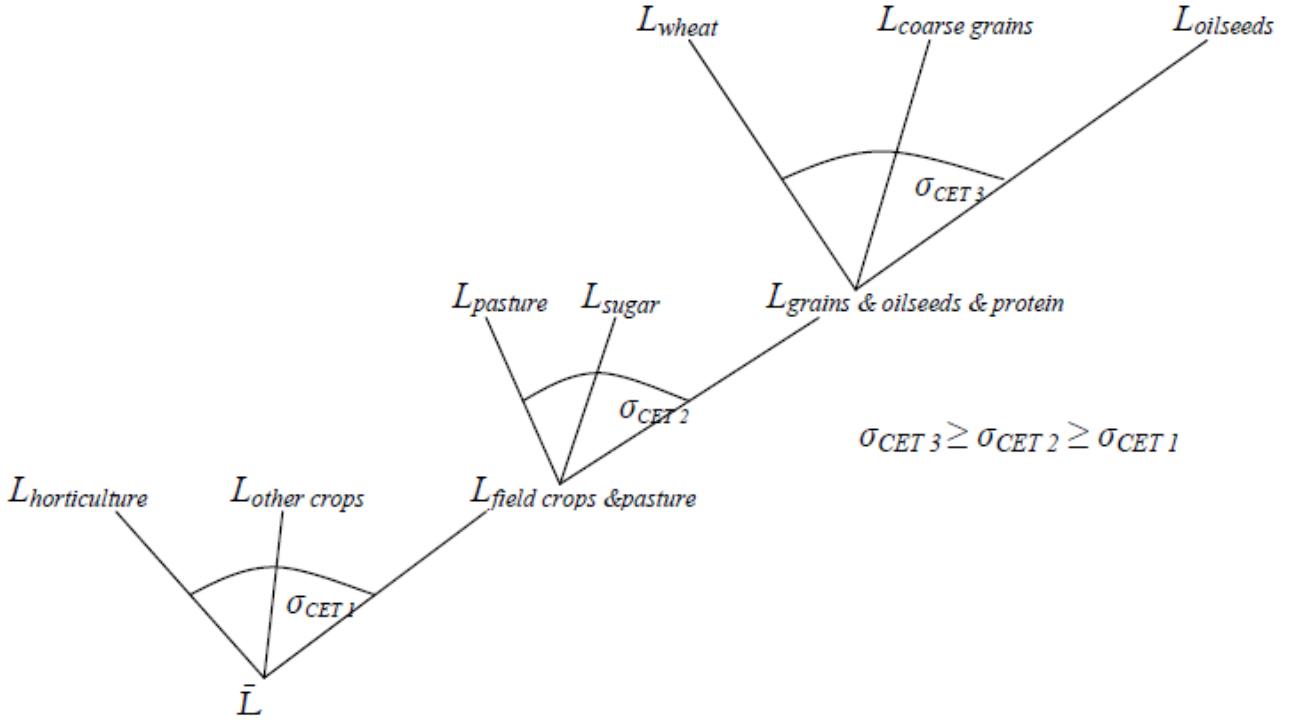


Figure 5c: Land allocation in Huang et al. (2004)

The parameters in GTAPEM have been calibrated to land supply elasticities used in the PEM model (Atwood and Helmers, 1998). The main drawbacks of this approach are that land supply elasticities in PEM are generally based on consultants report, the overall nested structure is often guess-work, and the resulting CET average values are roughly around -0.05, which implies a highly rigid land reallocation. As our modeling attempt aims to serve long term analyses of climate change impact, these low CET values can hardly reflect long term transformation possibilities.

5. Application and Results

In this section we apply newly estimated CET frontier, validate the resulted model, and evaluate the economic impact of climate-change induced shocks on agriculture in Mediterranean.

5.1. From ICES to ICESValue

We incorporate VALUE-based CET frontier as presented by Figure 4 above in ICES model. The modified model, ICESValue, introduces a nested structure to better reflect the transformation possibilities across uses. To advocate the importance of our modification we compare the baseline projection produced by ICES and ICESValue. Employing each model, we generate a baseline growth path for the world economy, in which climate change impacts are ignored, following economic growth of A1B IPCC scenario (Nakicenovic and Swart, 2000)⁵. We run both models at

⁵ This scenario was agreed to be the benchmark within the FP6 CIRCE project.

yearly time steps from 2001 (GTAP6 base-year) 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.

Even though no significant change was found in regional GDP growth path, in some countries the change in agricultural output was up to 160%. Figure 6 exemplifies changes in agricultural production when the baseline projection of ICES is compared to the baseline projection of ICESValue. In ICES, the rice production is projected to grow up to 115% more in Spain and up to 170% more in Tunisia compared to the projection generated by ICESValue.

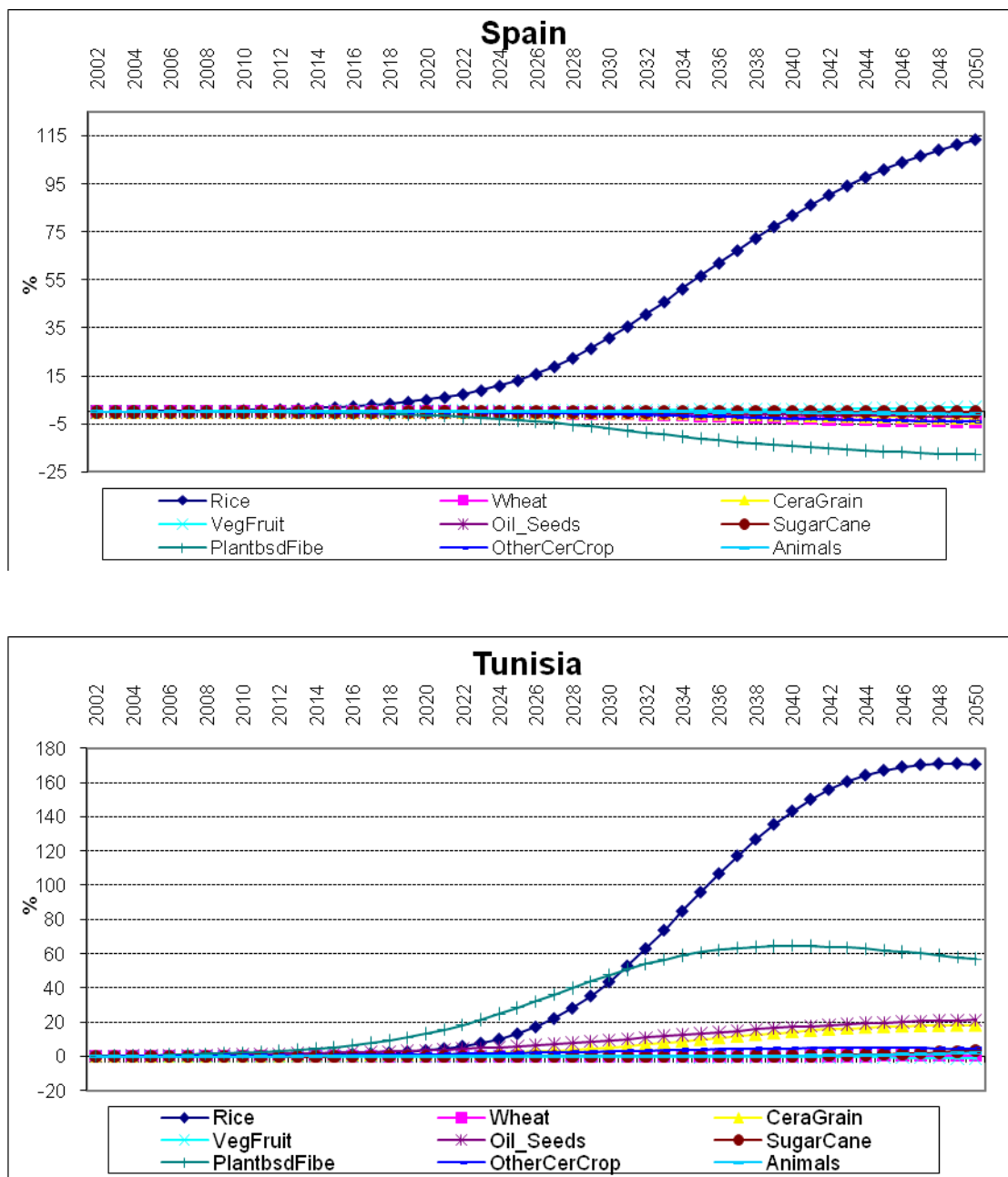


Figure 6: Change in agricultural production growth path in ICES vs ICESValue

Slower growth of agricultural production generated by ICESValue is evident in most of Mediterranean countries. It is explained by a higher rigidity of the land transformation frontier of ICESValue relative to the standard CET function used by ICES. The nested land allocation structure makes relative land allocation changes for crops in different nests less sensitive to price changes.

5.2. *Estimation of climate change impact on Mediterranean agriculture and economy*

The economics of greenhouse effect is usually and primarily considered in terms of the impact of climate change on agriculture, since food production is highly sensitive to changes in the prevailing climate conditions (temperature and rainfall patterns). This is particularly true in the Mediterranean region, whose economy strongly depends on agricultural production. The evaluation of climate change impacts on agricultural sectors is therefore crucial to formulate effective adaptation strategies and models of climate change impacts must rely on a well-defined structure of land-owners behavior.

Climate change impact on agriculture is modeled in ICESValue via shocks to land productivity. To evaluate climate induced variation in land productivity, climate conditions under the IPCC's A1B scenario, as modeled by Krichak et al. (2010), were used for simulating agricultural activities in VALUE model during three periods: 2001-2020, 2021-2040 and 2041-2060. Average rainfall is expected to change by +5%, -3.5% and -20%, in these 3 periods, respectively. Table 1 presents VALUE-estimated changes in land productivity due to climate change effect on precipitations. Changes in precipitations lead to changes in direct rainfall contribution to winter crops, and indirect effect on the water quotas allotted to farmers.

Table 1: Percentage variation in land productivity due to climate change

North Med.	Vegetables & fruits	Wheat	Plant based fibers	Cereal grains	Oil seeds	Forage
2001-2020	1%	4%	7%	4%	2%	5%
2021-2040	-3%	-11%	-18%	-11%	-8%	-12%
2041-2060	-7%	-20%	-30%	-21%	-18%	-21%

South Med.	Vegetables & fruits	Wheat	Plant based fibers	Cereal grains	Oil seeds	Forage
2001-2020	0%	3%	0%	7%	0%	6%
2021-2040	0%	1%	0%	4%	0%	3%
2041-2060	0%	-3%	0%	-7%	0%	-6%

Next, ICESValue is employed to produce a counterfactual scenario, in which climate change impacts are simulated as an exogenous shock on land productivity. This scenario differs from the baseline projection, not only because of the climate shocks, but also because exogenous and

endogenous dynamics interact, and climate change ultimately affects capital and foreign debt accumulation.

Figure 7 presents differences in GDP in the period 2001-2050, obtained by simulating a progressive change in land productivity, as reported in Table 1 above. Land productivity is generally reduced in North Mediterranean countries and, starting in year 2041, in South Mediterranean. This hits more severely agriculture-based, poor economies such as Albania; Bosnia, Serbia (FYug); and Turkey. Mediterranean as a region is almost not affected and the world economy even gets a slight benefit.

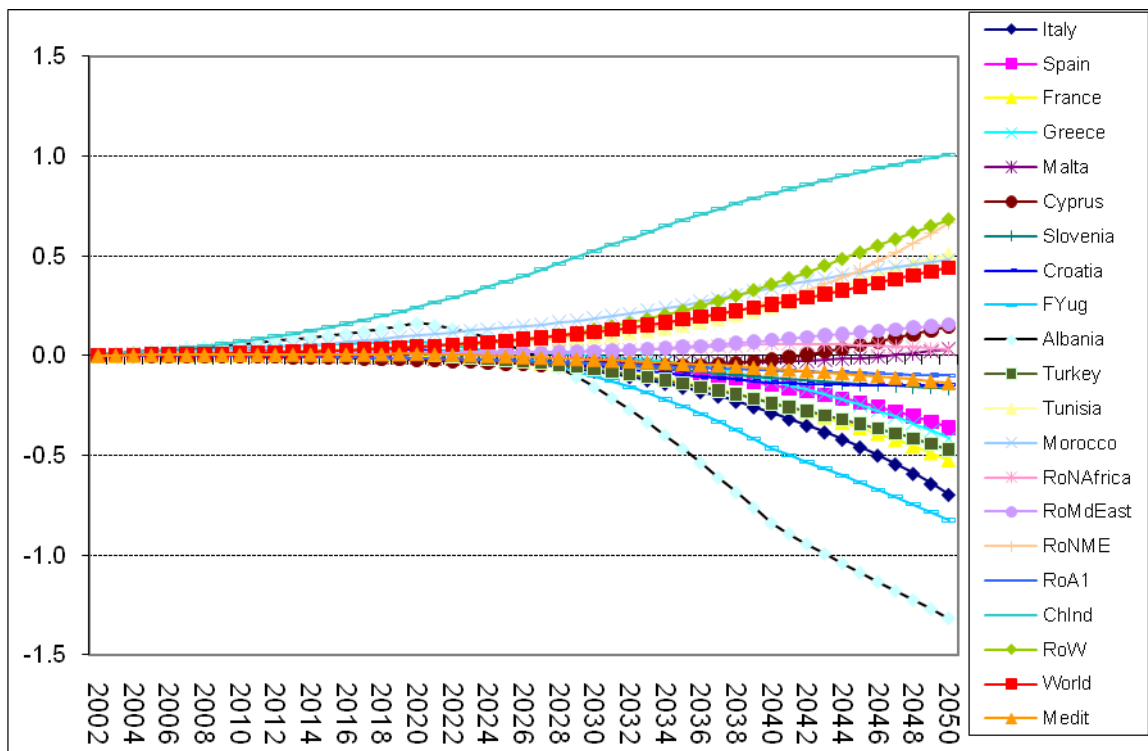


Figure 7: Percent Change in Regional Real GDP Due to Climate Change Impact on Land Productivity

Using a dynamic model allows to investigate the increasing influence of climate change not only on the global economic growth in general but also on sectoral (agricultural) production specifically. Such influence is twofold: on one hand, the magnitude of physical and economic impacts will rise over time; on the other hand, endogenous growth dynamics is affected by changes in income levels, savings, actual and expected returns on capital.

The impact of a changing climate on the sectoral output in France and Tunisia are shown in Figures 8 and 9 respectively. France is chosen to represent North Mediterranean countries where climate change first stimulates land productivity and then sharply reduces it. The output of crops in most North Mediterranean countries (as mirrored by Figure 8 for France) is highly affected in the

similar fashion. For example, the production of plant based fibers rises until year 2020 by more than 5% following the impact of climate change and then falls by about 18% by 2050. Outputs of other crops are almost unaffected by climate change until year 2020 and decline afterwards.

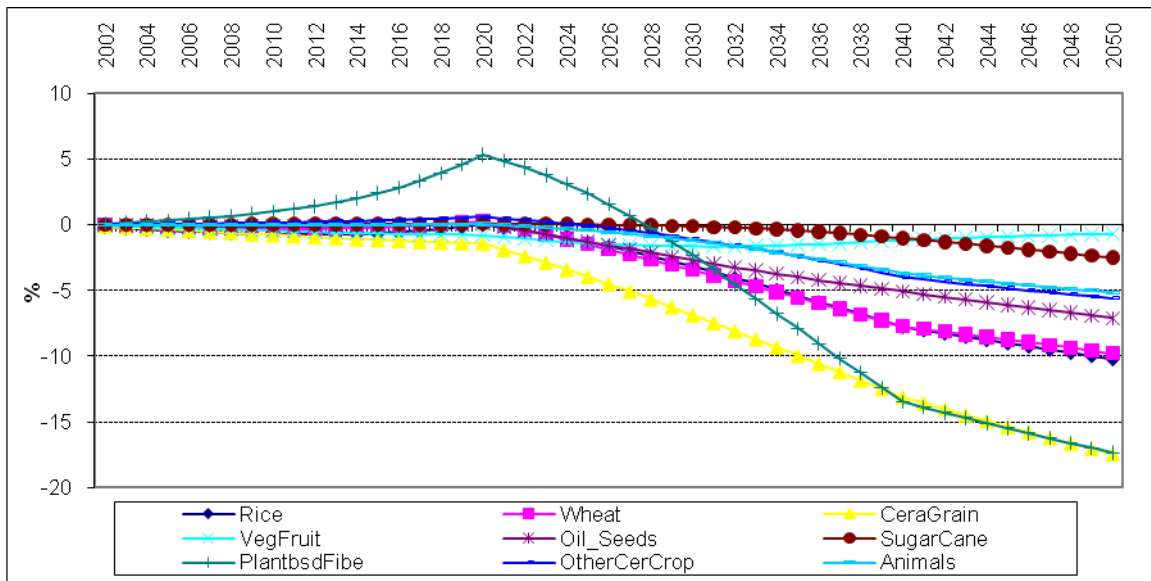


Figure 8: Climate Change Impact on Agricultural Output in France

In Tunisia and other South Mediterranean countries, the impact of climate change on most agricultural products is almost negligible until year 2050, except for cereal grains whose production declines by more than 6%.

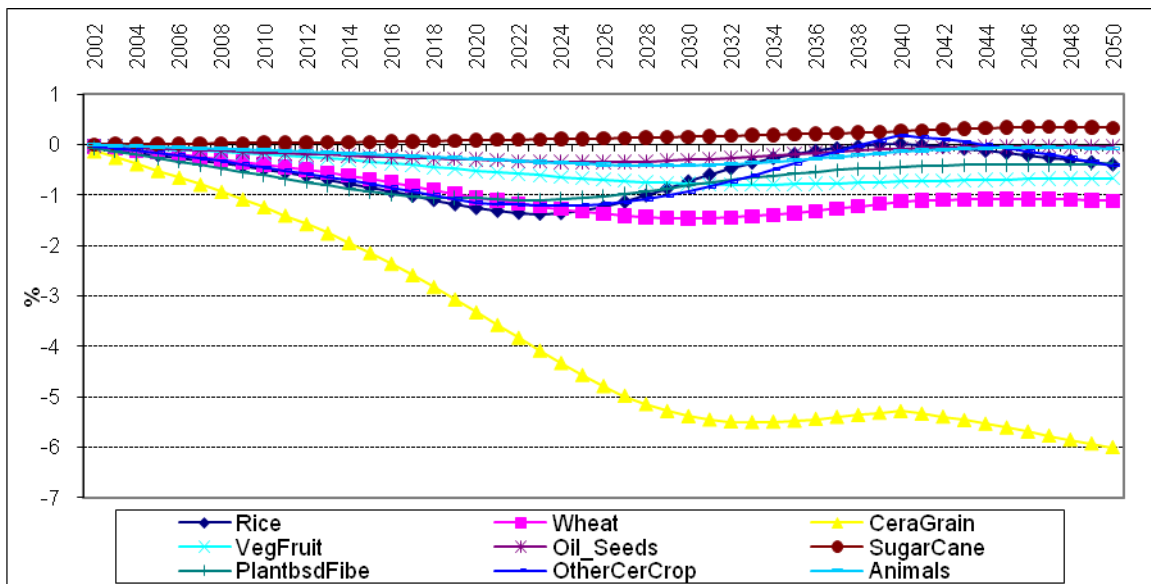


Figure 9: Climate Change Impact on Agricultural Output in Tunisia

In most of the regions and land using industries, yield losses are not compensated by area gains and rise of prices. Land allocation and output move in parallel paths.

At the world level, climate change until year 2050 mostly hits world output of cereal grain (Figure 10). The relatively high yield loss is followed by general reduction in land allocation for this crop reducing total output. Other crop products are either unaffected or even increase.

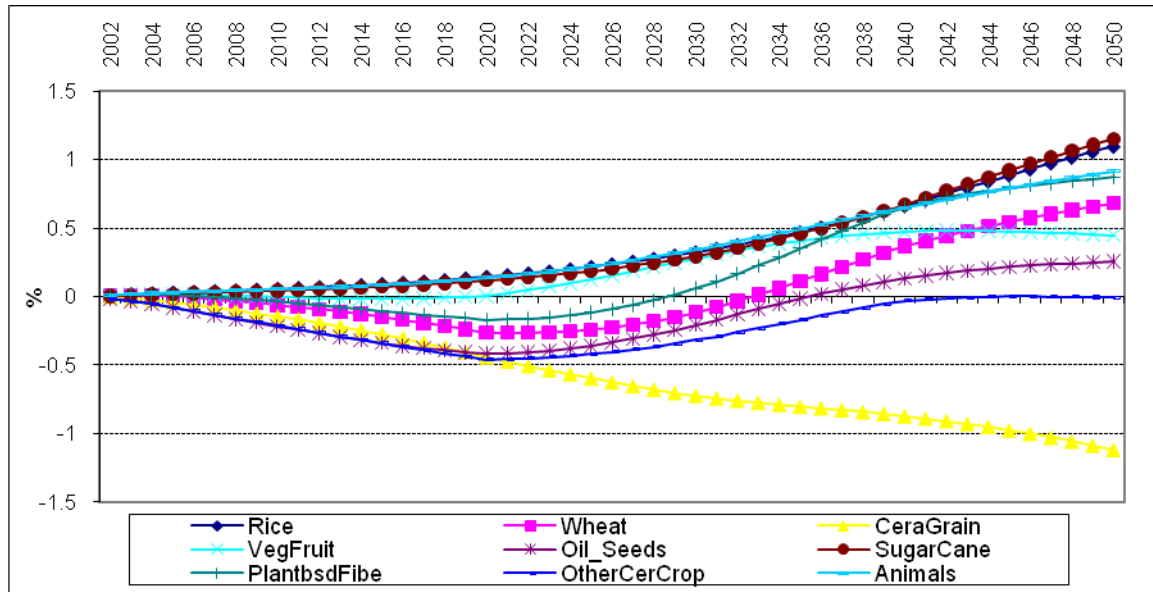


Figure 10: Climate Change Impact on World Agricultural Output

6. Conclusions

This study presents an internal modification of a CGE model employing inputs from a partial equilibrium model for the agricultural sector, with the aim of making the model more suitable to quantify and analyze the long-term socio-economic and environmental consequences of different climate scenarios on agriculture. The methodology is innovative as it combines state-of-the-art knowledge from economic and biophysical sources. Initially, to this end, the VALUE model is applied to two Mediterranean countries: Israel and Italy. The information from the VALUE model was incorporated in the economic model ICES to improve the agricultural production structure. The new land allocation method that was introduced takes into account the variation of substitutability between different types of land and water uses. It captures agronomic features included in the VALUE model. This modification gives a better representation of heterogeneous information of land productivity to the economic framework. Climate impacts and policy evaluation with ICESValue become reinforced due to the more refined system of land allocation. Our results reflect the significance of structural features specific to agriculture for consistent analyses of climate change impacts on land use, future crop patterns and economic development.

The main contribution of this paper is in highlighting the need for more detailed land market in modelling crop supply response. The modifications introduced in the model address frequently voiced criticisms that CGE models have a limited ability to capture crop specific supply response in

agriculture. The originality of this exercise lies in the use of empirically estimated parameters, which in other similar studies are generally assumed or guessed. Notably, we suggest diverse land CET frontiers to two main ecological regions in the Mediterranean basin, for more accurate representation of agronomic characteristics.

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Annex A

Table A1: ICES Sectoral and Regional Disaggregation

<i>Sectors</i>	
<i>Land using Industries</i>	<i>Additional Industries</i>
Rice	Forestry
Wheat	Fishing
Cereal Crops	Coal
Vegetable Fruits	Oil
Oil Seeds	Gas
Sugar Cane	Oil Products
Plant-Based Fibers	Electricity
Other Crops	Other industries
Animals	Market Services
	Non-Market Services
<i>Regions</i>	
<i>Code</i>	<i>Description</i>
Italy	Italy
Spain	Spain
France	France
Greece	Greece
Malta	Malta
Cyprus	Cyprus
Slovenia	Slovenia
Croatia	Croatia
FYug	Bosnia, Monaco, Serbia*
Albania	Albania
Turkey	Turkey
Tunisia	Tunisia
Morocco	Morocco
RoNAfrica	Rest of North Africa [Algeria, Egypt, Libya]*
RoMdEast	Rest of Middle East [Israel, Lebanon, Palestinian Authority, Syria]*
RoNME	non-Mediterranean Europe
RoA1	Other Annex 1 countries
ChInd	China & India
ROW	Rest of the World

Annex B

Table B1. Allocation of 45 groups of crops incorporated by VALUE for Israel into 8 land-using industries in ICES

ICES category	Crop(s)
Wheat	Wheat
Vegetables & Fruits	Orange, grapefruit, lemon, apple, pear, peach, plum, grape, banana, olive, almond, avocado, palm, tomato, cucumber, eggplant, pepper, marrow, strawberry, onion, carrot, lettuce, bean, cabbage, cauliflower, celery, radish, artichoke, garlic, sugar-melon, water-melon, potato
Sugar Cane	NA
Rice	NA
Plant-Based Fiber	Cotton
Oil Seeds	Sunflower, corn
Cereal Grains	Barley, chickpea, pea, groundnut
Forage	Summer forage, winter forage

Table B2. Allocation of the 45 groups of crops incorporated by VALUE for Italy into 8 land-using industries in ICES

Category	Code	Crop(s)
Wheat	WHT	Common wheat and spelt, Durum wheat
Vegetables, fruits and nuts	V_F	Potatoes, Fresh vegetables outdoor – open field, Fresh vegetables outdoor – market gardening, Fresh vegetables under glass, Fresh fruit of temperate climate zones, Fruit of subtropical climate zones, Nuts, Citrus plantations, Vineyard - quality wine, Vineyard - other wines, Vineyard - table grapes
Plants used for sugar manufacturing	C_B	Sugar beet
Paddy rice	PDR	Rice
Plant fibers	PFB	Flax, Hemp
Oil seeds and oleaginous fruit	OSD	Rape and turnip rape, Sunflower, Soya, Olive plantations - table olives, Olive plantations - olives for oil production
Other grains	GRO	Rye, Barley, Oats, Grain maize, Other cereals for the production of grain, Protein crops for the production of grain
Other crops	OCR	Fodder roots and brassicas, Flowers and ornamental plants outdoor, Flowers and ornamental plants under glass, Forage plants - temporary grass, Forage plants - other green fodder, Tobacco