

The importance of land heterogeneity in long-term scenario analyses

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In many long-term assessment reports like the Millennium Ecosystem Assessment, FAO's World Agricultural Outlook until 2015/2030, UNEP's Global Environment Outlook and OECD's Environmental Outlook projections of the agricultural sector are the basis for further conclusions in these assessments. However, in many of these studies the rationale of these food and feed projections is not explained in great detail. Many of these results are driven by assumptions on land availability in macro-economic models. Here, we present a new methodology for macro-economic models to consider the availability and heterogeneity of land. In this approach we constructed land-supply curves for a macro-economic model (GTAP), using detailed crop productivity data from a integrated biophysical model (IMAGE). Moreover, an iterative process of these models is suggested to improve economic and ecological foresights for the agricultural sector. Our simulation results show that inclusion of biophysical factors in GTAP affects the overall production level of the agricultural sector significantly. The model without land supply curves underestimates the increase of agricultural production and use of agricultural land and overestimates intensification of the agricultural production process. Endogenous land use supply curves imply lower pressure on land prices and a decrease of the real world price of agricultural products while in a case when the agricultural land is fixed, the land and food prices increase. Endogenization of land supply creates changes in the regional production distribution because of comparative advantage of land-abundant regions such as Africa and Indonesia. Therefore, a proper inclusion of land in economic models is essential for future global assessments of economic and ecological issues.

1. Introduction

Food supply and food distribution have been among the most important issues playing a role in the global political arena. In this context the issue of reforming agricultural support policies in industrialized countries and improving market access, in particular for developing countries, have been important subjects of The Doha Development Round of World Trade Organization (WTO). Given this Doha Round agenda, many shifts in the agricultural and trade policies are expected in the coming years. These expected changes in trade regimes coincide with other societal changes like growth in world population and global welfare. Consequently, the world food demand will experience huge changes. These developments need to be analyzed in an integrated manner focusing on shifts in global food supply market and vulnerability of environmental conditions.

So far, future agricultural scenarios are mostly provided by economic models, focusing on economic consequences of changes in trade regimes (see, e.g., Anderson, 1999; FAO, 2003). In these economic analyses the biophysical circumstances like land availability, soil quality and atmospheric conditions are poorly accounted for (Balkhausen and Banse, 2004). Moreover, land needs to be included in economic models since land can move into or out of agricultural production due to several reasons. For example, land supply to agriculture 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 correct treatment of this shift in agricultural land is essential for the plausibility of the results of agricultural economy models (Eickhout et al., 2006).

Over the years land has been implemented in both Partial Equilibrium (PE) and General Computable Equilibrium (GCE) models. Partial Equilibrium Models (PE) treat international markets for a selected set of traded goods, e.g. agricultural goods. They consider the agricultural system as a closed system without linkages with the rest of the economy. Partial models are in principle able to provide much product detail, including details on land. However, the PE models underestimate or do not endogenously include an impact of non-agricultural sectors on agriculture and substitution between land and other production factors in the agricultural production, which leads to intensification or extensification of production (Van Meijl et al., 2006).

CGE models provide a complete representation of national economies, next to a specification of trade relations between economies. CGE models are specifically concerned with resource allocation issues, that is, where the allocation of production factors over alternative uses is affected by certain policies or exogenous developments. International trade is typically an area where such induced effects are important consequences of policy choices. In general, in CGE models aspects of land-use modeling are treated in rudimentary manner compared to PE models (Van Meijl et al., 2006).

However, not only land availability should be included in economic models, but also land heterogeneity. Often the heterogeneity of land is only partly or not at all taken into consideration in economic models. By regarding land as a homogenous entity marginal lands and changes in productivity due to land degradation, water stress and climate change are not considered. In order to capture the heterogeneity of land in economic models the biophysical information should not only capture land availability, but should also address the differences in quality.

Here, a methodology is presented to take into account land availability and land heterogeneity in an economic model. For this methodology an extended version of the macro-economic model of the Global Trade Analysis Project (GTAP; Van Meijl et al., 2006) is used in conjunction with the biophysical tool 'Integrated Model to Assess the Global Environment' (IMAGE; Eickhout et al., 2006). Linking IMAGE with GTAP allows to:

- use the biophysical information from IMAGE concerning land availability to implement so-called land supply curves into the GTAP model;
- take into account the land heterogeneity and its relation with biophysical factors in GTAP calculations.

This leads to consistent integrated scenarios concerning development of the agricultural sector in the future from both an economic and biophysical point of view, allowing regional analyses as for Europe (Eickhout et al., 2007).

To show the importance of the implementation of land-supply curves the same scenario analysis is performed with a standard GTAP-model, where land is implemented exogenously. This means that the GTAP model 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 for this. In other words, factor markets are competitive, and labor, capital and land are mobile between sectors but not between regions (Hertel, 1997).

In Section 2, the methodology concerning economic and biophysical issues of agricultural land supply and land supply curve parameterization is discussed. The scenario construction is described in Section 3. Section 4 compares GTAP model simulation results with and without the land supply curve. Section 5 concentrates on discussion and conclusions.

2. Implementing land availability and heterogeneity in GTAP: agricultural land supply curve

From an economic point of view, the agricultural land supply is a function of the price of land as expressed by land rent. The supply of agricultural land depends on its biophysical availability (potential area of suitable land), institutional factors (agricultural and urban policy, policy towards nature) and land price. The assumption that the most productive land is taken into production first leads to the shape of the agricultural land supply curve presented in Figure 4. If the gap between agricultural land potentially available and land actually used in the agricultural sector is large, any increase in demand for agricultural land will lead to land conversion to agricultural use and will be accompanied by a modest increase in land price. Such a situation occurs in the flat part of the land supply curve (Figure 1). In contrast, when the agricultural land that is in use is close to the potential area, an increase in demand for agricultural land will lead to an increasing land price (land becomes scarce). In such a situation, land conversion is difficult to achieve, and therefore the elasticity of land supply with respect to land price is also low. Points situated on the steep part of the land supply curve in Figure 1 describe this situation.

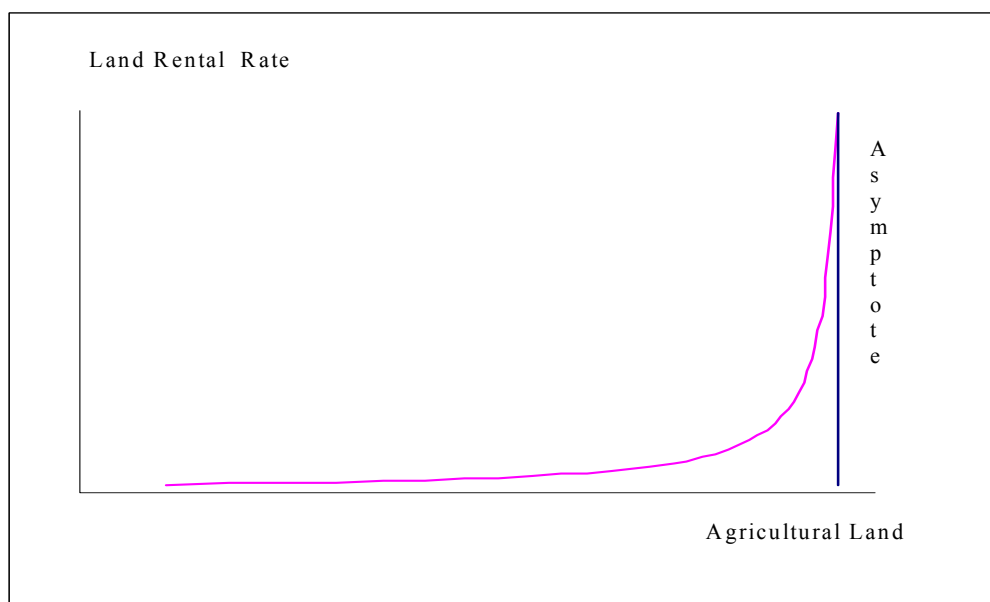


Figure 1: Land supply curve determining land conversion and land rental rate

The relation between the potential land productivity and accumulated land area - land productivity curve - depends on the number of biophysical factors like soil and climate characteristics. In IMAGE, the productivity for seven food crops is calculated for each 0.5 by 0.5 degree grid cell with the crop growth model of IMAGE (Leemans and Van den Born, 1994). For GTAP this information is aggregated to an average of the overall productivity for each grid cell, expressed on a relative scale between 0 and 1 on the basis of each theoretical maximum productivity per crop type (Eickhout et al., 2006). Land productivity curves are

obtained by ordering all grid cells in each of the 24 world regions from high to low productivity, and cumulating the total area (Figure 2). The land productivity curve can be translated to a land supply curve assuming that the land price is a function of the inverse of the land productivity (Figure 2).

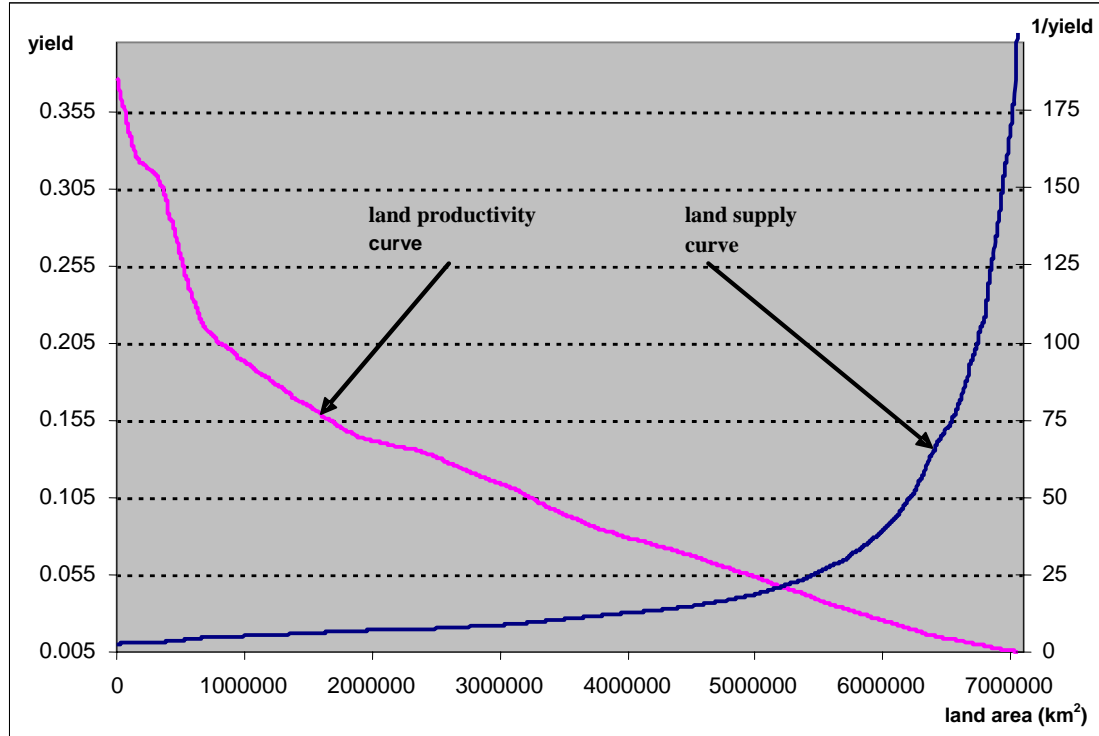


Figure 2: Land productivity and land supply curve for Canada on the basis of IMAGE simulations.

To parameterize this land supply curve, the following function is assumed:

$$L = a - b/[c_0 + (1/y)^p + \sum_{i=1, \dots, n} c_i (1/y)^{p+i}] \quad (1)$$

where L is land supply, “ a ” (>0) is an asymptote interpreted as the maximal potentially available agricultural land, b , c_0 , c_i and p are positive parameters and $1/y$ is an inverse of a land productivity.

Assuming that the denominator of the land function can be interpreted as the real land rental rate (r) power p , then the function (1) can be re-written as

$$L = a - b/r^p \quad (2)$$

The obtained function is identical to the land supply function as proposed by Cixous (2006).

In applications, the estimation or calibration of the land supply function parameters is very important. The shape of this function and, consequently, land supply reaction on the real rental rate changes, can differ significantly for different parameter settings. Figure 3 presents two different land supply functions calibrated under an assumption of $a = 20$, $b = 5$, $L = 15$ and $r = 1$.

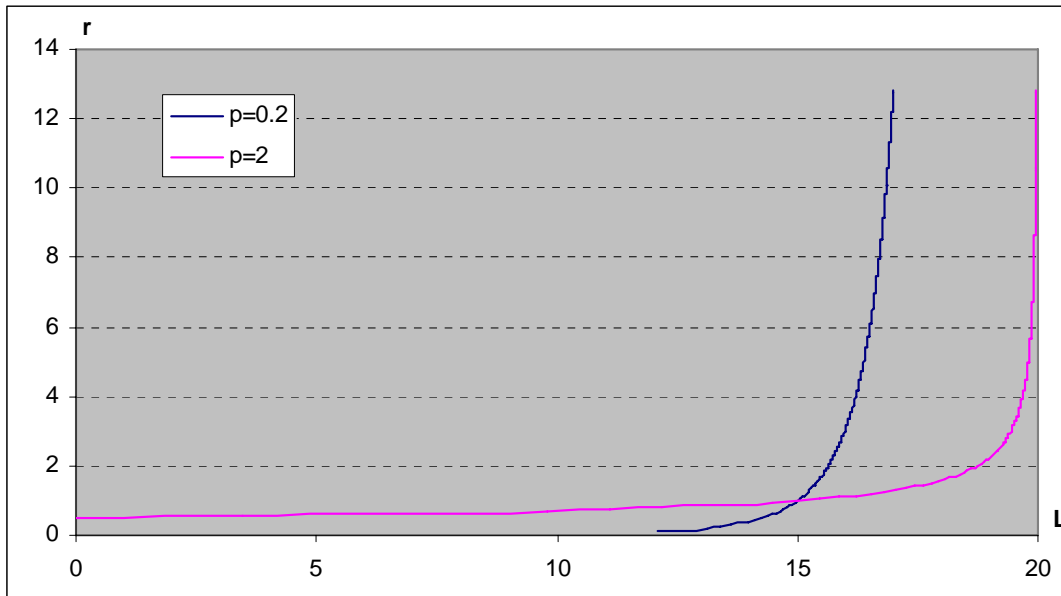


Figure 3: Land supply function for different values of parameter “p”.

For a small p (see equation 2), and therefore a small price elasticity of land supply, an increase of land supply is associated with high costs measured by rental rate increase. In this case, the highly productive land is scarce. A high p means the opposite: a large price elasticity and abundant high productive land, which allows for expanding agricultural land for a low price. Therefore, different values of the parameter p will lead to different reactions of the model in the case of comparable land scarcity cases (as a function of percentage of agricultural land used in the production process). This approach is a further extension of the land supply curve as introduced in Van Meijl et al. (2006).

The land supply curve is estimated for 25 countries and regions (see Table A in Appendix 2). The parameters b and c_i (Equation 1) are estimated using a non-linear least square estimation method for given parameters “ p ” and “ n ”. They are set to maximize the fit of the regression. Since the inverse of yield is not a good proxy of real land rental rate when land is very scarce or when land is in oversupply the observations at the beginning and the end of the curves are neglected¹.

Asymptote “ a ” of the land supply curve is also provided by the IMAGE model and shows the availability of land in each region. Grid cells are excluded from the land productivity curve when the productivity value is equal to zero (mainly ice and desert in regions like Canada and Middle East). Moreover, urban area and protected bioreserves are also excluded in each region to take into account nature conservation and urbanization. When agricultural land is scarce, the conversion of non-agricultural land to agricultural land can be very costly. In that case, the inverse of yield is not a good indicator of the cost. This is currently observed for two analyzed regions: Western Europe and Japan. For Western Europe and Japan, we estimated the asymptote simultaneously with other parameters of the land supply curve using only

¹ In the estimation process, all observations associated with yield higher than 0.0142 and lower than 0.4 are used (i.e. r higher than 2.5 and lower than 70). We also weight the observations by inverse of yield to give higher weights to relatively low number of observations concerning the “end” of the land supply curve.

observations concerning the accumulated land area lower than currently used agricultural area.

Moreover, in the case of EU15 the conversion of non-agricultural land to agriculture is strongly limited by EU15 policy towards nature. Therefore for EU15, the parameters of land supply function are estimated using price elasticities from Cixous (2006). Cixous (2006) estimated land supply elasticities in respect of land price while using a long run relation between land use and the land price. This function was estimated for all EU15 countries using 1973 - 2004 time series.

The selected estimation results of the land supply curve are presented in Appendix 1. In general, the estimated land supply curve fit the data very well and the R-square exceeds 0.90 being often close to 1.

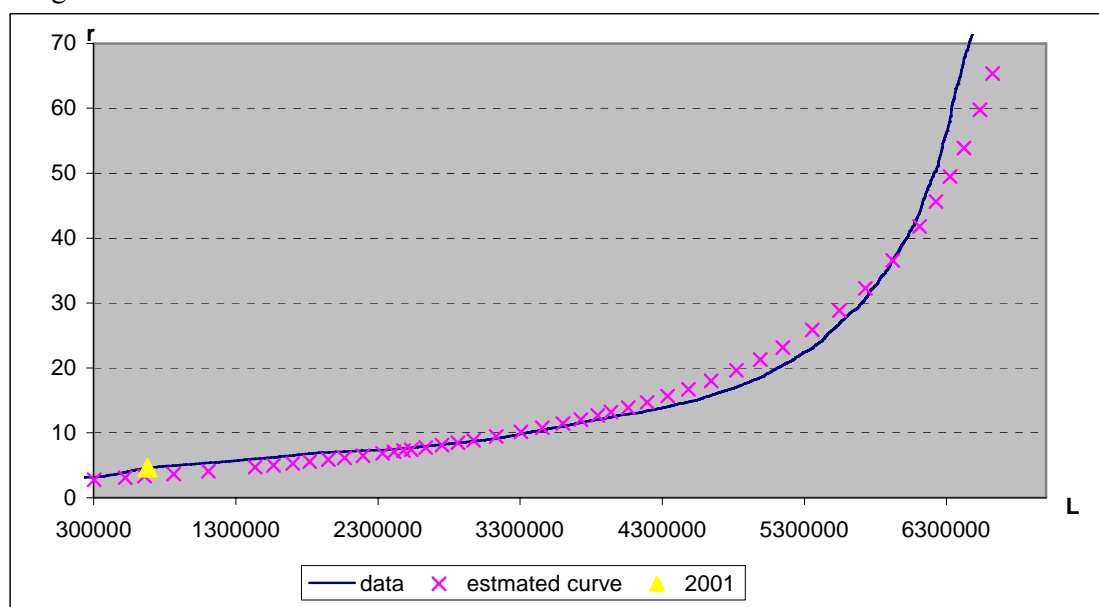


Figure 4: Current position of Canada on its land supply curve (L in km²)

The estimation results (Appendix 1) show agricultural land is scarce in North Africa, EU, Rest of Western Europe, Former Soviet Union, Middle East, Oceania and Japan. According to these results, all these regions are currently situated on the steep part of their land supply curve and the associated land supply elasticities in respect of the real land rental rate are lower than 1 for these regions.

The current position of Canada on the land supply curve indicates that the agricultural land in Canada can still be expanded without a steep increase in the real land rental rate (Figure 4). The opposite situation is observed for China. Even a small expansion in agricultural land in China will lead to a high increase in the real land rental rate, therefore stimulating intensification processes in agricultural practices (Figure 5).

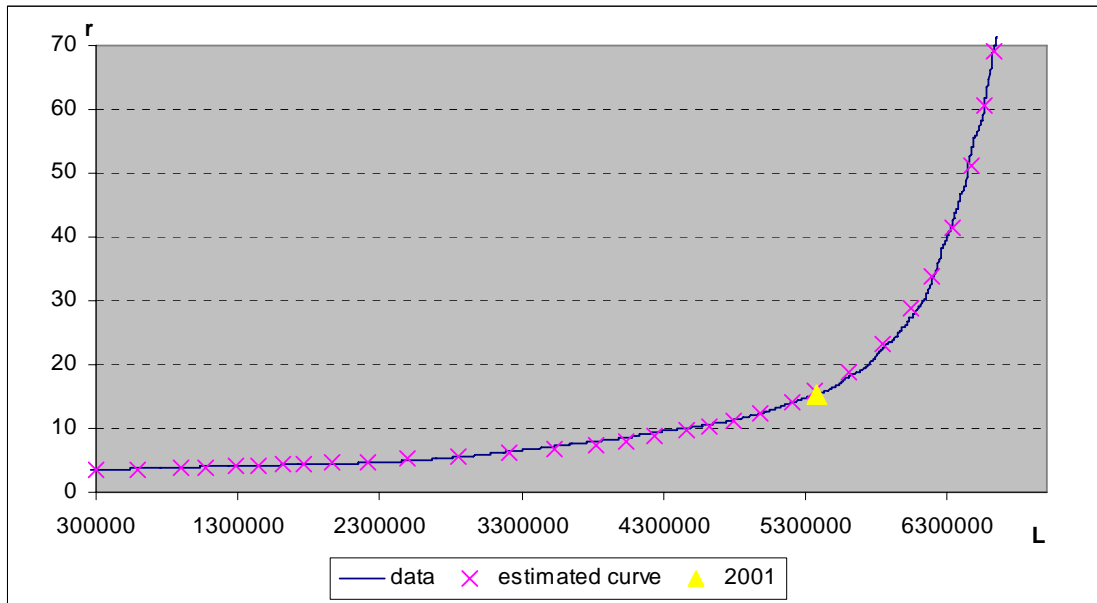


Figure 5: Current position of China on its land supply curve (L in km²)

Another part of the methodology is iterating GTAP results with the IMAGE models to alter land use efficiency (yields) in GTAP using environmental feedbacks from IMAGE (Eickhout et al., 2006). In this approach, yields in GTAP depend on an exogenous part (the trend component) and an endogenous part with relative factor prices (the management component; Van Meijl et al., 2006). The production structure used in LEITAP implies that substitution is possible among the different production factors. If land prices rise, the producer will substitute land for other production factors such as capital and as a consequence land productivity (yields) will increase.

The exogenous trend of the yield in GTAP and IMAGE is taken from Bruinsma (2003) where macro-economic prospects are combined with local expert knowledge to produce best-guesses of the technological change for each country for the coming 30 years. The FAO data were therefore used as exogenous input for the first model run with the GTAP model. However, many studies indicated that yields are also enhanced or reduced by other external environmental 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 as well.

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 (Eickhout et al., 2004). Therefore, in our approach, the exogenous part of the yield is updated in an iterative process with the IMAGE model (Figure 6), which is taking these factors into account when updating yields changes (Van Meijl et al., 2006; Eickhout et al., 2006).

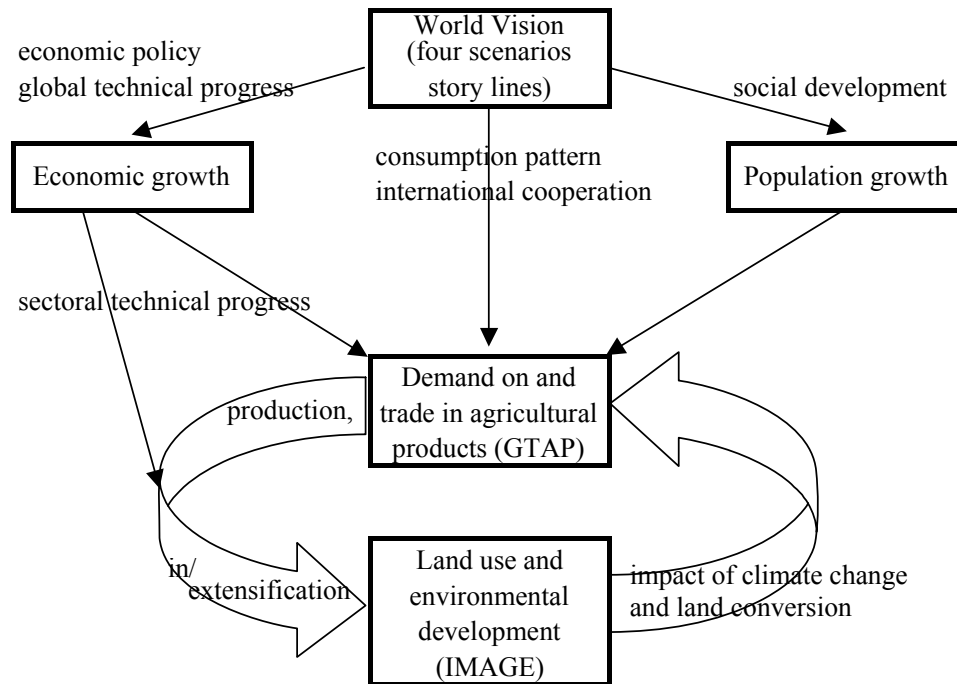


Figure 6. Scheme showing the methodology of model interaction (iteration) between LEITAP and IMAGE.

The iteration between GTAP and IMAGE is ended when arable land use projections in both models are similar. This iteration is only performed for crops. Since GTAP bases its calculations on land supply curves from IMAGE, the amount of iteration needed is limited. Convergence of the crop areas is not guaranteed, but several scenario studies showed that after three rounds of iteration, most of the crop areas in IMAGE and GTAP are similar.

3. Experimental set-up

In the scenario analyzed in this paper it is assumed that world economic growth is about 2.7% per year and population growth about 0.8% per year in 2001-2050 period. The assumed economic and population developments are very different for different regions. For instance, the real GDP in developed countries is growing almost two times slower than in the developing countries and population in developed countries is growing more than 5 times slower than in the developing countries. When agricultural policies are considered, the implementation of the 2003 reforms of the European Common Agricultural Policy is assumed. This means that decoupling of direct payments and reforms of dairy policy are introduced in the scenario calculations.

For simulation experiments, version 6 of the GTAP database was used (Dimaranan et al., forthcoming). The GTAP database was aggregated to 18 sectors and 25 regions (see Annex 2). The sectoral aggregation distinguishes agricultural sectors that use land and sectors engaged in the Common Agricultural Policy (CAP). The regional aggregation includes the most important countries and regions belonging to the OECD, transition economies and developing countries.

The simulations were done with the extended version of the standard GTAP model as explained in Section 2 and with a standard GTAP version where no land supply curves are implemented. Next, all calculations are performed twice: once with the model including the land supply curve (i.e.: endogenous land supply) and once with the standard GTAP model with exogenously fixed land supply (model without land supply curve). In both cases one iteration round is performed with the IMAGE model.

In the simulation experiments, the exogenous GDP targets are met given exogenous estimates on factor endowments - skilled labor, unskilled labor, capital and natural resources - and population. This implies that at the country level technological change is endogenously determined within the model (Hertel et al., 2004). Common trends for relative sectoral total factor productivity (TFP) growth are implemented (CPB, 2003). CPB assumed that all inputs achieve the same level of technical progress within a sector (i.e., Hicks neutral technical change). This approach is adjusted in the agricultural sector using additional information on yields from Bruinsma (2003). For non-land using sectors a Hicks neutral technical change is assumed.

4. Comparison of model simulation results with and without land supply curve

To compare the simulation results of the models with and without the land supply curve, we concentrate on the primary agricultural sector. Inclusion of the land supply curve in the model (the endogenous-run) affects the overall production level of the agricultural sector as well as its regional distribution compared with the model without the land supply curve (characterized as the exogenous-run).

When land supply is used endogenously additional land can be taken into production. On the global level, land use in agriculture is increased by 12.5% (see Figure 7), since in many developing regions land is available abundantly. Figure 8 shows most of the increase in regions like Central Africa, Indonesia, Turkey and South Asia (India+). The increase of agricultural area allows for production increase as well. As a result, economic models with exogenously fixed land supply underestimate global agricultural production growth by about 15% and world domestic consumption of home produced agricultural products by 30%. This obviously leads to overestimation of the world agricultural trade growth by almost 70% in the case when land is kept constant (Figure 7).

An increase in agricultural land supply generates less pressure on the intensification of agricultural production process. As a consequence, the model with fixed agricultural land overestimates the land use intensity by 6% (Figure 7). Higher agricultural land and production supply together with quite inelastic demand for agricultural products lead to lower pressure on the land prices and decrease of the world price of agricultural products by 40% when land is implemented endogenously compared with 26% increase when the global agricultural area stays unchanged (Figure 7). These global results clearly show the importance of a correct reflection of land availability in each region.

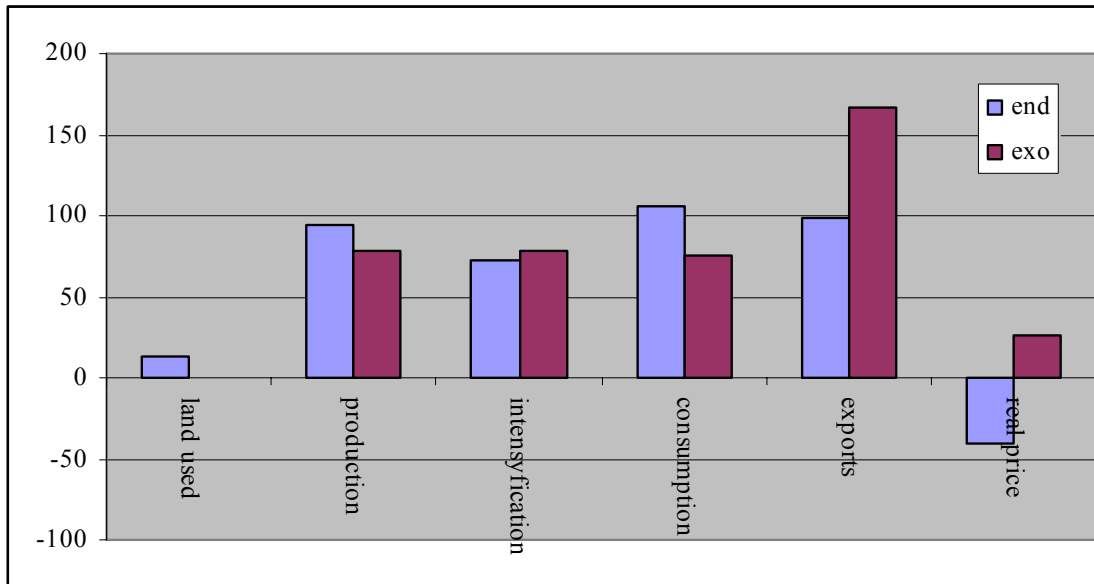


Figure 7. World wide development of the agricultural sector in 2001 - 2050 (percentage changes): endogenous (end) versus exogenously fixed (exo) land supply

Regional results

The response of the agricultural sector of different countries or regions to agricultural land supply endogenization is quite diverse depending on agricultural land availability in the particular region and the current position of the region on its land supply curve. In general, the amount of land use in the agricultural sector increases in all regions when land is abundant (see Figure 8). This is happening to a very large extent in regions like Central and South Africa, Turkey, Russia, South Asia and Indonesia, where agricultural land is increasing from 22% (in South Africa) to 84% in Turkey. In Japan and Korea and the European Union, where most of the high productive agricultural land is already in use, agricultural areas are decreasing from about 10 to almost 40 percent (Figure 8).

In the Western European and Russian regions where agricultural land is decreasing, the intensification of agricultural practices is lower compared to the intensification in the same region when land is simulated exogenously. In land scarce regions like Korea and Japan, a decrease of agricultural area leads to more intensive production process compared to the case when agricultural land is unchanged. Here, land abandonment is compensated by an intensified production process (Figure 8). Nevertheless, the total agricultural production in these regions is lower than in the case of exogenously simulated land (Figure 9).

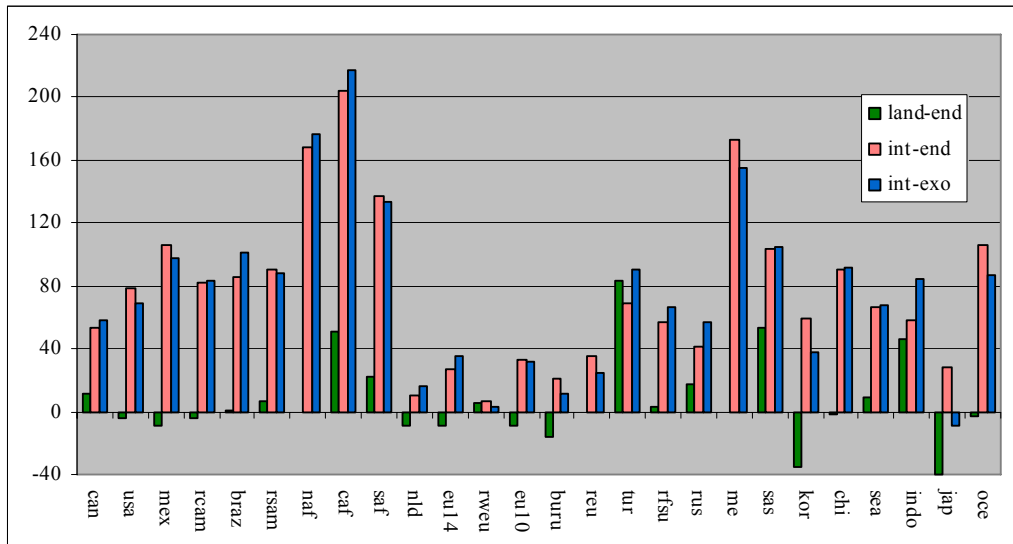


Figure 8. Agricultural land (land) and agricultural production intensity (int) changes (%) in 2001 - 2050 period in different regions: endogenous (end) versus exogenously fixed (exo) land supply.

In most of all other regions the total agricultural production is increased due to this additional availability of land (Figure 9). Especially in land abundant regions, the land increase is very large. In other words, models with exogenous land overestimate agricultural production development in land scarce regions like EU, rest of the Former Soviet Union, Russia, Japan, Korea and China. Similarly, the model with exogenous land underestimates production of most of the land abundant regions, which are mostly present in the Tropics. The exceptions here are Mexico, Brazil and Rest of the Central America. For these counties relatively low growth rates of capital and labor per unit of GDP growth are seen compared to regions like Central Africa, South Asia and Indonesia. Endogenization of land supply results in lower land price (Figure 7) and therefore land is often substituted by other than land primary production factors. Therefore, in some of the developing regions like Brazil, a lower production level is simulated, compensated by production levels in Africa, South Asia and Indonesia (Figure 9).

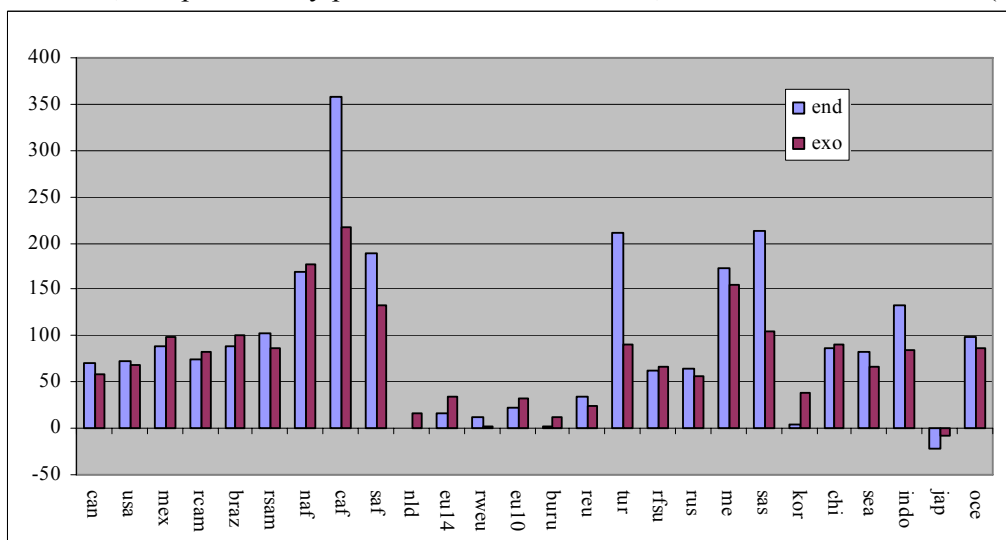


Figure 9. Agricultural production changes (%) in 2001 - 2050 period in different regions: endogenous (end) versus exogenously fixed (exo) land supply.

According to Figure 10, the model with exogenous land supply function underestimates consumption of the home produced agricultural products in all countries besides of Japan and Korea. The higher consumption in endogenous land case is driven by lower land prices and higher production level, which results in decrease of agricultural price level (see Figure 11).

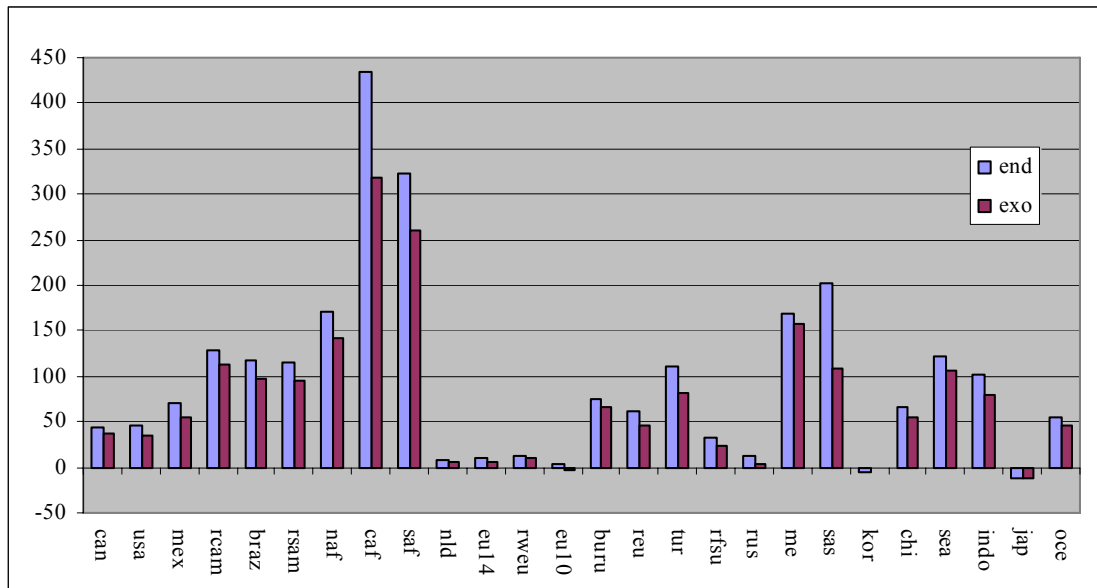


Figure 10. Changes (%) of agricultural consumption of domestic agricultural products in 2001 - 2050 period in different regions: endogenous (end) versus exogenously fixed (exo) land supply.

The model with exogenous land, spectacularly overestimate the real price changes of agricultural products in countries where land is abundant (Central and South Africa, Turkey, Russia, South Asia and Indonesia). For instance, agricultural prices in South Asia are almost twice as high (Figure 11). These differences are crucial in assessing future developments of the agricultural market, including its environmental consequences.

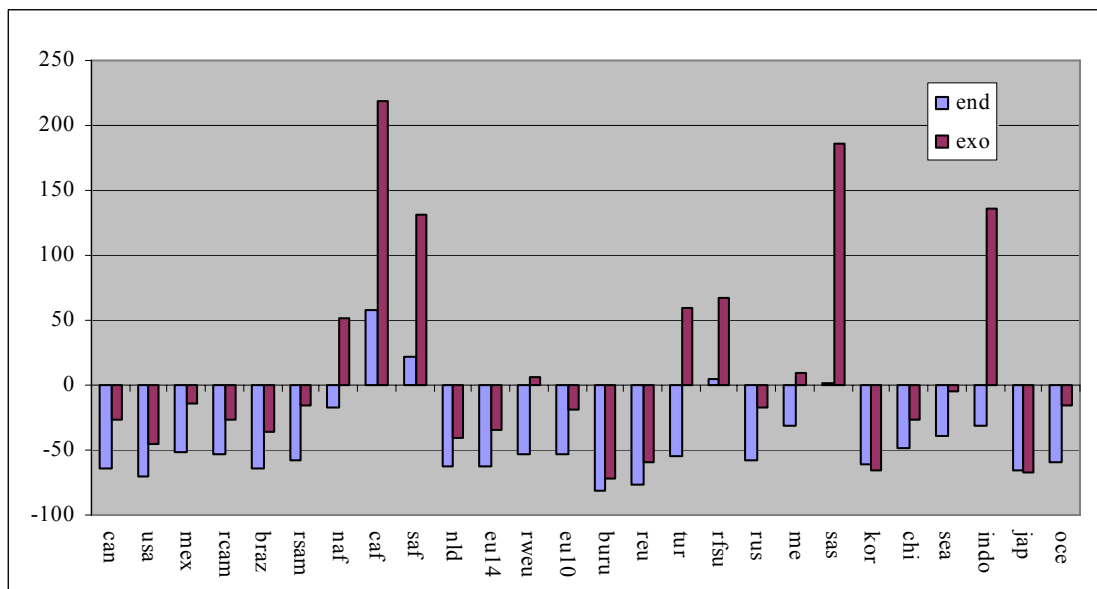


Figure 11. Changes (%) of real agricultural prices in 2001 - 2050 period in different regions: endogenous (end) versus exogenously fixed (exo) land supply.

Trade and environmental consequences

Most of the environmental consequences, like climate change, air pollution and biodiversity are driven by increases in consumption and production (GEO3, 2002). Therefore, a good reflection of land use in economic models is crucial to simulate environmental foresights correctly. The changes in consumption and production as simulated by GTAP with land implemented endogenously and exogenously (Figures 9 and 10), are having an immediate effect on environmental pressures as simulated by the IMAGE model (Figures 12 and 13).

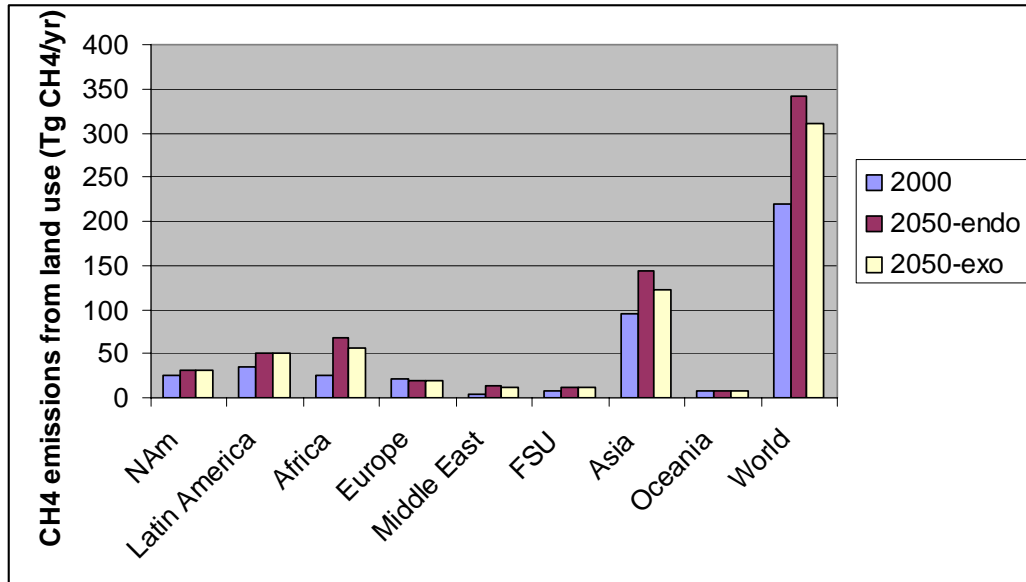


Figure 12. Land-use methane emissions in Tg CH₄ per year on a regional level in 2000 and 2050 in both modeling cases.

To visualize consequences for climate change land-use emissions for methane are plotted in Figure 12. Methane is one of the most important greenhouse gases (after CO₂) and is mostly emitted by the agricultural sector. Especially the cattle and rice sector are the most important CH₄ emitting sectors. Therefore, Asia is the most important methane emitter region in 2000. Increases in these emissions are expected in Asia and Africa as well, since consumption is expected to increase the most here (Figure 10). Globally, the methane emissions are increasing 55% in the case of land modeled in GTAP endogenously. When land is modeled exogenously, methane emissions are expected to increase 'only' with 40%. Clearly, a good reflection of land in economic models is also affecting environmental foresights. Standard economic models with land modeled exogenously are underestimating the environmental impact of growth in agricultural consumption and production.

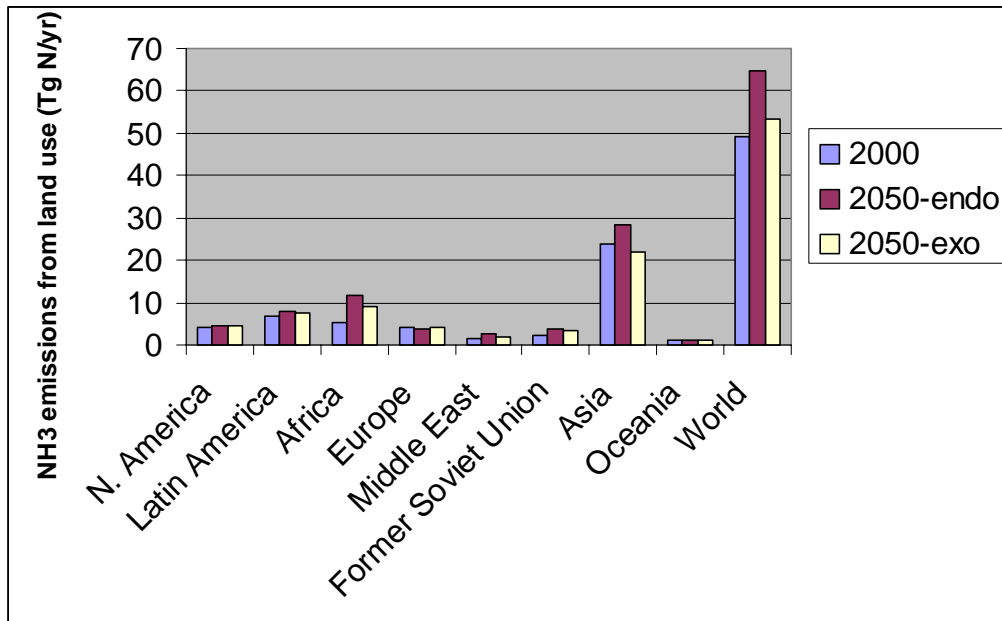


Figure 13. Land-use ammonia (NH₃) emissions in Tg N per year on a regional level in 2000 and 2050 in both modeling cases.

For ammonia emissions, the same regional trends as for CH₄ are visible (Figure 13). Ammonia can lead to acidification and is a good indicator of a nitrogen surplus that can impact aquatic biodiversity. Ammonia is emitted mostly by animal manure and fertilizers, which is used on agricultural land to increase the production. Intensification leads to higher NH₃ emissions, but also the increase in agricultural land will lead to additional use of manure and fertilizer. Therefore, this environmental pressure is also increasing more in the case of land simulated endogenously (with land supply curves).

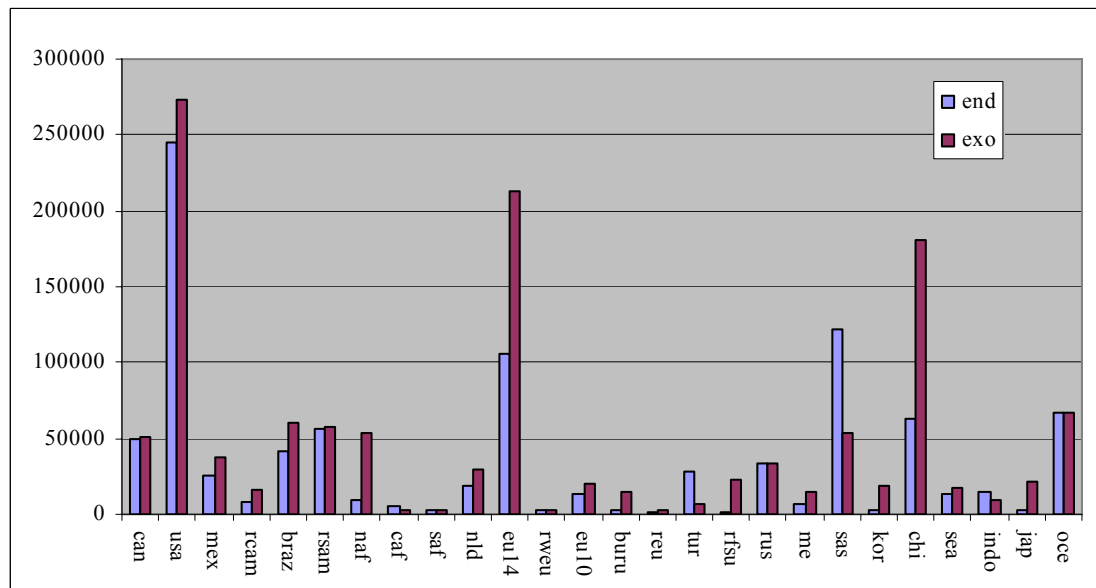


Figure 14. Export volume (mil 2001 \$) in 2050 in different regions: endogenous (end) versus exogenously fixed (exo) land supply.

Consistently with production and consumption results, the model with exogenous land overestimates agricultural exports in almost all other regions (see Figure 14). Only for Turkey and South Asia and Indonesia – countries with huge production increase – agricultural export is significantly underestimated. When the net-exports in analyzed (Figure 15), we can see that endogenization of the agricultural land supply changes Turkey and South Asia from net-importer to net-exporters and significantly lowers Central Africa and Indonesia net-exports. At the same time China become net-importer and EU15 net-exports is decreasing almost fivefold (Figure 15).

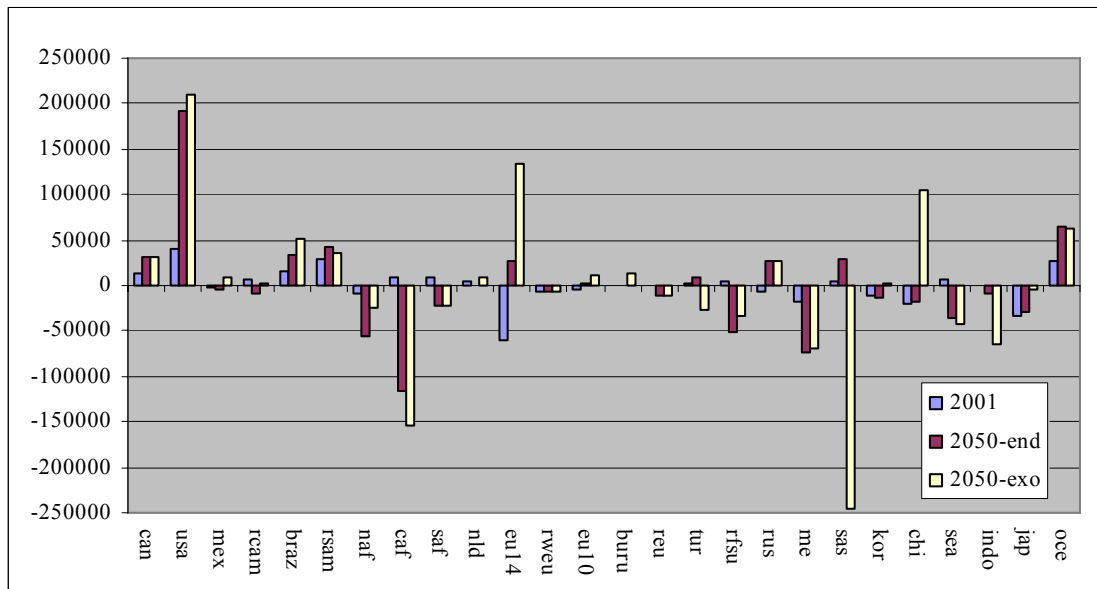


Figure 15. Net-exports volume (mil 2001 \$) in 2050 in different regions: endogenous (end) versus exogenously fixed (exo) land supply.

Importance of land productivity and macro-economic factors on land development

The conversion of land to land use for agricultural production is mainly driven by food demand factors and macroeconomic factors such as GDP and population growth (see Figure 16). The land productivity trend including land heterogeneity factors drives land out of the agricultural sector. The impact of land productivity is relatively larger for land abundant countries than for land scarce countries. For high developed and land scarce countries as: EU, Korea and Japan, it is the main factor driving land out of agriculture (Figure 16).

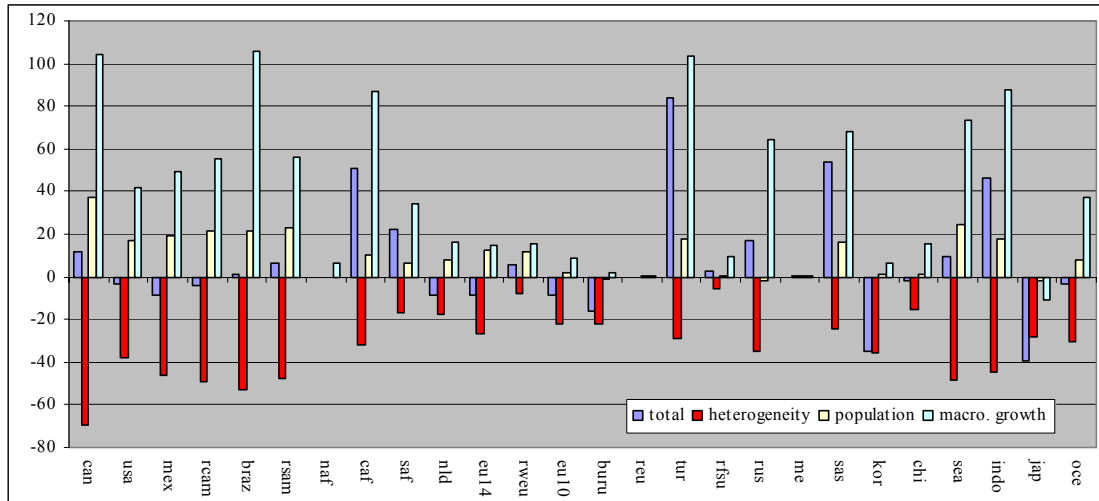


Figure 16: Total agricultural land growth in 2001-2050: the macro-economic and productivity impacts

The impact of the macro-economic growth (impact of GDP and other than land primary production factors growth) is mostly much higher than population growth impact. The relatively high population growth influence compared with GDP growth impact is observed for EU15 and rest of the Western Europe countries. The macro-economic growth is the main force causing land supply increase in the land rich regions. In these regions, it overshadows the negative impact of land productivity growth.

5. Conclusions

When GTAP is run with a fixed supply of agricultural land, the overall agricultural production increase is smaller than in the run *with* a land supply curve. Moreover, the degree of intensification is higher in the case of constant land availability, compared with the experiments with endogenous agricultural land supply. So “releasing” the land constraint causes a higher consumption and production level and a lower level of intensification. Endogenous land use implies lower pressure on land prices and a decrease of the world price of agricultural products. When agricultural land is fixed, land prices increase more than in the case of endogenous land.

There are regional differences in development of agricultural production and land use intensity. In general, agricultural production is higher and land use intensity is lower in land abundant regions when agricultural land is endogenously modeled. As an increase in food and feed demand leads to a relatively large increase in land area and a smaller increase in land price, land expansion is particularly high in regions like Central and South Africa, Turkey, South Asia and Indonesia. The lower increase in land price leads to lower prices for agricultural products and therefore to an additional increase in demand (expansion effect). The expansion effect is positive for all countries except Korea and Japan, since in these regions the land prices are very high, and, therefore, production shifts away to other regions.

In general, when land supply is modeled endogenously, the relation between agricultural products prices of different countries changes in favor of land abundant countries since land expansion is hardly possible in regions where land is scarce. This often leads to gains in world market share for land abundant countries (substitution effect).

The lower land price relative to the price of other production factors in the endogenous land scenario implies that producers substitute less land for other production factors (e.g. capital). This means that, in general, the intensification is less in the endogenous land scenario.

These different trends have a very important impact on environmental consequences. The most important drivers of environmental change are land-use change, air polluting emissions like ammonia and greenhouse gas emissions (MA, 2005). In most cases of biodiversity loss, land-use change is the most important driver of impacts on biodiversity (CBD/MNP, 2007). In our analysis it is clearly shown that these drivers differ substantially when land is modeled endogenously or exogenously. When land supply curves are applied, more land is used for agricultural processes (causing deforestation and additional fertilizer use) and the production of agricultural products is substantially higher (leading to higher emissions from the livestock sector). Therefore, it is obvious that environmental and biodiversity impacts are underestimated substantially when land is modeled exogenously by economic models. This clearly shows the importance of a good reflection of land availability and heterogeneity in economic models. The proposed methodology of land-supply curves is a first attempt to include these land dynamics in a GTAP model. Clearly, this first attempt should be seen as a starting point for a range of further developments in the field of economic and ecological modeling (Heisterman et al., 2006).

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Appendix 1: Estimation results of the land supply curve

	agricultural land used** (%)	price elasticity	land rental rate in GTAP (1000\$/ha)	R square
can	8.8	3.06	5.24	0.97
usa	50.7	0.71	10.20	0.91
mex	65.1	0.76	7.97	0.97
rcam	52.0	3.80	11.97	0.99
braz	32.6	3.95	1.27	0.99
rsam	50.0	1.64	3.37	0.99
naf	100.0	0.00	3.81	0.98
caf	49.5	0.62	0.57	0.99
saf	66.9	0.43	0.42	0.91
nld	88.1	0.08	52.59	N.A.***
eu14	90.3	0.15	23.52	N.A.***
rweu	63.5	1.17	43.91	0.87
eu10	78.9	0.15	12.45	0.99
buru	95.2	0.15	15.14	0.99
reu	75.1	1.76	8.73	0.98
tur	50.3	1.70	4.25	0.99
rfsu	92.5	0.02	1.87	0.99
rus	14.0	1.87	1.67	0.99
me	100.0	0.00	2.44	0.93
sas	60.1	0.85	22.05	0.98
kor	78.9	2.29	424.84	0.98
chi	92.2	0.05	7.33	0.99
sea	27.7	6.46	20.54	0.99
indo	24.6	5.97	18.19	0.99
jap	78.9	2.29	156.97	0.95
oce	89.8	0.11	0.75	0.93

* Percentage of agricultural land use is calculated as a ratio of current agricultural land supply (use) to potentially available agricultural land (the land supply curve asymptote).

** Equal to land value in GTAP divided by land supply.

*** Land supply curve for EU14 and The Netherlands was calibrated using Cixous, 2006 results. Because of pro-nature policy, the agricultural land is scarce in the by EU. This is situation is not depicted by biophysical data, which hampers the possibility to use these data to estimate the land supply curve.

Appendix 2: Regional and sectoral aggregations

Table A: Region aggregation

Code	Description	Original GTAP regions
can	Canada	Canada.
usa	USA	United States.
mex	Mexico	Mexico.
rcam	Rest of Central America	Rest of North America; Central America; Rest of FTAA; Rest of the Caribbean.
braz	Brazil	Brazil.
rsam	Rest of South America	Colombia; Peru; Venezuela; Rest of Andean Pact; Argentina; Chile; Uruguay; Rest of South America.
naf	North Africa	Morocco; Tunisia; Rest of North Africa.
caf	Central Africa	Rest of SADC; Madagascar; Uganda; Rest of Sub-Saharan Africa.
saf	South Africa	Botswana; South Africa; Rest of South African CU; Malawi; Mozambique; Tanzania; Zambia; Zimbabwe.
nld	Netherlands	Netherlands.
eu14	EU15	Austria; Belgium; Denmark; Finland; France; Germany; United Kingdom; Greece; Ireland; Italy; Luxembourg; Portugal; Spain; Sweden.
rweu	Rest of Western Europe	Switzerland; Rest of EFTA.
eu10	EU10	Cyprus; Czech Republic; Hungary; Malta; Poland; Slovakia; Slovenia; Estonia; Latvia; Lithuania.
buru	Bulgaria, Romania	Bulgaria; Romania.
reu	Rest of Europe	Rest of Europe; Albania; Croatia.
tur	Turkey	Turkey.
rfsu	Rest of Former Soviet Union	Rest of Former Soviet Union.
rus	Russian Federation	Russian Federation.
me	Middle East	Rest of Middle East.
sas	South Asia	Bangladesh; India; Sri Lanka; Rest of South Asia.
kor	Korea	Korea.
chi	China	China; Hong Kong; Taiwan.
sea	South-East Asia	Rest of East Asia; Malaysia; Philippines; Singapore; Thailand; Vietnam; Rest of Southeast Asia.
indo	Indonesia	Indonesia.
jap	Japan	Japan.
oce	Oceania	Australia; New Zealand; Rest of Oceania.

Table B: Sector aggregation

Code	Description	Original GTAP sectors
pdr	Rice	Paddy rice; Processed rice.
wht	Wheat	Wheat.
grain	Cereal grains nec	Cereal grains nec.
oils	Oil seeds	Oil seeds.
sug	Sugar cane and beet, sugar	Sugar cane, sugar beet.
hort	Vegetables, fruit, nuts	Vegetables, fruit, nuts.
crops	Other crops	Plant-based fibers; Crops nec.
cattle	Cattle,sheep,goats, horses	Cattle,sheep,goats,horses.
oap	Animal products nec	Animal products nec.
milk	Raw milk	Raw milk.
wool	Wool, sil-worn cocoons	Wool, silk-worm cocoons.
be_she	Meat:cattle,sheep,g oats,horse	Meat: cattle,sheep,goats,horse.
pig_pol	Meat products nes	Meat products nec.
dairy	Dairy products	Dairy products.
sugar	Sugar	Sugar.
agro_nec	Rest of agro	Fishing; Vegetable oils and fats; Food products nec; Beverages and tobacco products.
ind	Industry	Forestry; 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.