

MODELING SHIFTS IN AGRICULTURAL LAND AS A CONSEQUENCE OF DIFFERENT AGRICULTURAL POLICIES

H. van Meijl¹, T. van Rheenen¹, A. Tabeau¹ and B. Eickhout²

¹ Agricultural Economics Research Institute (LEI), The Hague, The Netherlands

² Netherlands Environmental Assessment Agency (MNP-RIVM), Bilthoven, The Netherlands

Corresponding author:

Hans van Meijl, LEI, Wageningen University and Research Centre, P.O. Box 29703, 2502 LS The Hague, The Netherlands, ph: +31 70 335 81 69, fax: +31 70 361 56 24, e-mail: hans.vanmeijl@wur.nl, internet: <http://www.lei.wageningen-ur.nl>

Abstract

The impact of globalization on trade, production and land-use was key to the Doha development round. This paper deals with the complex interaction between agricultural trade regimes, production and land-use given two key uncertainties. Firstly, a world where Doha and subsequent rounds succeed and globalization proceeds versus a world that moves to regionalism with a stronger orientation towards bilateral and regional trade agreements. Secondly, a world that focuses on economic incentives and economic growth and a limited role for the government versus a world where public and private institutions value also the environment. These two key uncertainties lead to a world that can evolve in four directions.

This paper presents a dovetailing of an economic (GTAP) and a bio-physical (IMAGE) model. The methodology is innovative as it combines state of the art knowledge. First, the treatment of agriculture and land use is improved in the economic model. For example, information from the OECD Policy Evaluation Model (PEM) was incorporated 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 use. The new land supply curve that was introduced facilitates the conversion of idle land to productive land or the other way while given consideration to the level of intensification. Secondly, the adapted economic model is linked to the ecological-environmental modeling framework IMAGE allowing feedbacks of heterogeneous information of land productivity to the economic framework.

While often a rather pessimistic picture is portrayed for future developments of the agricultural sector in the EU (especially in liberalizing scenarios), results show that changes in the use of land for agricultural purposes will not be very distinctive for the EU25 the coming 30 years. Changes in land use will mainly be driven by (global) food demand factors such as GDP and population growth. The negative impact of liberalization of agricultural policies on land use is small because on the one hand loss in EUs competitiveness leads partly to extensification instead of land abandonment, and secondly, the recent agricultural reforms of the EU changed the protection from market to income support which has less production effects. Changes in land use will be dramatic for Africa. In this part of the world, area of agricultural land use will increase up to 70 % over 30 years.

Key words: Land use, policy, trade liberalization, long-term scenarios, global economy model, global environmental model

1. Introduction

In November 2001, Trade Ministers in Doha agreed on the mandate for a new World Trade Organization (WTO) Round on trade liberalization serving both development and environment. Recent research suggests that trade liberalization in agriculture can contribute to trade and growth and reduce poverty and hence, deliver at least partly on the Doha Development Agenda. However, to what extent these beneficiary effects can be used by the different developing countries, is heavily debated (Francois, et al., 2005). Moreover, most studies leave the environmental outcome of trade liberalization untouched. The implications of agricultural reform on the environment remain largely uncertain, especially for the outcome for global and, more specific, the European land use, leaving the other half of the Doha mandate unchallenged.

This paper deals with the complex interaction between agricultural trade regimes, production and land-use given two key uncertainties. Firstly, a world where Doha and subsequent rounds succeed and globalization proceeds versus a world that moves to regionalism with a stronger orientation towards bilateral and regional trade agreements. Secondly, a world that focuses on economic incentives and economic growth and a limited role for the government versus a world where public and private institutions also value the environment. These uncertainties are an elaboration on the four long-term greenhouse gas emission scenarios published by the Intergovernmental Panel on Climate Change (IPCC) in 2000 (Nakicenovic et al., 2000). In our analyses we quantify the economic impact of different agricultural trade liberalization regimes along the line of these four scenarios (Westhoek et al., 2005). In contrast to existing studies of trade liberalization we specifically focus on land-use implications.

To perform the scenario analysis a consistent modeling framework was constructed, consisting of a global economic equilibrium model (Global Trade Analysis Project, GTAP), and an ecological-environmental based modeling framework (Integrated Model to Assess the Global Environment, IMAGE). In this framework the long-term economic and environmental consequences of different scenarios were quantified and analyzed in time steps of 10 years, starting from 2001 up to 2030. More specifically, a modified version of the global general equilibrium GTAP model was used to improve the representation of agriculture in general and land use in particular. Information was used from the OECDs Policy Evaluation Model (PEM) to improve the agricultural production structure (see also Hertel and Keening, 2003) and a new land allocation method that considers the variation of substitutability between different types of land (Huang et al., 2004). A new land supply curve was introduced that allowed for the conversion of idle land to productive land as well as abandonment of agricultural land, taking the level of intensification of land use into consideration. Additionally, we linked the adapted economic model to the ecological-environmental modeling framework IMAGE (Alcamo et al., 1998) through yields and feed efficiency rates changes. In the IMAGE model, climate and soil conditions determine the crop productivity on a grid scale of 0.5 by 0.5 degrees, allowing the feedback of heterogeneous information of land productivity to the economic framework.¹

¹ The IMAGE model was also used for the implementation of the IPCC SRES scenarios (IMAGE Team, 2001) with specific focus on land use and land-use emissions (Strengers et al., 2004).

In this paper we focus on the methodology of the constructed modeling framework and focus on the land-use results for the globe and more specifically for Europe. The trade-offs between the economy and the environment are elaborated upon in Eickhout et al. (2005).

In Section 2, the scenarios will be introduced while in Section 3 we elaborate on the extensions that were made to the GTAP model. Section 4 focuses on the projection methodology and scenario implementation. Sections 5 and 6 will concentrate in the results and conclusions.

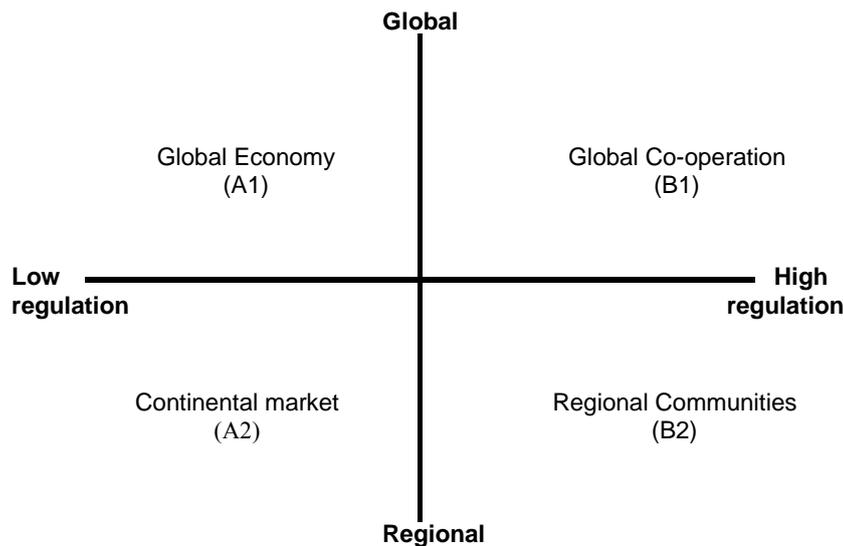


Figure 1: Four scenarios in a nutshell

2. Four long-term scenarios

The two key uncertainties mentioned in Section 1 lead to a world that can evolve in four different directions (see Figure 1). The **vertical axis** depicts a world where Doha and subsequent rounds succeed and globalization proceeds (Global) versus a world that moves to regionalism with a stronger orientation towards bilateral and regional trade agreements (Regional). The **horizontal axis** depicts a world that focuses on economic incentives and economic growth and a limited role for the government (Low Regulation) versus a world where public and private institutions value issues such as the environment and animal welfare (High Regulation). The rationale for these four scenarios is based on the recognition that different worldviews exist and it is impossible to predict the future in which a combination of these 4 world visions will prevail.

The scenarios are an elaboration of the four emission scenarios of the IPCC, as published in its Special Report on Emission Scenarios (SRES; Nakicenovic et al., 2000) and the Dutch Central Planning Bureau (CPB) detailed focus on Europe with more regional and sectoral disaggregation (CPB, 2003). These scenarios enable us to perform region and sector specific analyses and to assess the impact of globalization on trade, production and land-use and were used in the EURURALIS project (Westhoek et al., 2005).

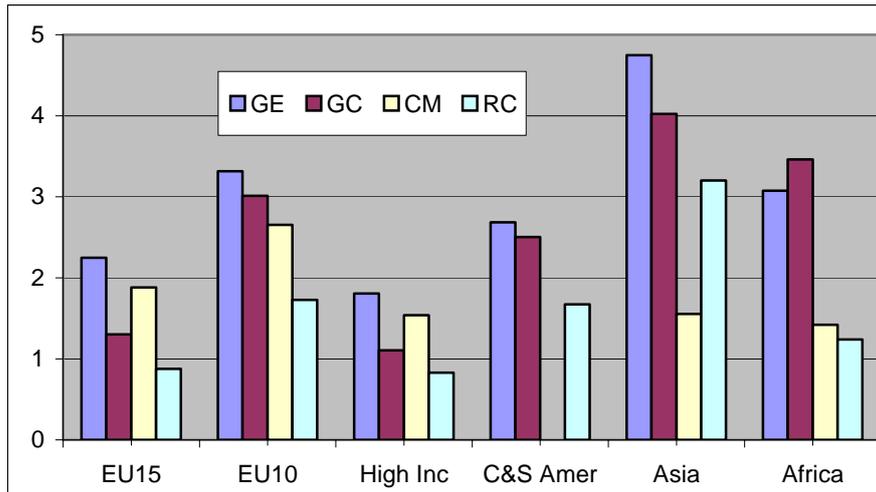


Figure 2: Assumed GDP growth per capita for different groups of countries yearly growth rates in 2001-2030 (CPB, 2003).²

The Global Economy (GE; elaboration of A1 of SRES) assumes the WTO negotiations are successful, global trade fully liberalized and a further eastwards enlargement of the EU including Turkey. Technological change is high. Poor countries will catch-up and experience high economic growth. This scenario shows the highest income growth for almost all regions (CPB, 2003; see Figure 2). Technological change is driven by economic profit and not directed to or hampered by environmental (planet) or social (people) considerations. Genetically modified crops are accepted and there are few environmental concerns.

Global Co-operation (GC; elaboration of B1 of SRES) scenario assumes that international cooperation is successful and trade will be liberalized, but under conditions for people and planet (e.g. environment and climate change). Consequently, economic growth will be lower compared to the GE scenario, especially for the EU where these concerns are important. We observe a high growth rate in the new member states of the EU (EU10) and also high growth rates in poor countries. This – for example - is because rich people are concerned with reducing poverty (people dimension resulting in high growth rates for Africa as can be seen in Figure 2). Contrary to the GE scenario, GC scenario implies that domestic support in agriculture will partly be sustained because subsidies will be linked to nature and environment.

In the Continental Market (CM; elaboration of A2 of SRES) scenario the focus is on markets, though national or continental interests prevail. The United States and EU create a Trans-Atlantic internal market. This yields welfare gains in EU and the United States in contrast with developing countries where markets become more segmented and separated. At the same time slow population growth is assumed in industrial countries and fast population growth in developing countries due to continuing poverty.

² In contrast to the original CPB projections, in this study Latin America was assumed not to be part of the EU-US trade block, leading to lower economic growth than in CPB (2003). These data were kindly provided by Arjan Lejour (CPB).

In the Regional Communities (RC; elaboration of B2 of SRES) scenario both economic and non-economic values are important while regional or national interests prevail. Trade and agricultural policies remain almost unchanged, except for export subsidies that are abolished because this kind of “dumping” is socially not considered acceptable. EU integration is only partial and technological change is limited because of segmented markets and the focus on non-economic issues (GMOs not allowed and the environment is important). The resulting economic growth is lower than in other scenarios. Social values lead to increased growth rates in developing countries because they can adopt existing technologies from developed countries.

Table 1: Policies and consumer preferences in the scenarios

	All scenarios	Global Economy (GE)	Global Co-operation (GC)	Continental Markets (CM)	Regional Communities (RC)
Border support					
Export subsidies	2003 CAP reform	Abolished	Abolished	No change	Abolished
Import tariffs	2003 CAP reform	Abolished	Abolished	No change	No change
Trade blocks	Enlargement to EU27	Rumania, Bulgaria, FSU accede EU	Rumania, Bulgaria, FSU accede EU	EU-USA	Manufacturing: FTAA (North and South America), Turkey-Middle East and North Africa, Rest Africa, FSU
Domestic support					
Domestic subsidies	2003 CAP reform (incl. decoupling)	Abolished	-67%, rest linked to environmental and social targets	No change	+10%, linked to environmental and social targets
Milk and sugar quota	2003 CAP reform	Abolished	Abolished	Self sufficient EU	Self sufficient EU
Consumer preferences					
Preference for regional products		No	no	preference for products from own region (5%)	preference for products from own region (5%)
Consumption of animal protein from meat		endogenous outcome	Meat consumption 10% lower	endogenous outcome	meat consumption 10% lower

Following these storylines, specific assumptions were made to implement trade liberalization, agricultural policies and consumer preferences (see Table 1). The technological change is taken from the study ‘World Agriculture towards 2030’ (FAO, 2003). To make a distinction between the scenarios it is assumed GE and GC are on the high-side of the FAO-projection and CM and RC on the low-side (Eickhout et al., 2004).

3. Modeling framework

The modeling framework used in this study was based on GTAP – a multi-region, multi-sector, computable general equilibrium model – and the IMAGE model – a multi-region, multi-sector, dynamic environmental model. GTAP was used to assess the economic consequences while IMAGE was employed to determine the environmental consequences of the scenarios. The standard GTAP model will be described in Section 3.1. The model was improved with a new land allocation method taking into account the degree of substitutability between different types of land use (Section 3.2). A new land supply curve allowing for conversion and abandonment of land is described in Section 3.3. The linkage of the adapted economic model to the IMAGE framework in order to model yields and feed efficiency rates is described in Section 3.4. Additionally, we used information from the OECDs Policy Evaluation Model (PEM) to improve the production structure and we introduced an endogenous quota mechanism (Section 3.5).

3.1 Standard GTAP model

The economic analysis was done with an extended version of the general equilibrium model of GTAP (Hertel, 1997). The standard model is characterized by an input-output structure (based on regional and national input-output tables) that explicitly links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing, to the final assembling of goods and services for consumption. In the model, a representative producer for each sector of a country or region makes production decisions to maximize a profit function by choosing inputs of labor, capital, and intermediates to produce a single sectoral output. In the case of crop and livestock production, farmers also make decisions on land allocation. Intermediate inputs are produced domestically or imported, while primary factors cannot move across countries. Markets are typically assumed to be competitive. When making production decisions, farmers and firms treat prices for output and input as given. Primary production factors land, labor and capital are fully employed within each economy, and hence returns to land and capital are endogenously determined at the equilibrium, i.e., the aggregate supply of each factor equals its demand.

In contrast to most PE models, GTAP assumes that land is heterogeneous. The heterogeneity is introduced by specifying a transformation function, which takes total land as an input and distributes it among various sectors in response to relative rental rates. A Constant Elasticity of Transformation (CET) function is used, where the elasticity of transformation is a synthetic measure of land heterogeneity.

Prices on goods and factors adjust until all markets are simultaneously in (general) equilibrium. This means that we solve for equilibria in which all markets clear. While we model changes in gross trade flows, we do not model changes in net international capital flows. Rather our capital market closure involves fixed net capital inflows and outflows. To summarize, factor markets are competitive, and labor, capital and land are mobile between sectors but not between regions.

GTAP assumes that products are differentiated by country. This is modeled using the so called Armington approach, which assumes that imports and domestic commodities are imperfect substitutes in demand and uses the CES function to describe the

substitution possibilities between these goods. In this way the bilateral commodity trade is modeled.

Taxes and other policy measures are included in the theory of the model at several levels. All policy instruments are represented as ad valorem tax equivalents. These create wedges between the undistorted prices and the policy-inclusive prices.

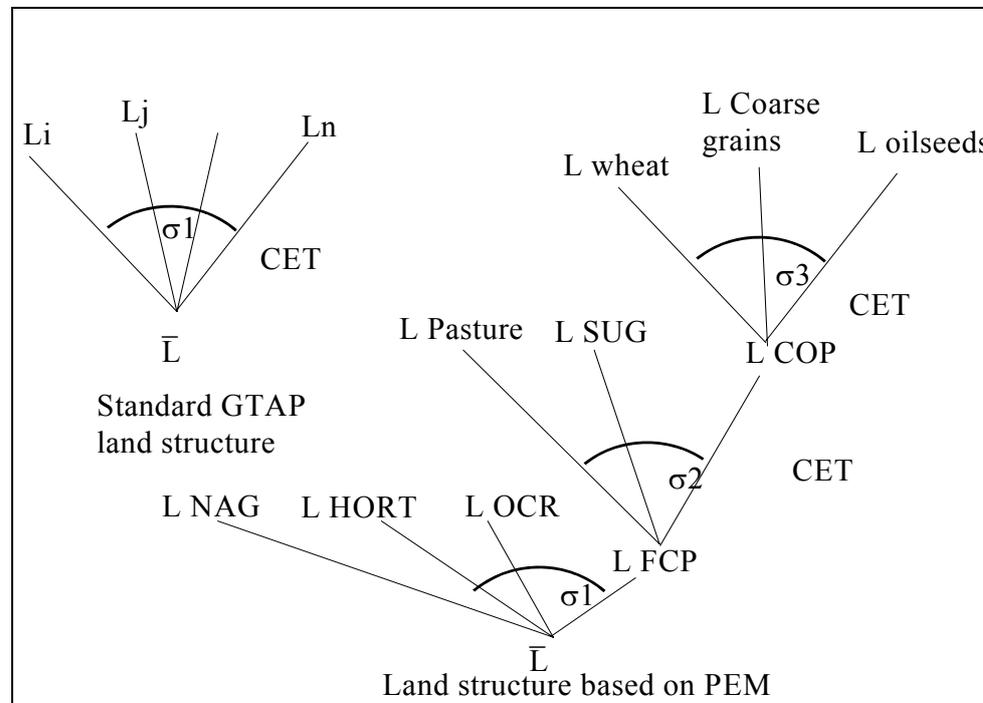


Figure 3: Land allocation 'tree'

3.2 Agricultural land allocation under the heterogeneity of land assumption

The base version of GTAP represents land allocation in a CET structure (see left part of Figure 3). It was assumed that the various types of land use are imperfectly substitutable, but the substitutability is equal among all land use types. We extended the land use allocation structure by taking into account that the degree of substitutability of types of land differs between types (Huang et al., 2003). We used the more detailed OECD's Policy Evaluation Model (OECD, 2003) structure. It distinguishes different types of land in a nested 3-level CET structure. The model covers several types of land use more or less suited to various crops (i.e. cereal grains, oilseeds, sugar cane/sugar beet and other agricultural uses). The lower nest assumes a constant elasticity of transformation between 'vegetables, fruit and nuts' (HORT), 'other crops' (e.g. rice, plant based fibres; OCR), the group of 'Field Crops and Pastures' (FCP) and non-agricultural land (NAG)³. The transformation is governed by the elasticity of transformation σ_1 . The FCP- group is itself a CET aggregate of Cattle and Raw Milk (both Pasture), 'Sugarcane and Beet' (SUG), and the group of 'Cereal, Oilseed and Protein crops' (COP). Here the elasticity of transformation is σ_2 . Finally,

³ The non-agricultural commodities do not use land in the current GTAP model version. However, since land allocation in GTAP is defined over all commodities we add the non-agricultural land to the land allocation tree.

the transformation of land within the upper nest, the COP-group, is modeled with an elasticity σ_3 .

In this way the degree of substitutability of types of land can be varied between the nests. It captures to some extent agronomic features. In general it is assumed that $\sigma_3 > \sigma_2 > \sigma_1$. This means that it is easier to change the allocation of land within the COP group, while it is more difficult to move land out of COP production into, say, vegetables. The values of the elasticities are taken from PEM (OECD, 2003).

3.3 Variability of total agricultural area

In the standard GTAP model the total land supply is exogenous. In this extended version of the model the total agricultural land supply was modeled using a land supply curve which specifies the relation between land supply and a rental rate (Abler, 2003). Land supply to agriculture as whole can be adjusted as a result of idling of agricultural land, conversion of non-agricultural land to agriculture, conversion of agricultural land to urban use and agricultural land abandonment.

The general idea was that when there is enough agricultural land increases in demand for agricultural purposes will lead to land conversion to agricultural land and a modest increase in rental rates (see, left part of Fig. 4). However, if almost all agricultural land is in use then increases in demand will lead to increases in rental rates (land becomes scarce, see right part of Fig. 4). When land conversion and abandonment possibilities are low the elasticity of land supply in respect to land rental rates are low and land supply curve is steep.

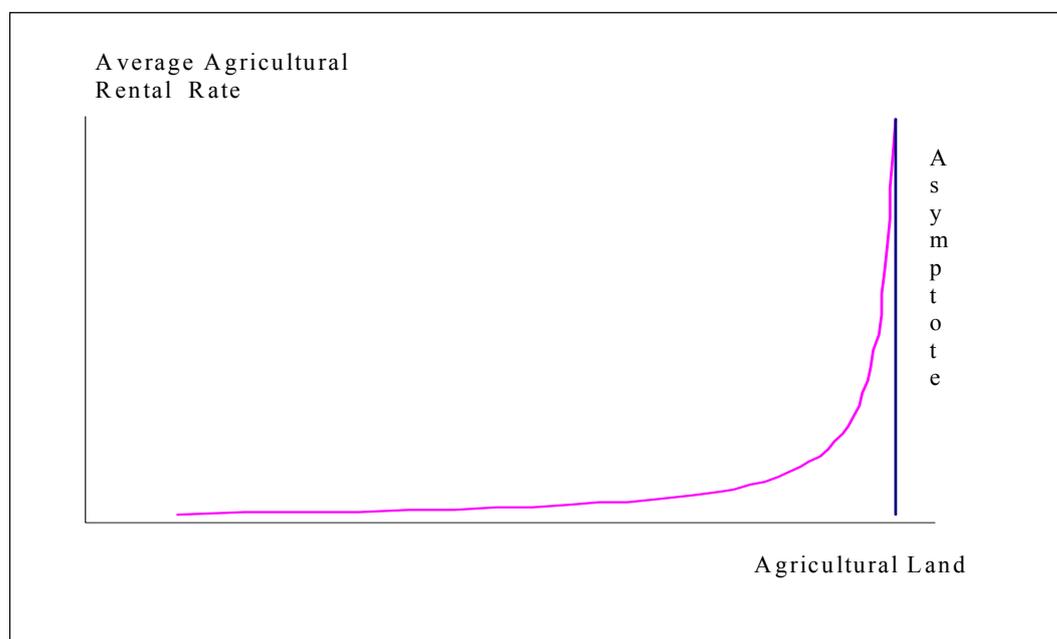


Figure 4: Land supply curve: land conversion and abandonment

We assumed the following land supply function:

$$\text{Land supply} = a - b/\text{real land price} \quad (1)$$

where: $a (>0)$ is an asymptote, b is a positive parameter and the land supply elasticity E in respect of the land price is equal to

$$E = b/(a \cdot \text{real land price} - b) \quad (2)$$

We calibrated the parameters a and b of the land supply function in such a way that it reproduces the GTAP land data for 2001. The calibrated elasticities E vary between 0.01 - .20 for EU countries, between 0,05 – 0,40 for other high developed countries and between .5 and 3 for low developed countries and regions

3.4 Yield and feed conversion: Linkage with IMAGE

Section 3.1 showed that yields are only dealt with implicitly and that the feed livestock linkage in the GTAP is calculated using input-output coefficients. To improve the treatment of these issues the adjusted GTAP model was linked with the IMAGE model (Alcamo et al., 1998; IMAGE Team, 2001).⁴ The objective of IMAGE 2.2 is to explore the long-term dynamics of global environmental change. Ecosystem, crop and land-use models are used to compute land use on the basis of regional production of food, animal products and timber, and local climatic and terrain properties. The production of food and animal products come from the adjusted GTAP model. The corresponding land-use change and greenhouse gas emissions were determined. The atmospheric and ocean models calculate changes in atmospheric composition by employing the emissions and by taking oceanic CO₂ uptake and atmospheric chemistry into consideration. Subsequently, changes in climatic properties are computed by resolving oceanic heat transport and the changes in radiation forcing by greenhouse gases and aerosols. The impact models involve specific models for sea-level rise and land degradation risk and make use of specific features of the ecosystem and crop models to depict impacts on vegetation and crop growth (Leemans and Eickhout, 2004). Since the IMAGE model performs its calculations on a grid scale (of 0.5 by 0.5 degrees) the heterogeneity of the land is taken into consideration on a grid level (Leemans et al., 2002). The climate and CO₂ feedbacks are simulated dynamically, which allows the inclusion of these direct feedbacks on crop yield as input for the extended version of GTAP.

Yields

In the adjusted GTAP model yield depends a trend factor a prices. The production structure used in this model implies that there are substitution possibilities among production factors. If land gets more expensive, the producer uses less land and more other production factors such as capital. The impact of a higher land price is that land productivity or yields will increase. Consequently, yield is dependent on an exogenous part - the **trend** component - and on an endogenous part with relative factor prices, which is the **management** component.

Firstly, the exogenous trend of the yield was taken from the FAO study ‘Agriculture towards 2030’ (FAO, 2003) where macro-economic prospects were combined with local expert knowledge. This approach led to best-guesses of the technological change for each country for the coming 30 years. Given the scientific status of the FAO-work

⁴ In this paper we focus on the yield and feed efficiency linkage. The environmental consequences are described in Eickhout *et al.* (2005).

these data were used as exogenous input for a first model run with the adjusted GTAP model. However, many studies indicated this change in productivity are enhanced or reduced by other external factors, of which climate change is mentioned most often (Rosenzweig et al., 1995; Parry et al., 2001; Fischer et al., 2002). These studies indicated increasing adverse global impacts because of climate change will be encountered with temperature increases above 3 to 4°C compared to pre-industrial levels. These productivity changes need to be included in a global study. Moreover, the amount of land expansion or land abandonment will have an additional impact on productivity changes, since land productivity is not homogeneously distributed over each region.

In our approach, the exogenous part of the yield was updated in an iterative process with the IMAGE model (see Figure 5). The output of GTAP used for the iteration with IMAGE is sectoral production growth rates and a management factor describing the degree of land intensification. Next, the IMAGE model calculates the yields, the demand for land and the environmental consequences of crop growth productivity. IMAGE simulates global land-use and land-cover changes by reconciling the land-use demand with the land potential. The basic idea is to allocate gridded land cover within different world regions until the total demands for this region are satisfied. The results depend on changes in the demand for food and feed and a management factor as computed by GTAP. The allocation of land-use types is done at grid cell level on the basis of specific land allocation rules like crop productivity, distance to existing agricultural land, distance to water bodies and a random factor (Alcamo et al., 1998). This procedure delivers an amount of land needed per world region and the corresponding changes in yields, because of changes in the extent of used land and climate change. Next, these additional changes in crop productivity are given back to GTAP. A general feature is that yields decline if large land expansions occur since marginal lands are taken into production.

Feed conversion in livestock

The intensification of livestock production systems also influences the composition of the animal feed required by livestock production systems. In general, intensification is accompanied by decreasing dependence on open range feeding and increasing use of concentrate feeds, mainly feed grains, to supplement other fodder. At the same time improved and balanced feeding practices and improved breeds in ruminant systems enabled more of the feed to go to meat and milk production rather than to maintenance of the animals. This has led to increasing overall feed conversion efficiency (Seré and Steinfeld, 1996). In the IMAGE model, the production of animal products is used as input to simulate the number of animals required for this production. For this conversion, the animal productivity is taken from FAO (2003) including the future developments until 2030. The calculation of total feed required in dairy and beef production were modified from EPA (1994). In this approach the net energy requirements for dairy cattle are divided into maintenance, feeding, lactation and pregnancy (Bouwman et al., 2004). Based on the animal diets, the intake of crops and grass/fodder are calculated to feed the animals. The feed composition in 2000 is taken from FAO (2003). Future shifts in feed composition were assumed to follow the intensification or extensification coming from GTAP. Intensification will lead to a shift towards more concentrate feeds (maize and soy beans). On the basis of these feed diets the demand for grass and fodder was calculated, assuming that grazing animals such as cattle, goats and sheep depend mainly on pasture and fodder species,

while pigs and poultry rely primarily on crops. Hence, the importance of food crops in the animal diet increases at the cost of pasture and fodder species and crop residues, along with increasing intensity of production on the basis of recent trends observed. More details of the IMAGE grazing simulation were described in Bouwman et al. (2004). This procedure delivers feed conversion or efficiency rates for the livestock sectors that were used as input for the GTAP modeling framework.

Feed demand in food processing industry

As noted above, developments in livestock are important for the demand for feed crops. In many countries feed crops are delivered to the feed-processing industry and this sector adds value and delivers it to the livestock sectors. The feed-processing sector in GTAP is a part of a very heterogeneous food processing sector which causes the problem that feed demand is determined by the growth of this larger food processing sector and only indirectly by the growth of the livestock sectors.⁵ Given the importance of crop feed demand for land use we adjust this aggregation issue by creating a direct link between feed demand in agro-food processing sector (“agro”) and the growth of the livestock complex. Demand for feed crops in food processing sector is a sales weighted average of growth of livestock sectors:

$$qf(i, "agro" r) = \sum_{k=livestock} \frac{VFA("agro", k, r)}{\sum_{m=livestock} VFA("agro", m, r)} * (qo(k, r) - af(i, k, r))$$

where

qf (i, “agro”, r) industry demands in food processing sector (agro) for intermediate feed crop input i in region r, VFA (“agro”,k,r) is producer expenditure of k industry on sales from food processing industry (agro) in region r, qo(k,r) is production growth in sector k in region r, sector k is a livestock sector, and af(i,k,r) is the feed efficiency rate in livestock sector k in region r. This efficiency rate af(i,k,r) is provided by IMAGE.

3.5 Segmentation of factor markets and endogenous production quota

Factor market segmentation

If labor were perfectly mobile across domestic sectors, we would observe equalized wages throughout the economy for workers with comparable endowments. This is clearly not supported by evidence. Wage differentials between agriculture and non-agriculture can be sustained in many countries (especially developing countries) through limited off-farm labor migration (De Janvry et al., 1991). Returns to assets invested in agriculture also tend to diverge from returns of investment in other activities.

To capture these stylized facts, we incorporate segmented factor markets for labor and capital by specifying a CET structure that transforms agricultural labor (and capital) into non-agricultural labor (and capital) (Hertel and Keening, 2003). This specification has the advantage that it can be calibrated to available estimates of agricultural labor supply response. In order to have separate market clearing conditions for agriculture and non-agriculture, we need to segment these factor

⁵ In the aggregation used in this paper the problem is more serious because it separates only a very aggregated food-processing sector where the feed processing industry is only a minor part.

markets, with a finite elasticity of transformation. We also have separate market prices for each of these sets of endowments. The economy-wide endowment of labor (and capital) remains fixed, so that any increase in supply of labor (capital) to manufacturing labor (capital) has to be withdrawn from agriculture, and the economy-wide resources constraint remains satisfied. The elasticities of transformation can be calibrated to fit estimates of the elasticity of labor supply from OECD (2003).

Agricultural production quotas

An output quota places a restriction on the volume of production. If such a supply restriction is binding, it implies that consumers will pay a higher price than they would pay in case of an unrestricted interplay of demand and supply. A wedge is created between the prices that consumers pay and the marginal cost for the producer. The difference between the consumer price and the marginal costs is known as the tax equivalent of the quota rent.

In our model both the EU milk quota and the sugar quota are implemented at the national level. Technically, this is achieved by formulating the quota as a complementarity problem. This formulation allows for endogenous regime switches from a state when the output quota is binding to a state when the quota becomes non-binding. In addition, changes in the value of the quota rent are endogenously determined. If t denotes the tax equivalent of the quota rent, and r denotes the difference between the output quota \bar{q} and output q , then the complementary problem can be written as:

$$r = \bar{q} - q$$

and

either $t > 0$ and $r = 0$	the quota is binding
or $t = 0$ and $r \geq 0$	the quota is not binding.

4. Projections and scenario implementation

4.1. Projection methodology

Figure 5 shows the methodology of iterating the extended version of GTAP with IMAGE. The four scenario-dependent (see Section 2) macroeconomic drivers are based on Westhoek et al. (2005; population in EU countries), Nakicenovic et al. (2000; population in other non-European world regions) and CPB (2003; economic growth). These drivers are used as input in both the GTAP and IMAGE model.⁶ The economic consequences for the agricultural system, on the basis of these scenario assumptions (see Section 2) are calculated by GTAP. The output of GTAP is, among others, sectoral production growth rates, land use, and a management factor describing the degree of land intensification. These are in turn used by IMAGE model to calculate yields, the demand for land, feed efficiency rates and environmental indicators. This procedure delivers adjustments to the achieved changes in yields and changes in feed conversion, which are given back to GTAP. Through this procedure comparable land foresights are simulated in both models.

⁶ The exact numbers are available from authors on request.

The scenarios are constructed through recursive updating of the database for three consecutive time steps, 2001 – 2010, 2010 – 2020 and 2020 – 2030 such that exogenous GDP targets are met and given the exogenous estimates on employment, capital and population⁷.

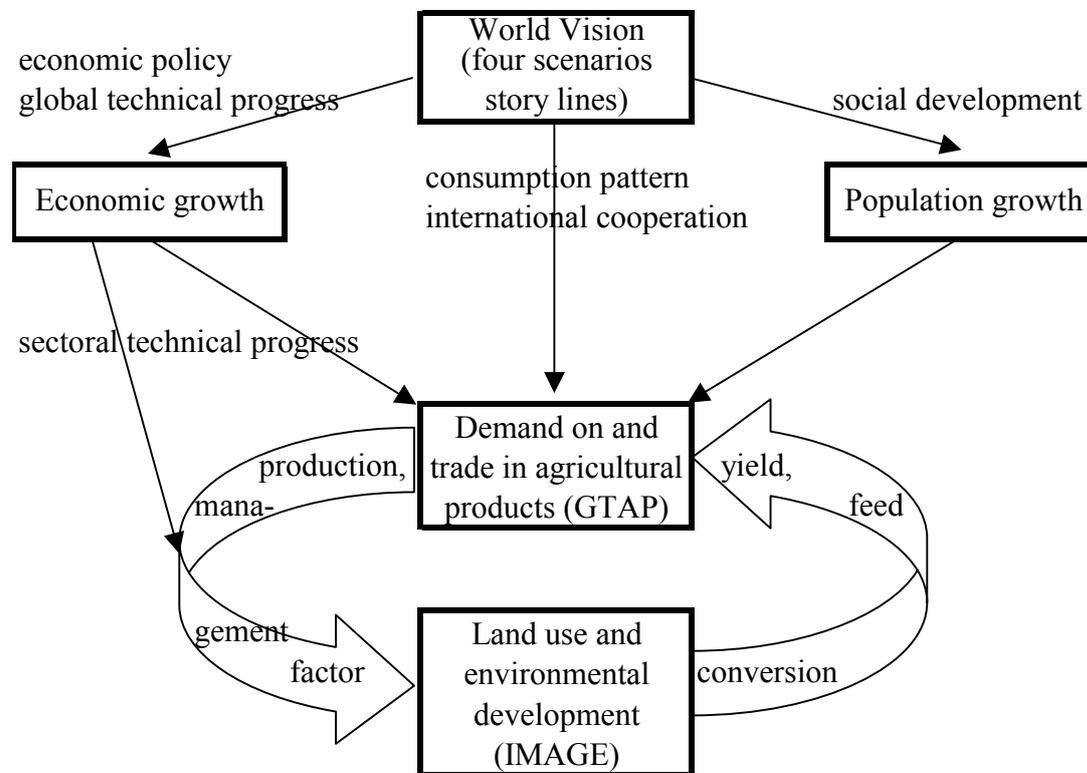


Figure 5: The modeling framework of GTAP and IMAGE

The procedure implies that an additional technological change is endogenously determined within the model (see also Hertel et al. 1999). In line with CPB, we assumed common trends for relative sectoral total factor productivity (TFP) growth (CPB, 2003). CPB assumed that all inputs achieve the same level of technical progress within a sector (i.e. Hicks neutral technical change). We deviate from this approach by using additional information on yields and feed conversion or efficiency rates from FAO and the IMAGE model. For the land-using sectors yields are exogenous and obtained in the base run from scenario specific assumptions based on deviations (see annex Table A3) of the FAO yield projections (FAO, 2003). In the iteration process adjustments to yields are obtained from the IMAGE model. For the livestock sectors (cattle, pigs and poultry, dairy) we obtain in addition feed conversion or feed efficiency rates from the IMAGE model. Within the heterogeneous food processing sector feed input augmenting technical change is endogenous (see section 3.4.5). For the non-land using sectors we assume Hicks neutral technical change.

4.2. Data

Version 6.2 of the GTAP data for simulation experiments was used (GTAP, 2004). The GTAP database contains detailed bilateral trade, transport and protection data

⁷ We have assumed the capital growth rate is the same as GDP growth rate.

characterizing economic linkages among regions, linked together with individual country input-output databases which account for intersectoral linkages. All monetary values of the data are in \$US millions and the base year for version 6 is 2001. This version of the database divides the world into 88 regions. An additional interesting feature of version 6 is the distinction of the 25 individual EU member states. The database distinguishes 57 sectors in each of the regions. That is, for each of the 65 regions there are input-output tables with 57 sectors that depict the backward and forward linkages amongst activities. The database provides quite a great detail on agriculture, with 14 primary agricultural sectors and seven agricultural processing sectors (such as dairy, meat products and further processing sectors).

The social accounting data were aggregated to 13 sectors and 37 regions (see Annex Table A1 and A2). The sectoral aggregation distinguishes agricultural sectors that use land and sectors engaged in the Common agricultural policy (CAP). The regional aggregation includes all EU 15 countries (with Belgium and Luxembourg as an one region) and all EU 10 countries (with Baltic regions aggregated to an one region and with Malta and Cyprus included in one region) and the most important countries and regions outside EU.

The initial quota rents level are taken from SEC (2003) for sugar. For milk, the quota rents are taken from Jensen and Nielsen (2004) and Kleinhanß et al. (2001) for the EU 15.

The crop- and regionally- specific management factors of IMAGE that represents the gap between the theoretically feasible crop yields (simulated by the crop production model) and the actual crop yield (which is limited by less than optimal management practices, technology and know-how) are based on FAO statistics (FAO, 1999). These regional management factors are used to calibrate the model to regional estimates of crop yields and land-cover for the period 1970-1995. For years after 1995 the management factor is a scenario variable, which is generally assumed to increase with time as an indication of the influence of technological development on crop yields. In this analysis we used the same estimates of the productivity increases from FAO as was used in the GTAP calculations (FAO, 2003), plus the intensification or extensification estimates from GTAP.

Other data are used within IMAGE for the 1765-1995 period to initialize the carbon cycle and climate system (Marland and Boden, 2000; Keeling and Whorf, 2001). To calculate climate change under the four scenarios, we used the CPB/RIVM prognoses for the energy system along the line of the identical four scenarios (Bollen et al., 2004).

4.3. Policy assumptions and their implementation

Enlargement and Free Trade Areas (FTAs)

The enlargement of the EU is implemented by elimination of all import tariffs and export subsidies as between the EU15 countries and ten new members (EU10) countries. At the same time all (EU10) countries get the same level of protection against third countries as EU15 before enlargement. This is implemented by setting EU10 import tariffs and export subsidies on the average level of EU15 tariffs and

subsidies. In case of FTAs only bilateral import tariffs and export subsidies are eliminated.

Decoupled payments implementation

Decoupling of domestic support is one of the key features of the Mid Term Review (MTR), which we implemented until 2010 in all four scenarios. The different mechanisms through which decoupled payments may affect production were discussed in Westcott and Young (2003). Frandsen et al. (2002) model decoupling of payments by converting all kinds of payments including output, intermediate input and factor payments and subsidies into uniform land payments. This is also known as full decoupling. This approach can be interpreted as per hectare payment. Alternatively, decoupling of payments can be approached by converting all kinds of payments to homogenous payment for all factors, which can be interpreted as farm payments (premium). In this study, the two above approaches are combined⁸. The payments are assumed to stay partially coupled because the payments still have production effects and because countries have the option to keep part of the payments coupled and because farmers do not react fully on decoupling of payments (see Westcott and Young (2003)).

For EU-15 countries, we assume uniform land subsidy rates for all cereals and oilseeds equal 0.75 and uniform land subsidy rate sectors equal 0.5 for sugar, other crops, beef and milk sectors. The 0.25 difference between these rates depicts the possibility of coupling of 25% hectare payments for cereals and oilseeds agreed in MTR proposal. All remaining factor payments we distributed equally among other than land production factors. Since, we treated the milk sector related payments as partially coupled to the sector, the milk and not-milk sectors have different subsidy rates for others than land production factors.

For EU10 countries we model decoupled payments as farm payments. The total amount of payments was calculated using European Commission estimates (EC, 2002).

5. Simulation results

In this section we will present results by starting with the production developments in the world, according to country groups in Section 5.1 and the effects of the iteration process in Section 5.2. We will then proceed by presenting the total agricultural land use changes between 2001 and 2030 that were caused by macro-economic and policy impacts. We then focus more closely on land use in the EU 15, highlighting the structural changes and driving forces.

5.1. Production developments

Crop production growth is low in the EU relative to other countries/continents (see Figure 6). Lower economic growth in combination with low income elasticity are important in this respect. In the Global scenarios (Global Economy and Global Cooperation) the protected sugar production in the EU will decline substantially because

⁸ See Britz (2004) for similar approach.

of liberalizing policies and the competition from other regions. However, the negative impact of liberalization of agricultural policies on land use in Europe is small because on the one hand loss in EU's competitiveness leads partly to extensification instead of land abandonment, and secondly, the recent agricultural reforms of the EU changed the protection from market to income support which has less production effects.

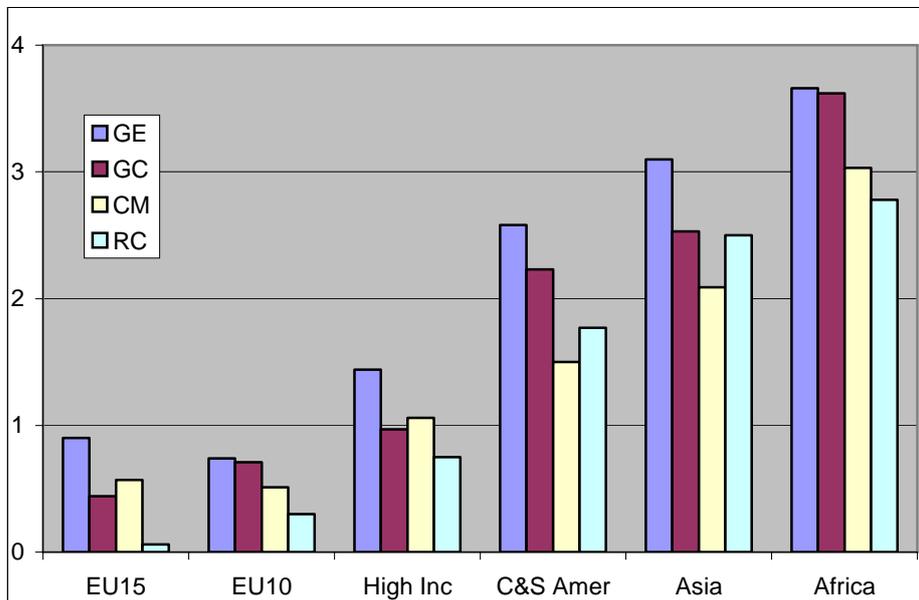


Figure 6: Annual growth of crop production, 2000-2030. (GE = Global Economy; GC = Global Co-operation; CM = Continental markets; and RC = Regional Communities).

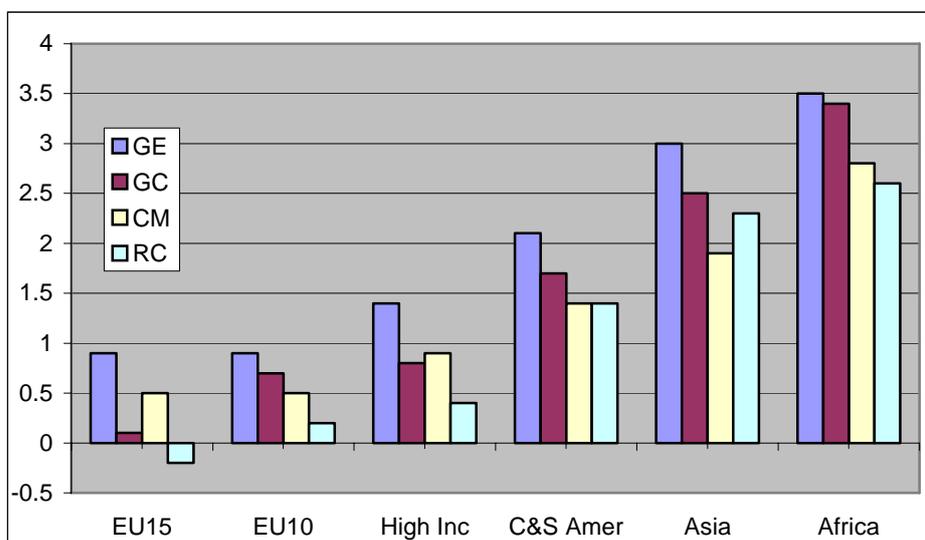


Figure 7: Annual growth of livestock production, 2000-2030. (GE = Global Economy; GC = Global Co-operation; CM = Continental markets; and RC = Regional Communities).

In Global Co-operation and Regional Communities crop production is relatively low due to lower demographic and economic growth and less demand for fodder crops due to less meat consumption (see Figure 7). These effects are higher for the EU15 than for the EU10 because decline in income growth is higher (see Figure 2). For countries outside the EU-US market in the CM scenario crop production is lower than in other scenarios due to low economic growth and no enhanced access to the Transatlantic market.

Livestock production growth is low in the EU relative to other countries. This is explained by lower demographic and economic growths. In the EU15 and other high income countries meat consumption declines due to preference shifts in diet, especially in Global Co-operation and Regional Communities. For the EU10 (and developing countries) this effect is smaller. Here higher income will lead to higher consumption.

5.2 Convergence via model iteration

Over a period of 30 years, technology change is the most important factor determining the changes in yield. The effects of climate change on crop yield are only marginal. Changes in yield because of shifts in agricultural lands are reasonable important in world regions where dietary preferences are expected to change to a great extent. Table 4 illustrates this feature for the crop maize. From Table 4 it can be concluded that in all regions the technology is expected to increase significantly, especially in African and Latin American regions. Until 2030, climate change only influences the yield marginally, and mainly positive through CO₂ fertilization. However, on the longer term this effect can become more important when the global temperature increase reaches higher values than the 1°C in 2030 (Bollen et al., 2004). The decrease in maize production in Europe mainly occurs in the Mediterranean regions, because of the drying of the European summers. The effect of land expansion is more important, especially in regions where large land expansions are expected (in the globalizing scenario GE USA, South America and Africa are expected to experience an increase in crop demand for the global market because of population growth and a steep increase in feed demand for the increased high-caloric diets as shown in Section 5.1). Table 4 shows that the expansion of land on less productive areas, partly offsets the yield increase that was expected due to technological advancements. Interestingly, the decrease in land use in Europe because of liberalization has an opposite effect: less productive lands are taken out of production and consequently, an additional yield increase is experienced. The corrections on yield by climate, CO₂ and land-use change are fed back to GTAP that is rerun.

Table 4: Sources of yield increase of maize between 2001 and 2030 for the GE scenario; determined by IMAGE.

	USA	South America	Western Africa	EU-15	EU-10	Former USSR	East Asia
Yield increase by technology	43%	59%	94%	45%	26%	16%	34%
Climate change and CO ₂ fertilization	2%	1%	2%	-14%	2%	3%	2%
Land use change	-6%	-19%	-12%	3%	-1%	-13%	8%

After the iteration between GTAP and IMAGE both land projections are harmonized, indicating that the mechanisms in both models are taken into account by both model approaches. Hence, economic and ecological characteristics of both models can be analyzed in a consistent manner (see Eickhout et al., 2005 for these analyzes). In Figure 8, an example of the size of pasture land according both models before and after the iteration process is given for the region South – South-East Asia (mainly India and Indonesia) and South America. Especially in South – South-East Asia the

converging land projections of GTAP and IMAGE indicate the successfulness of simulating land processes in both models consistently.

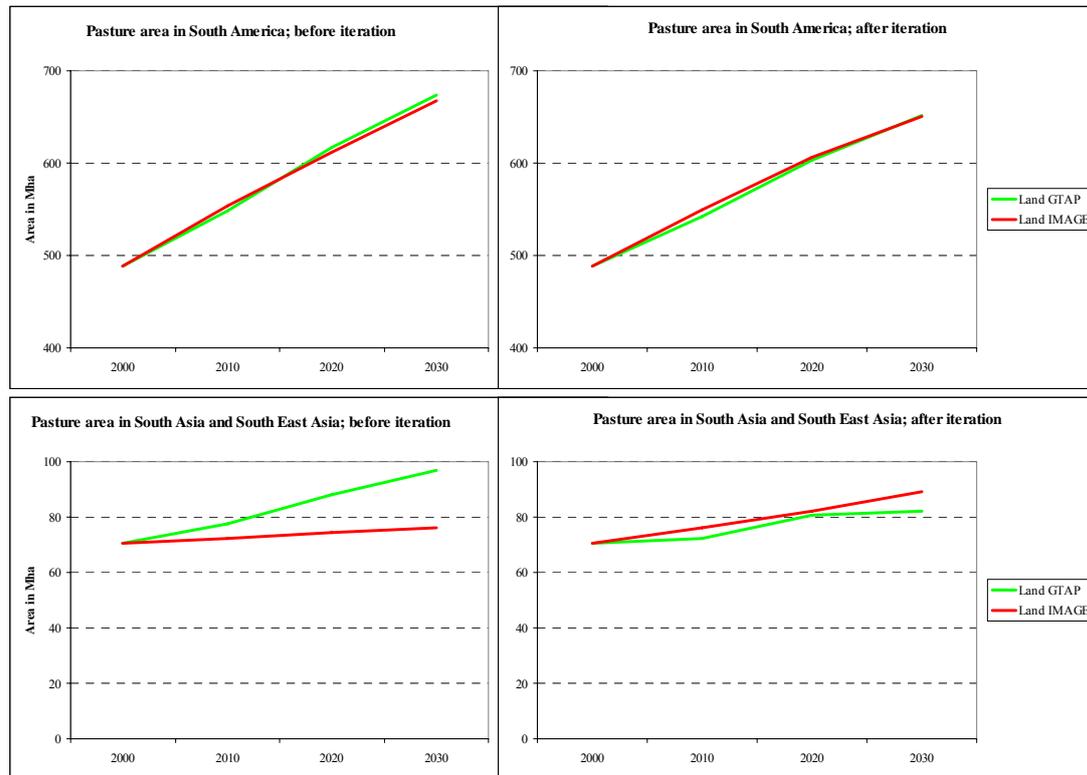


Figure 8: Size of pasture land for regions South America and South- and South-East Asia between 2000 and 2030 before and after iteration for the GE scenario. Green lines are results from the GTAP model; red lines from the IMAGE model.

5.3. Total land use changes in different regions

Developing regions such as Africa, Asia, South and Central America obtain the highest growth in total agricultural land use. The position of a region on the land supply curve, yield developments, and developments in food demand are important determinants. In these regions agricultural land can still be expanded without leading to a high increase in the rental rate for land as they are on the left side of the land supply curve in Figure 4. The conversion of land to land use for agricultural production is mainly driven by food demand factors, macroeconomic factors such as GDP and population growth (see Figure 9). Because economic growth in the developing countries is higher in the GE and GC scenarios more land conversion will take place. In the liberalizing scenarios GE and GC, South and Central America experience an additional demand (due to policy changes) for agricultural land as protection is relatively low in these countries and they profit from liberalization as their exports grow and because exports are important part of their demand. The negative effect of policies in globalizing scenarios in the High Income Countries are mainly attributable to the protected low-competitive agricultural sector of Japan.

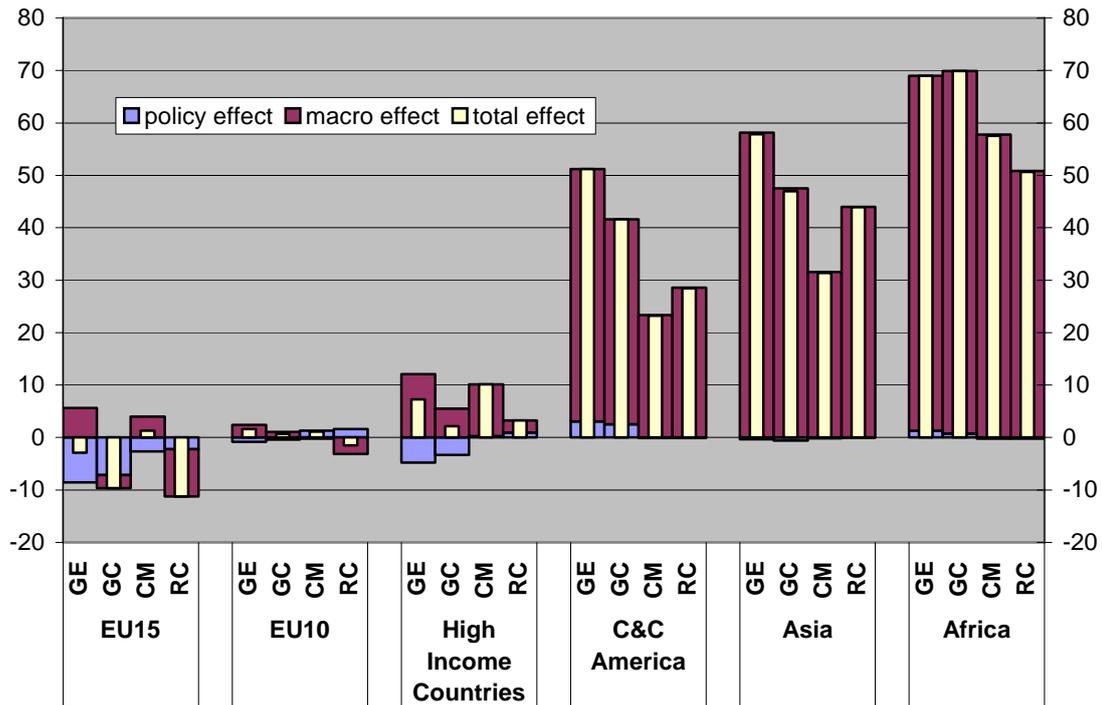


Figure 9: Total agricultural land growth in 2001-2030: the macro-economic and policy impacts

The possibilities for conversion of agricultural land in EU-15 countries are much lower than in the developing regions. The liberalization and agricultural policies play an important role in the agricultural land development, especially in the global scenarios GE and GC and causes a decrease of the total area of agricultural land use in the production process. The macroeconomic factors are less important than for developing regions. In case of the EU15 the high GDP and population growth in the profit driven scenarios GE and CM compensate the negative impact of reduction of domestic and border support for agriculture, and small changes in the agricultural land use are observed for these scenarios in EU15. In CM the EU total agricultural land will even expand a little because economic growth is high and protection with countries outside the Transatlantic Market will stay in place. The relatively low GDP and population changes in the regulated scenarios GC and RC accelerate the negative impact of the domestic and border support on the agricultural land changes and causes a significant but not massive reduction in the total agricultural land use in the production process. This reduction in land is augmented by the positive feedback in crop yields due to abandonment of less productive lands (resulting from the GTAP-IMAGE iteration).

6. Discussion and conclusions

This paper has presented a dovetailing of an economic and a bio-physical model, with the aim to explore the impact of different policy environments on agricultural markets, land use and the bio-physical environment. The methodology is innovative as it combines state of the art knowledge. First, the treatment of agriculture and land use is improved in the economic model. For example, information from the OECD

Policy Evaluation Model (PEM) was incorporated 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 use. The new land supply curve that was introduced facilitates the conversion of idle land to productive land or the other way while given consideration to the level of intensification. Secondly, the adapted economic model is linked to the ecological-environmental modeling framework IMAGE allowing feedbacks of heterogeneous information of land productivity to the economic framework.

While often a rather pessimistic picture is portrayed for future developments of the agricultural sector in the EU (especially in liberalizing scenarios), results presented in this paper do not confirm this bleak outlook. Results show that changes in the use of land for agricultural purposes will not be that spectacular for the EU25 the coming 30 years. Changes in land use will mainly be driven by global food demand factors such as GDP and population growth. Especially the growth of demand for food in Asia will mean that the prospects for agriculture in the EU will not be gloom and doom. The negative impact of liberalization of agricultural policies on land use is small and important only for EU15 countries because on the one hand loss in EU's competitiveness leads partly to extensification instead of land abandonment, and secondly, the recent agricultural reforms of the EU changed the protection from market to income support which has less production effects. Changes in land use will be dramatic for Africa. In this part of the world, area of agricultural land use will increase up to 70 % over 30 years and annual crop production growth is expected to increase with approximately 3 %. In these regions the macro effects like population growth and shifts in diets are far more important driving forces in changing the size of agricultural land than changes in agricultural policies.

In this paper, we made a first step to link an economic with a bio-physical model profiting from the strengths of both models. The economic model captures features of the global food market, whereas the bio-physical model adds geographical explicit information on crop growth. In the future the iteration can be improved by using a more consistent database for both models. Moreover, the calibration of the land supply curve in GTAP needs to be improved by output from IMAGE to mimic changes in land prices as a response to land scarcity and the inclusion of low-productive lands. Also the sectoral distinction of both models needs to be harmonized in order to implement future land-use options like modern biofuels, which are part of the fuel mix in the energy model of IMAGE. And the feed conversion from IMAGE has to be endogenized in GTAP in combination with other agricultural inputs like water and nutrients. Through these improvements the consequences of several policy options like climate mitigation and extensification or intensification of agriculture on economy and the environment can be analyzed in a consistent modeling framework.

References:

Abler, D., 2003. Adjustment at the Sectoral Level. An IAPRAP workshop on Policy Reform and Adjustment. The Wye Campus of Imperial College, October 23-25.

Alcamo, J., R. Leemans and G.J.J. Kreileman, 1998. Global change scenarios of the 21st century. Results from the IMAGE 2.1 model. Pergamon & Elseviers Science, London.

Balkhausen, O. en M. Banse 2004. Modeling of Land Use and Land Markets in Partial and General Equilibrium Models: The Current State. Institute of Agricultural Economics, University of Goettingen. Workpackage 9, deliverable No. 3. IDEMA Project.

Bollen, J.C., T. Manders and M. Mulder, 2004. Four Futures for Energy Markets and Climate Change. CPB Special Publication 52, ISBN 90-5833-171-7, Netherlands Bureau for Economic Policy Analysis, The Hague, and National Institute for Public Health and the Environment, Bilthoven, the Netherlands.

Bouwman, A.F., K.W. van der Hoek, B. Eickhout and I. Soenario, 2004. Exploring changes in world ruminant production systems. *Agricultural Systems*, **84(2)**: 121-153, doi:10.1016/j.agsy.2004.05.006.

Britz, W., 2004, Impact analysis of the Luxembourg Agreement implementation options: CAPRI results. Powerpoint presentation.

CPB, 2003. Four Futures of Europe. Netherlands Bureau for Economic Policy Analysis, the Hague, the Netherlands. See: <http://www.cpb.nl>

De Janvry, A., M. Fafchamps and E. Sadoulet, 1991. Peasant Household Behavior with Missing Markets: Some Paradoxes Explained. *Economic Journal* 101:1400-17.

EC, 2002, FACT SHEET - Enlargement and agriculture: A fair and tailor-made package which benefits farmers in accession countries, MEMO/02/301, Brussels

Eickhout, B., H. van Meijl, A. Tabeau, and H. van Zeijts, 2004. Between Liberalization and Protection: Four Long-term Scenarios for Trade, Poverty and the Environment. Presented at the Seventh Annual Conference on Global Economic Analysis, June, Washington, USA.

Eickhout, B., H. van Meijl and A. Tabeau, 2005. Economic and ecological consequences of four European land-use scenarios. *Land Use Policy*, (forthcoming).

EPA, 1994. International anthropogenic methane emissions: estimates for 1990. EPA 230-R-93-010, U.S. Environmental Protection Agency, Washington, D.C., USA.

FAO, 1999. FAOSTAT database collections. Retrieved 6 March 1999 from <http://aps/fao.org/default.html>. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, 2003. World Agriculture: Towards 2015/2030. An FAO perspective. Food and Agriculture Organization, Rome, Italy.

Fischer, G., M. Shah and H. van Velthuisen. 2002. Climate Change and Agricultural Vulnerability. International Institute of Applied Systems Analysis, Vienna, Austria.

Francois, J., H. van Meijl and F. van Tongeren, 2005. Trade Liberalization and Developing Countries Under the Doha Round, *Economic Policy*, (forthcomming).

Frandsen, S. E., B. Gersfelt and H. G. Jensen, 2002, Decoupling Support in Agriculture: Impacts of redesigning European Agricultural Support, Conference Paper, The 5th Annual Conference on Global Economic Analysis, Taipei.

GTAP, 2004, GTAP 6 Data Package, Purdue University.

Hertel T. W. (ed.), 1997, *Global Trade Analysis. Modeling and Applications*. Cambridge University Press.

Hertel, T. W., K. Anderson, B. Hoekman, J.F. Francois, and W. Martin, 1999. Agriculture and nonagricultural liberalization in the millennium round, paper presented at the Agriculture and New Trade Agenda, October 1-2, 1999, Geneva, Switzerland.

Hertel, T and R. Keening, 2003. Assessing the Impact of WTO Reforms on World Agricultural Markets: A New Approach.

Huang, H., F. van Tongeren, F. Dewbre and H. van Meijl, 2004. A New Representation of Agricultural Production Technology in GTAP. Paper presented at the Seventh Annual Conference on Global Economic Analysis, June, Washington, USA.

IMAGE team, 2001. The IMAGE 2.2 implementation of the SRES scenarios. A comprehensive analysis of emissions, climate change and impacts in the 21st century. RIVM CD-ROM publication 481508018, National Institute for Public Health and the Environment, Bilthoven, the Netherlands.

Jensen, H.G. and Ch.P. Nielsen, 2004. EU dairy policy analysis: Assessing the importance of quota rent estimates, Paper prepared for the 7th Annual Conference on Global Economic Analysis. June 17-19, 2004, Washington, D.C., USA.

Keeling, C. D. and T. P. Whorf. 2001. Atmospheric CO₂ records from sites in the SIO air sampling network. In: "Trends: A Compendium of Data on Global Change", Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

Kleinhanß, W., D Manegold, M. Bertelsmeier, E. Deeken, E. Giffhorn, P. Jägersberg, F. Offermann, B. Osterburg and P. Salamon, 2001. Mögliche Auswirkungen eines Ausstiegs aus der Milchquotenregelung für die deutsche Landwirtschaft [online]. Arbeitsbericht 05/2001 aus dem Institut für Betriebswirtschaft, Agrarstruktur und ländliche Räume der FAL, Braunschweig.

Leemans, R. and B. Eickhout, 2004: Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. *Global Environmental Change*, **14**: 219–228.

Leemans, R., B. Eickhout, B. Strengers, L. Bouwman and M. Schaeffer, 2002. The consequences of uncertainties in land use, climate and vegetation responses on the terrestrial carbon. *Science in China*, **45**, 126-141.

Marland, G. and T. A. Boden, 2000. Global, Regional, and National CO₂ Emissions. In: "Trends: A Compendium of Data on Global Change", Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

Nakicenovic et al., 2000. Special Report on Emission Scenarios. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

OECD 2003. PEM technical Document Draft, Paris.

Parry, M., N. Arnell, T. McMichael, R. Nicholls, P. Martens, S. Kovats, M. Livermore, C. Rosenzweig, A. Iglesias and G. Fischer, 2001. Millions at Risk: Defining Critical Climate Change Threats and Targets, *Global Environment Change*, 11(3): 1-3.

Rosenzweig, C., M. Parry and G. Fischer, 1995. World Food Supply. In: "As Climate Changes: International Impacts and Implications", K.M. Strzepek and J.B. Smith (Eds.). Cambridge University Press, UK, pp. 27-56.

SEC, 2003, Overwegingen bij de Hervorming van het Suikerbeleid van de Europese Unie: Resultaten van het Onderzoek naar de Gevolgen van Hervorming, Werkdocument van de Diensten van de Commissie, Commissie van de Europese Gemeenschappen, Brussel.

Seré, C. and H. Steinfeld, 1996. World livestock production systems. Current status, issues and trends. Animal Production and Health Paper 127, Food and Agriculture Organization of the United Nations, Rome.

Stout, J. and D. Abler, 2004. ERS/Penn State Trade Model Documentation. Electronical version (pdf, June 2nd, 2004): http://trade.aers.psu.edu/pdf/ERS_Penn_State_Trade_Model_Documentation.

Strengers, B., R. Leemans, B. Eickhout, B. de Vries and L. Bouwman, 2004. The land-use projections and resulting emissions in the IPCC SRES scenarios as simulated by the IMAGE 2.2 model. *Geojournal.*, **61**: 381-393.

Van Tongeren, F.W., H. van Meijl and Y. Surry, 2001. Global models of trade in agriculture and related environmental modeling: a review and assessment, *Agricultural economics*, Vol 26/2, p.149-172.

Van Meijl, H. and F.W. van Tongeren, 2002. The Agenda 2000 CAP reform, world prices and GATT-WTO export constraints, *European Review of Agricultural Economics*, Vol. 29 (4) (2002) pp. 445-470.

Westhoek, H.J., Van den Berg, M. and Bakkes, J.A., 2005. Scenario development to explore the future of Europe's rural areas. Submitted to Agriculture, Ecosystems and Environment.

Westcott, P. C. and C.E. Young, 2003. Influences of Decoupled Farm Programs on Agricultural Production, U.S. Department of Agriculture, Economic Research Service.

APPENDIX

Table A1. Region aggregation

Regions identified in GTAP	Coinciding region in IMAGE	Description	Original GTAP v 6.4 regions
Belu	OECD Europe	Belgium and Luxembourg	Belgium; Luxembourg.
Dnk		Denmark	Denmark.
Deu		Germany	Germany.
Grc		Greece	Greece.
Esp		Spain	Spain.
Fra		France	France.
Irl		Ireland	Ireland.
Ita		Italy	Italy.
Nld		The Netherlands	Netherlands.
Aut		Austria	Austria.
Prt		Portugal	Portugal.
Fin		Finland	Finland.
Swe		Sweden	Sweden.
Gbr		United Kingdom	United Kingdom.
Euis	Eastern Europe	Cyprus, Malta	Cyprus; Malta.
Cze		Czech Republic	Czech Republic.
Hun		Hungary	Hungary.
Pol		Poland	Poland.
Svn		Slovenia	Slovenia.
Svk		Slovakia	Slovakia.
Apeu		EU applicants countries	Bulgaria; Romania.
Reur	Resf of Europe	Switzerland; Rest of EFTA; Rest of Europe; Albania; Croatia.	
Euba	Former Soviet Union	EU Baltic countries	Estonia; Latvia; Lithuania.
Fsu		Former Soviet Union	Russian Federation; Rest of Former Soviet Union.
Tur	Middle East	Turkey	Turkey.
Meast		Rest of Middle East	Rest of Middle East.
Usa	USA	USA	United States.
Can	Canada	Canada	Canada.
Cam	Central America	Central America	Mexico; Rest of North America; Central America; Rest of FTAA; Rest of the Caribbean.
Sam	South America	South America	Colombia; Peru; Venezuela; Rest of Andean Pact; Argentina; Brazil; Chile; Uruguay; Rest of South America.
Oce	Oceania	Australia, New Zealand	Australia; New Zealand; Rest of Oceania.
Jap	Japan	Japan	Japan.
Eas	East Asia	East Asia	China; Hong Kong; Korea; Taiwan; Rest of East Asia.
Seas	South Asia	South-East Asia	Indonesia; Malaysia; Philippines;

	South East Asia		Singapore; Thailand; Vietnam; Rest of Southeast Asia; Bangladesh; India; Sri Lanka; Rest of South Asia.
Naf	Northern Africa	North Africa	Morocco; Rest of North Africa
Caf	Eastern Africa Western Africa	Central Africa	Rest of SADC; Uganda; Rest of Sub-Saharan Africa.
Saf	Southern Africa	South Africa	Botswana; South Africa; Rest of South African CU; Malawi; Mozambique; Tanzania; Zambia; Zimbabwe.

Table A2. Sector aggregation

Sectors in GTAP	Coinciding sector in IMAGE	Description	Original GTAP v 6.4 sectors
Grain	Temperate cereals Tropical cereals Maize	Cereal grains nec	Wheat; Cereal grains nec.
Oils	Oil crops	Oil seeds	Oil seeds.
Sug	Sugar	Sugar cane and beet, sugar	Sugar cane, sugar beet.
Hort		Vegetables, fruit, nuts	Vegetables, fruit, nuts.
Crops	Roots & Tubers Pulses	Other crops	Paddy rice; Plant-based fibers; Crops nec.
Cattle	Non-dairy cattle Sheep & goats	Cattle,sheep,goats,s,horses	Cattle,sheep,goats,horses; Meat: cattle,sheep,goats,horse.
Oap	Pigs Poultry	Animal products nec	Animal products nec; Meat products nec.
Milk	Dairy cattle	Raw milk	Raw milk.
Dairy		Dairy products	Dairy products.
Sugar		Sugar	Sugar.
Agro		Other agr-food products	Wool, silk-worm cocoons; Forestry; Fishing; Vegetable oils and fats; Processed rice; Food products nec; Beverages and tobacco products.
Ind		Industry	Coal; Oil; Gas; Minerals nec; Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Petroleum, coal products; Chemical,rubber,plastic prods; Mineral products nec; Ferrous metals; Metals nec; Metal products; Motor vehicles and parts; Transport equipment nec; Electronic equipment; Machinery and equipment nec; Manufactures nec.
Ser		Services	Electricity; Gas manufacture, distribution; Water; Construction; Trade; Transport nec; Sea transport; Air transport; Communication; Financial services nec; Insurance; Business services nec; Recreation and other services; PubAdmin/Defence/Health/Educat; Dwellings.

Table A3. GDP and population yearly growth rates in 2001 – 2030

	GDP				POP			
	GE	GC	CM	RC	GE	GC	CM	RC
belu	2.6	1.5	1.9	0.8	0.2	0.1	0.0	-0.1
dnk	2.7	1.7	2.1	1.1	0.3	0.2	0.1	0.0
deu	2.2	1.2	1.7	0.6	0.1	0.0	-0.1	-0.2
grc	2.6	1.6	2.0	0.9	0.2	0.1	0.0	-0.2
esp	3.1	1.9	2.3	0.9	0.1	0.0	-0.2	-0.3
fra	2.7	1.5	2.0	0.8	0.4	0.3	0.2	0.0
irl	3.3	2.2	2.6	1.6	0.8	0.8	0.6	0.5
ita	2.1	1.1	1.3	0.2	0.0	-0.1	-0.3	-0.4
nld	2.7	1.8	2.0	1.0	0.6	0.5	0.3	0.1
aut	2.5	1.5	1.9	0.8	0.1	0.0	-0.1	-0.2
prt	2.6	1.6	2.0	0.9	0.2	0.1	-0.1	-0.2
fin	2.6	1.6	2.1	1.0	0.2	0.1	0.0	-0.1
swe	2.7	1.6	2.1	1.0	0.2	0.2	0.1	0.0
gbr	2.4	1.5	1.9	0.9	0.3	0.2	0.1	0.0
euis	3.1	2.1	2.3	1.3	0.7	0.6	0.3	0.2
cze	3.2	2.7	2.0	1.0	0.1	0.0	-0.5	-0.5
euba	3.8	3.6	2.3	1.5	-0.1	-0.2	-0.7	-0.7
hun	3.1	2.7	1.8	0.8	-0.2	-0.3	-0.8	-0.8
pol	3.6	3.3	2.2	1.3	0.2	0.1	-0.4	-0.4
svn	2.5	1.5	1.7	0.8	0.1	0.0	-0.4	-0.5
svk	4.0	3.7	2.5	1.6	0.3	0.2	-0.2	-0.3
apeu	5.2	5.6	2.8	1.9	-0.1	-0.2	-0.9	-0.9
reur	2.8	1.8	2.0	0.8	0.4	0.3	0.0	-0.1
fsu	4.0	3.6	2.4	1.4	0.0	-0.1	-0.8	-0.8
tur	5.2	5.1	3.3	3.0	1.3	1.2	0.8	0.7
usa	2.7	2.0	2.6	1.6	0.8	0.8	0.9	0.7
can	2.7	2.1	2.0	1.5	0.5	0.5	0.6	0.6
cam	4.1	3.9	1.7	3.1	1.0	1.0	1.6	1.1
sam	3.7	3.5	1.4	2.8	1.0	1.0	1.6	1.1
oce	2.4	1.8	1.7	1.2	0.2	0.2	0.3	0.3
jap	1.7	0.9	1.1	0.6	0.0	0.0	-0.1	-0.1
eas	6.1	5.1	3.1	4.5	0.3	0.3	1.0	0.6
seas	5.3	4.7	3.0	4.2	0.9	0.9	1.3	0.9
meast	4.4	4.4	2.5	3.2	1.7	1.7	2.1	1.5
naf	5.2	5.2	3.2	4.0	1.6	1.6	2.1	1.5
caf	6.3	7.0	4.9	3.9	2.1	2.1	2.3	2.4
saf	5.1	5.8	4.0	3.0	2.1	2.1	2.3	2.4