Endogenous agricultural land supply: estimation and implementation in the GTAP model

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1. Introduction

Food supply and food distribution have, for many decades, been among the most important issues playing a role in the global political arena. At the first World Food Summit in 1974, political leaders from around the world set a goal to eradicate hunger in the world within 10 years. Obviously, this ambitious goal was not met, leading to new goals at the second World Food Summit in 1996. The world leaders committed themselves to reduce by half the number of chronically undernourished by the year 2015. This target has been endorsed at many other meetings since then and is now known as one of the eight Millennium Development Goals (MDGs) of the United Nations (UN, 2001). The importance of reforming agricultural support policies in industrialized countries and improving market access, in particular for developing countries, has been recognized at the top political level as one of the most important ways to meet this MDG. Negotiations on lowering subsidies linked with trade regimes are the mandate of the World Trade Organization (WTO). In Doha, in 2001, consensus was reached on a mandate to dedicate the new round of trade liberalization to serve development and environment and produce an outcome that specifically benefits the developing world. In the discussions and on-going negotiations afterwards, this mandate has been referred to as the Doha Development Agenda.

Given this Doha Development Agenda, many shifts in the agricultural and trade policies are expected in the coming years. Moreover, in the coming period world population and world food demand will also continue to increase (UN, 2002; FAO, 2003). In combination with expected increases in economic growth (World Bank, 2003), these demographic shifts will have a major impact on the global food supply market. At the same time, environmental conditions impacting food productivity will also change, of which climate change (IPCC, 2001), nutrient circumstances (Eickhout et al., 2006) and land degradation (Delgado et al., 1999) are best-known. Hence, future agricultural scenarios need to be considered in the light of changing global conditions and agricultural policies.

So far, future agricultural scenarios are mostly provided by economic analyses (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; Van Meijl et al., 2005). Many economic models used to lack well-founded land availability curves, leading to poor estimations of food production growth. 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. Not many models account for this land availability. The exception is the World Bank model LINKAGE (Van der Mensbrugghe, 2005). Here, the land supply is determined by a constant elasticity function or, alternatively, by a logistic function of real land price. In the case of the constant elasticity function, the assumed elasticities are 0.25 for land constrained countries and 1 for other countries. The logistic function is calibrated to replicate the base supply level assuming an exogenously given elasticity and asymptote.

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. Much information on the heterogeneity of land is available, but not yet to a full extent used within economic models. Here, we present a method to include detailed biophysical information on land within an extended GTAP model. In van Meijl et al. (2006) the land supply curve was conceptually implemented into the GTAP model. It was derived on theoretical considerations (see Abler, 2003) and calibrated using expert knowledge and FAO land use projections. In this paper, we show that detailed biophysical data concerning land use and associated land productivity provide an empirical foundation of the land supply curve in which both land availability and differentiated land quality are included.

This paper is organized as follows. In Section 2, economic and biophysical issues concerning the agricultural land supply are discussed. The concept of the land supply curve is introduced in Section 3. Section 4 is devoted to land supply curve parameterization. It describes the data use, the estimation procedure and the estimation results. Section 5 focuses on the implementation of the land supply function in GTAP and consequences of this inclusion for simulation results. The systematic sensitivity analysis is conducted to investigate the sensitivity of simulation results in respect of the land supply function parameters. Section 5 concentrates on discussion and conclusions.

2. Land supply to agriculture - biophysical issues

Land availability is not only changing because of urbanization and other land-use purposes, but the land productivity is also changing because of environmental conditions. One of the most important environmental concerns affecting land productivity is 'land degradation'. Land degradation is an aggregate definition indicating loss of land quality due to several reasons. There are two different types of land degradation processes: 1. by displacement of materials (water erosion and wind erosion) and 2. by internal deterioration of the soil (physical degradation, like crusting, chemical degradation and biological degradation). Some specific forms of land degradation are more assigned to regional circumstances. For example, desertification is defined as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. All the forms of land degradation lead to lower land productivity, driven by different factors. Water and wind erosion can be caused by mismanagement of agricultural sites and overexploitation. Chemical degradation (nutrient depletion) is caused by using not enough inputs (fertilizers) or legumes (for nitrogen fixing) to maintain the high productivity that is required for agricultural practices. The effect of land degradation can have a major impact on future land productivity, which may lead to an underestimation of land needed for future food productions. For example, on the basis of a compilation of data, Bouwman and Leemans (1995) estimated an annual global loss of 4 Mha of degraded arable land that would need to be compensated for by forest clearing.

Climate change is another environmental condition affecting the food production in the future. Although the extent of climate change is highly uncertain, it is obvious this environmental feedback needs to be included in analyses focusing on future food production. Rosenzweig et al. (1995), Parry et al. (2001) and Fischer et al. (2002) 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. On the other hand, CO2 fertilization effect may increase food productivity. Van Meijl et al. (2005) concluded climate change is impacting the food productivity the coming 30 years, but the height of this impact is much smaller than changes in land productivity because of land expansion. Nevertheless, on the long term this climatic effect needs to be included in agricultural foresight studies.

3. Agricultural land supply curve

Potential agricultural land supply, including the land quality can be provided by a biophysical model, taking into consideration soil conditions and climatic circumstances outlined above. From economic point of view, however, the agricultural land supply is a function of the land rental rates. In this section, we introduce the agricultural land supply curve, which translates the biophysical information into land rental rates.

The supply of agricultural land depends on its biophysical availability (potential number of hectares of suitable land available), institutional factors (agricultural and urban policy, policy towards nature) and the land price on the market. Biophysical availability defines maximal potentially available agricultural land. The assumption that the most productive, i.e. the less expensive to bring in cultivation, land is first taken into production leads to the agricultural land supply curve presented in Figure 1. The information about productivity is provided by biophysical data.

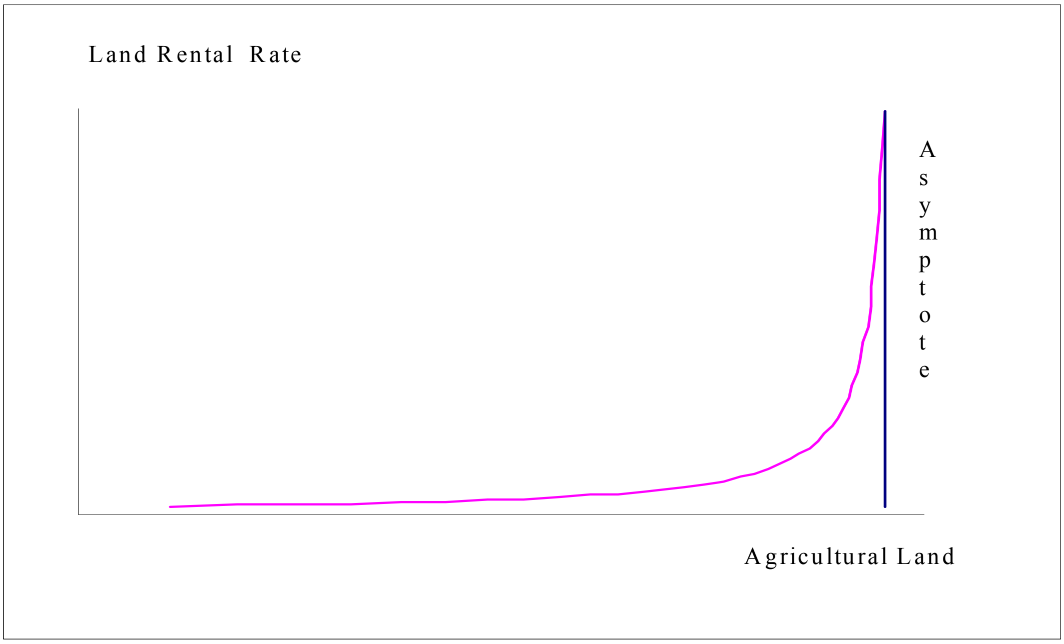

Figure 1: Land supply curve determining land conversion and land rental rate

According to Figure 1, if the gap between potentially available agricultural land and land used in the agricultural sector is large, the increase in demand for agricultural land will lead to land conversion to agricultural land and a modest increase in rental rates to compensate for the cost to take this land into production. Points situated on the left flat part of the land supply curve in Figure 1 depict such a situation. However, when almost all agricultural land is in use, an increase in demand for agricultural land will mainly lead to high increase of the land rental rates (land becomes scarce). In this case, land conversion is difficult to achieve, and therefore, the elasticity of land supply in respect to land rental rates is low as well. Points situated on the right steep part of the land supply curve in Figure 1 describe this situation.

4. Estimation of the land supply curve

In this section, we derive and estimate the land supply curve using biophysical data from the modeling framework IMAGE (Integrated Model to Assess the Global Environment; Alcamo et al., 1998). IMAGE takes into account marginal lands and changes in the potential land productivity due to changes in land use and climate change. 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. We use IMAGE to generate the land productivity curve describing the potential crop productivity (accumulated for all crops) as a function of the accumulated land area (Section 4.1). We translate the land productivity curve into land supply curve under the assumption that the land rental rate is a function of the inverse of the land productivity and we propose their mathematical specification. Section 4.2 describes estimation procedure and estimation results of the agricultural land supply curve for 25 countries and regions.

4.1. The biophysical data

Within the IMAGE model the crop productivity is calculated on a grid level of 0.5 by 0.5 degrees. The IMAGE crop model simulates the consequences of changes in atmospheric CO_2 concentrations and climate on the crop productivity. The productivities for 7 food crops[1] are calculated in the crop growth model of IMAGE 2.2 as presented in Figure 2. The crop production model (Leemans and Van den Born, 1994) is based on the FAO Agro-Ecological Zones Approach (FAO, 1981). This model calculates 'constraint-free rainfed crop yields' accounting for local climate and light attenuation by the canopy of the crop considered. The climate-related crop yields are adjusted for grid-specific conditions by a soil factor with values ranging from 0.1 to 1.0. This soil factor takes into account three soil quality indicators: (1) nutrient retention and availability; (2) level of salinity, alkalinity and toxicity; and, (3) rooting conditions for plants. The crop growth model is calibrated using historical productivity figures.

To capture the overall productivity of each grid cell, the sum of the productivity of the seven crop types is simulated in each grid cell and the average crop productivity is calculated. Since the crop productivity is in Mg per square kilometre, we transferred each crop productivity to a relative scale between 0 and 1 on the basis of a potential, maximum feasible crop productivity. Therefore, the average value of each grid cell lies between 0 and 1 and gives a good representation of the quality of the specific grid cell. By ordering all the grid cells in each region from high productivity to low productivity and cumulate the total area, land productivity curves are obtained (as plotted in Figure 3).

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[1] The seven crop types within the current version of IMAGE are: temperate cereals, rice, maize, tropical cereals, pulses, roots & tubers and oil crops.

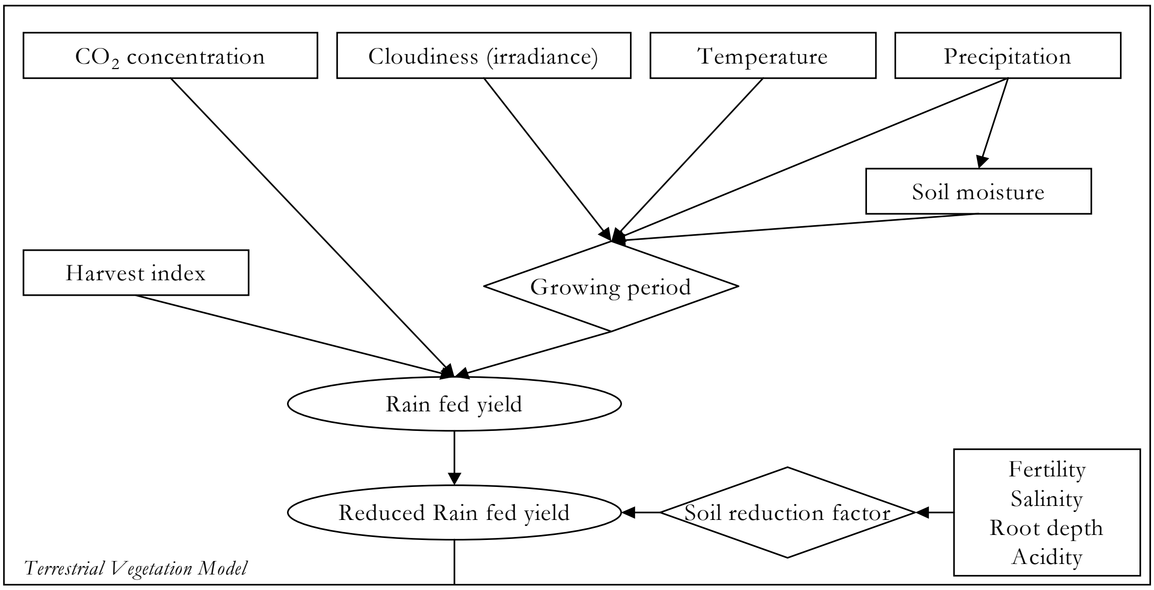


Figure 2: Schematic representation of the IMAGE crop model (based on Leemans and Van den Born, 1994; taken from Hoogwijk et al., 2005).

4.2. Derivation and parameterization of the land supply curve

The land productivity curve can be translated into land supply curve under the assumption that the land rental rate is a function of the inverse of the land productivity. Figure 3 represents such a productivity curve and the derived land supply curve for Canada. This empirical land supply curve is consistent with the conceptual model presented in Section 3.

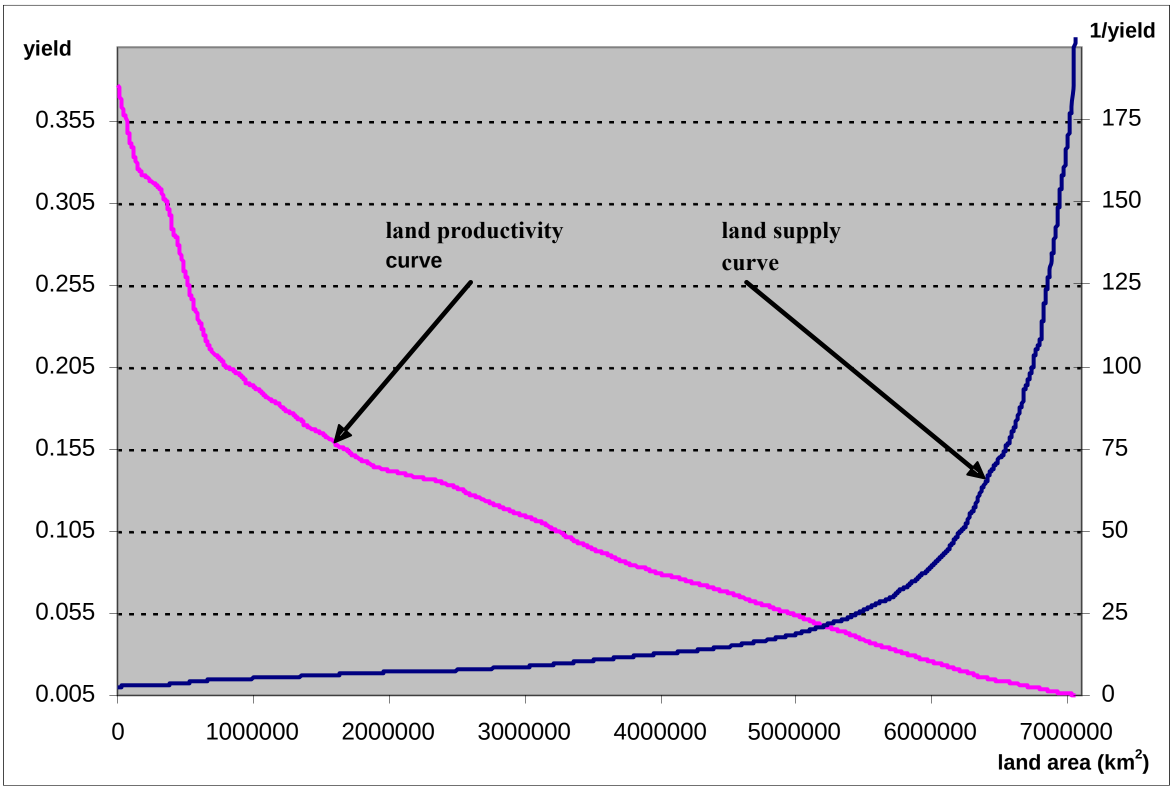


Figure 3: Land productivity and land supply curve for Canada on the basis of IMAGE simulations.

We assumed the following functional for land supply function:

$$L = a - \beta/f(\Delta\cdot 1/y) \qquad (1)$$

Where L is land supply, "a" (>0) is an asymptote interpreted as the maximal potentially available agricultural land, "β" and "Δ" are positive parameters and f(1/y) is an increasing function of the inverse of land productivity. Function f(1/y) can be interpreted as a function of real land rental rate (R) that is inverse proportional, with the proportionality coefficient Δ, to the yield (i.e.: $R = \Delta\cdot 1/y$). We have assumed that f(1/y) function is defined as follows

$$f(1/y) = \gamma_o + (1/y)^p + \Sigma_{i=1,\ldots,n}\, c_i(1/y)^{p+i} \qquad (2)$$

where γ_o, c_i (≥0) and p (≥0) are unknown parameters of function f. This yields the following equation for the land supply function:

$$L = a - b/(c_o + (1/y)^p + \Sigma_{i=1,\ldots,n}\, c_i(1/y)^{p+i})$$

or

$$L = a - b/(c_o + r^p + \Sigma_{i=1,\ldots,n}\, c_i\, r^{p+i}) \qquad (3)$$

where: $r = 1/y$ is the land rental rate indicator, $c_o = \gamma_o/\Delta$ and $b= \beta/\Delta$.

The parameters "b" and "p" determine in big extend a shape of the land supply curve. It can be easy seen when all $c_i = 0$. In this case, the elasticity of land supply in respect of the and the land rental rate indicator "r" is less than 1 when

$$r > (b(p+1)/a)^{(1/p)} = \rho. \qquad (4)$$

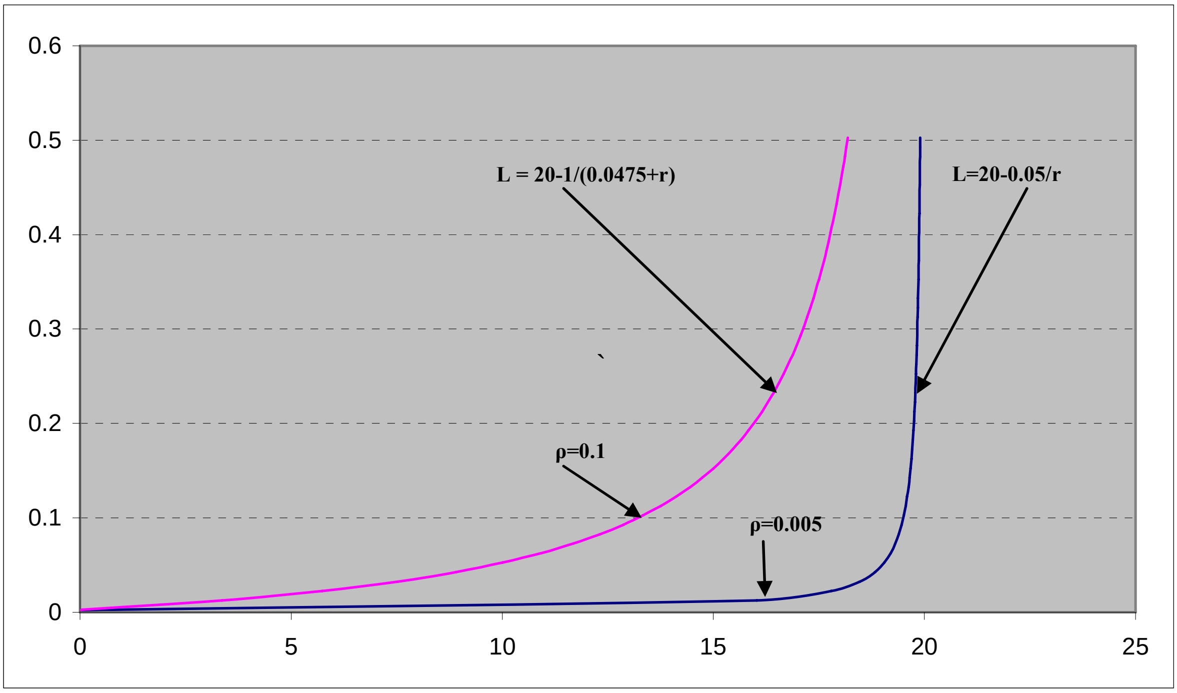


Figure 4: Land supply function for different values of parameter "b".

In such a case, the increase of the agricultural area is less than proportional to the increase of the land rental rate indicator. If "b" is small or "p" is large, than "ρ" is small. In this case, the land supply curve is close to the one-kink function. For large "b" and small "p", "ρ" is rather large and the land supply curve is relatively flat (see Figure 4).

We estimated the land supply function for 25 countries and regions (see Table A in Appendix 2). We estimated the parameters b and c_i using non-liner least square estimation method for a 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 if land is very scarce as well as when it is oversupply of land we exclude same number of observations at the beginning and ending of the curves[2].

Asymptote "a" of the land supply curve is also provided by the IMAGE model and therefore, approaches the availability of land in each region. To obtain values higher than 0, we excluded all the grid cells from the land productivity curve that are equal to zero (mainly ice and desert in regions like Canada and Middle East). Moreover, we excluded urban area and protected bioreserves in each region to take into account nature conservation and anthropogenic land use. There were few exceptions from this approach. When the 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. When the agricultural land is scarce the potential land productivity is close to the observed land productivity. 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 observations concerning the accumulated land area lower than currently used agricultural area.

In the case of EU, the conversion of the non-agricultural land to agriculture is strongly limited by EU policy towards nature. Therefore, we assumed that only set-aside and abandoned agricultural land can be converted to the agricultural land in EU. In other words, further land expansion is only possible in this region when land abandonment has occurred compared to current land use.

For North Africa and Middle East, the biophysical IMAGE biophysical data concerning the available agricultural land are inconsistent (lower) with currently reported land use by FAO statistics. For these regions we assumed there is 3% more agricultural land available compared to the data reported by FAO.

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. However, since "last" observations used to estimate the land supply curve are often irregular the curve often does not fit the data very well at the end of the sample. However, here the inverse of yield is not a good proxy of the real land rental rate since land is very scarce in those cases. The curve often does not fit the data very well at the beginning of the sample as well: if we have an oversupply of land, the inverse of yield is not good proxy of the real land rental rate as well.

The estimated parameters are highly significant. The estimated function "f" has, besides the parameter c_o, mostly only one non-zero parameter c_i. The exceptions are the land supply functions for Russia, Korea and Oceania.

[2] In the estimation process, we use all observations associated with yield higher than 0.0142 and lower than 0.4 (i.e. r higher than 2.5 and lower than 70). We also weight the observations by inverse of yield to give higher weighs to relatively low number of observations concerning the "end" of the land supply curve.

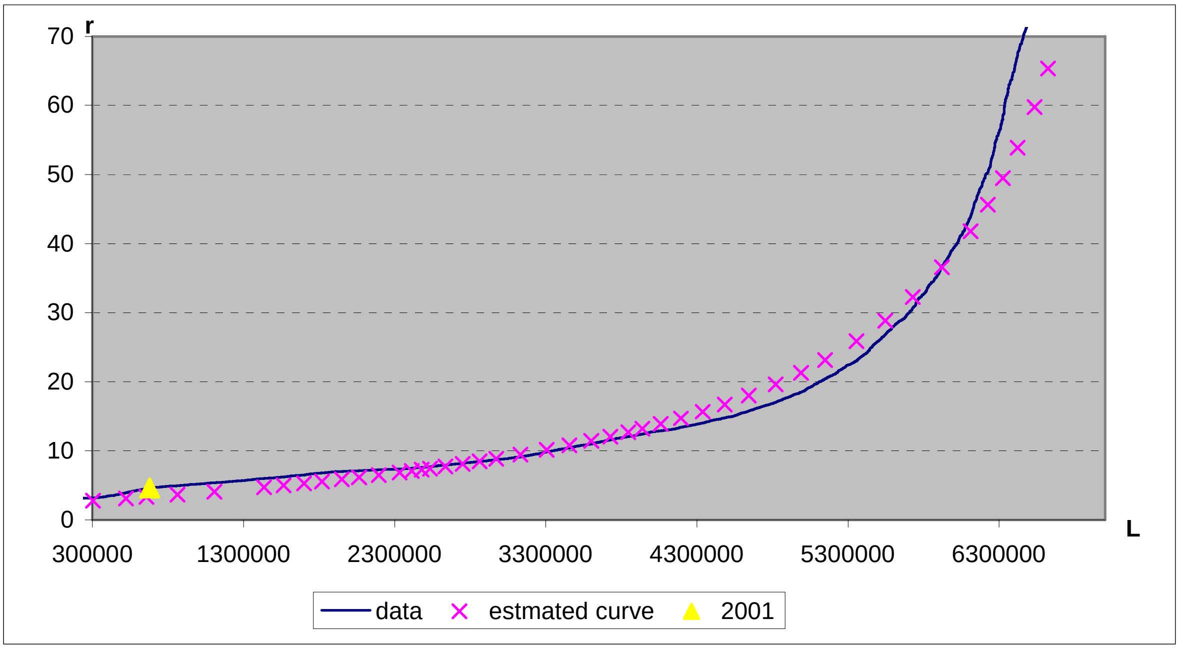


Figure 5: Current position of Canada on its land supply curve (L in km^2)

The estimation results shows that the agricultural land is scarce in North Africa, EU, Rest of Western Europe, Former Soviet Union, Middle Ease, Oceania and Japan. According to these results, all these regions are currently placed 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.

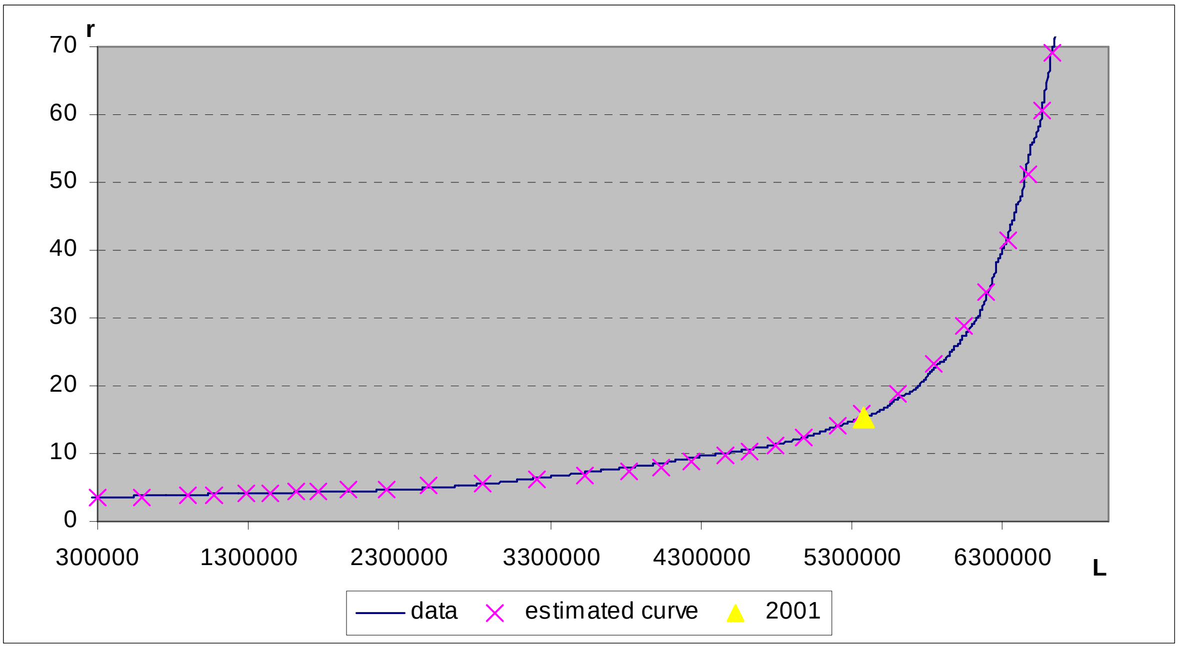


Figure 6: Current position of China on its land supply curve (L in km^2)

The current position of region on the estimated land supply functions differs for different regions. For instance, the current position of Canada on their land supply curve indicates that the agricultural land in Canada can still be expanded without a high increase in the real land rental rate (Figure 5). The opposite situation is observed for China. Small expansion in the agricultural land in China will lead to a high increase in the real land rental rate, therefore stimulating intensification processes in the agricultural practices (Figure 6).

5. Comparison of GTAP model simulation results with and without the land supply curve

This section aims to compare GTAP model simulation results with and without the land supply curve. In Section 5.1, we define the simulation scenario looking on the world agricultural sector development up to 2015. In Section 5.2, the implementation of land supply curve in GTAP is described. The scenario implementation into GTAP model and simulation results are presented in Section 5.3. The sensitivity of simulation results in respect of the land supply function parameters is investigated in the Section 5.4 by mean of the systematic sensitivity analysis.

5.1. Land supply function implementation in GTAP

To implement the land supply function in GTAP, we introduced the agricultural land area per sector in GTAP. For crops, we use IMAGE data for crop harvested area per crop type. We convert these data to the arable area data using a uniform conversion factor per region. This factor is calculated using FAO regional data concerning arable area of arable and permanent crops.

The FAO permanent pasture area data are used to assign land to the animal sectors. We distribute this land between dairy cows (row milk sector) and other grazing animals (cattle, sheep, goats and horses sector, and wool sector) proportional to the animal numbers expressed in livestock units (LU). The numbers of animals per region are taker from IMAGE data[3]. Finally, we distribute land between cattle, sheep, goats and horses sector and wool sector proportionally to output of these two sectors[4]. This procedure results in the agricultural land use distribution LD_i per sector "i" in each region.

To model land supply changes in GTAP we introduce the land supply equation (3) to the GTAP model code together with the agricultural land market equilibrium condition:

$$\Sigma_{i=1,\ldots,n} LD_i = L \quad . \qquad (5)$$

We assume that real land rental rate indicator "r" and land used per sector LD_i are growing together with real price (pfactreal) and demand for land in the sector "i" (qfe(land,i)) respectively. As the result, regional supply of land in constant prices (qo) is now endogenous in the model.

The implementation of the land supply curve into GTAP influence the land use and land price development. This in turn affects land cost and prices of agricultural products.

5.2 Scenarios and data input

[3] IMAGE provides information abut dairy and non-dairy cattle and sheep and goats. We use 1 LU for dairy cattle, 0.6 LU for non dairy cattle and 0.15 LU sheep and goats.

[4] We use GTAP output value (VOM) for these calculations.

The scenario analyzed in this paper is based on a preliminary draft of the OECD Baseline Scenario used for the OECD's Second Environmental Outlook. The future economic growth is derived from a combination of labour productivity increases and labour supply changes and assumes that the capital-labour ratio is increasing over time. The labour productivity in turn is mainly driven by improvements in skills, which subsequently depend on scientific and other advances. To capture these forces, the past labour productivity trends are analyzed. The labour supply is driven by population and labour participation rates projection. The first of these two factors is assumed to develop according to the "medium variant" of UN population projections; the second one – labour participation rates – is set using the past trends analysis (Chateau et al., 2005).

The resulting world economic growth is about 3% per year and population growth 1.1% per year in 2001-2015 period. The 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. The highest population growth is expected in the developing countries (about 1.3% per year). The OECD population increase more than two times slower. When the agricultural policy is considered, the implementation of the 2003 reforms of the Common Agricultural Policy is assumed. It means that the 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 counties.

The simulations were done with an extended version of the standard GTAP model (Hertel, 1997). The standard version of GTAP was modified to model such specific features of agricultural sector as the variation of substitutability between different types of land use, factor markets segmentation between agriculture and non-agriculture and agricultural production quotas (Van Meijl et al., 2006). We performed all calculations twice: once with the model including the land supply curve (i.e.: endogenous land supply) and once with model with exogenous land supply (model without land supply curve).

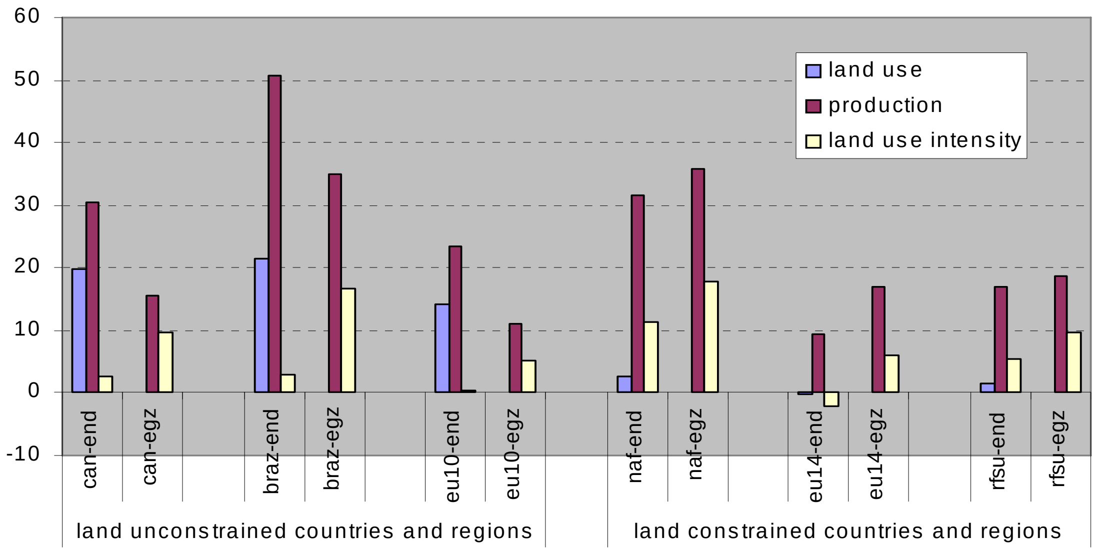
In the simulation experiments, the exogenous GDP targets are met given exogenous estimates on factor endowments - skilled labor, unskilled labor, capital and natural resources - and population. This implies that at the overall country level technological change is endogenously determined within the model (Hertel et al., 2004). 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 from FAO (FAO, 2003) for land using sectors. For the non-land using sectors we assume Hicks neutral technical change.

5.3 Simulation results

To compare the simulation results of the models with and without the land supply curve, we concentrate on the results concerning the agricultural sector. Inclusion of the land supply curve in the model affects the overall production level of the agricultural sector as well as its regional distribution compared with the model without the land supply curve. When the land supply is endogenous, additional land can be taken into or out of production. The land use change is dependent on the agricultural land availability in the particular region, the current position of the region on its land supply curve and the change in the demand for land. In case of endogenous land supply, the overall agricultural land use increases by 13%, which is caused by a growth in agricultural production of 30% in combination of yield growth of 17%. Given a fixed supply of agricultural land, the overall agricultural production increases only by 23% and the degree of intensification is higher (23%) than with endogenous agricultural land supply. So "releasing" the land constraint causes a higher 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 by 12%. When the agricultural land is fixed, the land prices increase. As a result, the world price of agricultural products increases by 12%.

There are regional differences in the agricultural production and land use intensity[5] development in different regions in a case of endogenous and exogenous agricultural land supply. In general, the agricultural production is higher and land use intensity is lower when the agricultural land is endogenous. Since more agricultural land is available, the production can grow more and land use intensity can be lower.

However, in land scarce or constrained countries both the agricultural production and land use intensity are lower when the agricultural land is endogenous (Figure 7). These countries are close to the land asymptote and releasing the land constraint does not lead to the potential of taking more land into production. In the land abundant or unconstrained countries (far away from the asymptote) an increased demand for agricultural products now leads to an expansion in agricultural land and a lower increase in the land rental rate than in case with a fixed supply. Therefore products prices in the land abundant countries decrease relatively more than in the land constrained countries with endogenous land supply (see Figure 8). These relative adverse price developments in the land constrained countries causes a loss in their exports and an increase in their imports and therefore agricultural production decreases (see, Figure 9). Lower production implies that the fixed factor land gets cheaper and the degree of intensification is less.



[5] The land use intensity is defined as a difference between production change and land and exogenous yield change. It is endogenous in the model and depends on the relative land and other factors prices.

Figure 7: Agricultural land, production and land intensity development (% changes) in different regions production when the agricultural land is endogenous (“end”) and “exogenous (“egz”).

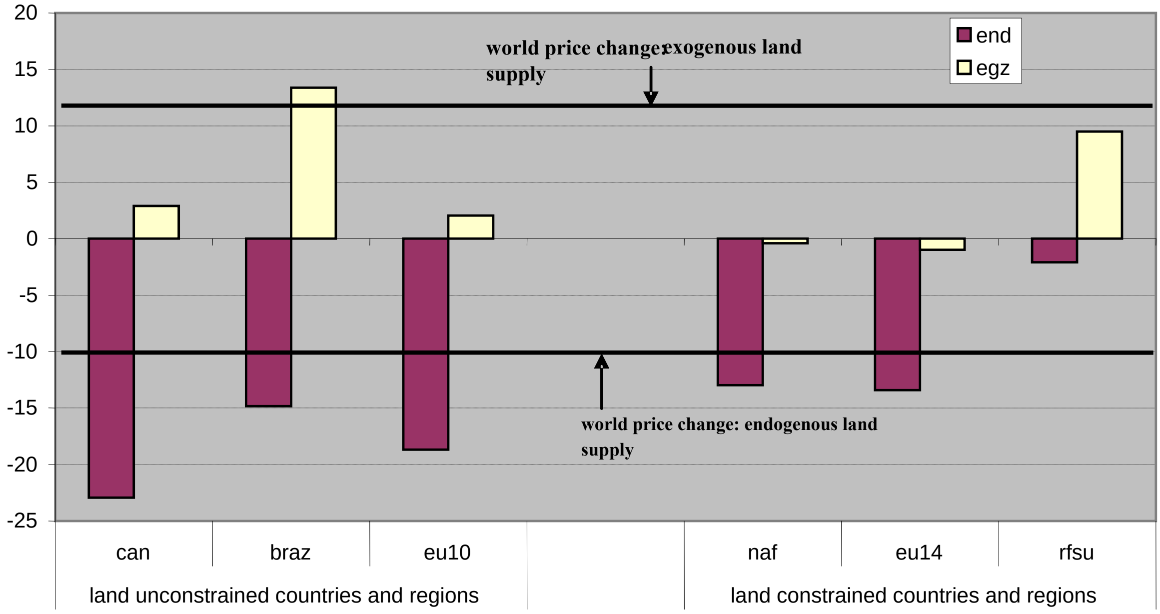


Figure 8: Percentage change of price of agricultural products in different regions and in the world when the agricultural land is endogenous (“end”) and “exogenous (“egz”).

Endogenization of land in the model creates more trade in the agricultural products because the comparative advantage of the big exporters such as Brazil increases as they can easily take more land into production. When the agricultural land is endogenous, the world agricultural trade increase by 32% compared with 28% in a case when the agricultural land is exogenous (Figure 9).

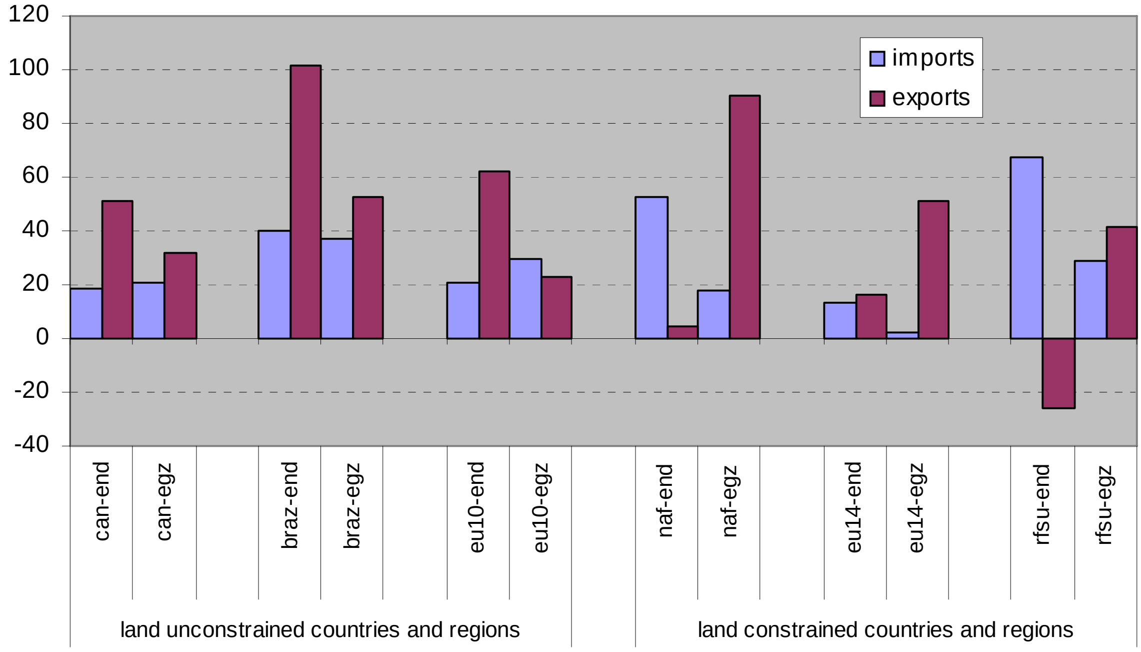


Figure 9: Percentage change of agricultural imports and exports in different regions when the agricultural land is endogenous (“end”) and “exogenous (“egz”).

In general, if agricultural land is abundant, the agricultural imports are lower and the agricultural exports are higher when the agricultural land is endogenous in the model compared with the situation when the agricultural land is exogenous. The reverse is observed for countries where the agricultural land is scarce.

5.4 Sensitivity analysis with regard to land supply function parameters.

The land supply curve parameters were estimated using biophysical data generated by IMAGE model. Such data as well as the estimation results of the curve are surrounded with uncertainty. Here, we analyze the robustness of the simulation results with regard to the parameters of the land supply curve. We assume that the asymptote of the land supply curve is estimated with an error ± 2.5%. We run the simulation experiments with the asymptote 2.5% lower and 2.5% higher than estimated and look on the simulation results concerning land supply, the real land rental rate and production changes. Before running the simulation experiments, we have to restore the initial benchmark equilibrium situation on the land market when the asymptote "a" is changed. We have assumed that real land rental rate is the same as the initial real land rental rate in the model with estimated asymptote and we adjust the parameter "b" of the land supply function to achieve the equilibrium situation for the new asymptote. This leads to steeper land supply function when the asymptote is reduced and to flatter land supply function when the assumptive increases.

In the simulation experiments, we changed the asymptote and the parameter "b" only for one country at once. We run the simulation experiments for four countries having different position on their land supply curves: Canada, North Africa and Rest of the Former Soviet Union. The simulation results are presented in the Table 1.

Table 1 shows that when less agricultural land is available, the agricultural land supply decreases compared with the original situation. This causes increase of the real land rental rate compared with the original situation since the land supply function is much steeper than the original one. The opposite changes are observed when more agricultural land is available.

Table 1: Simulation results with the shifted asymptote of the land supply curve: percentage change of the land supply and the real land rental rate compared with the results obtained for estimated land supply curve.

	can-2,5	can+2,5	naf-2,5	naf+2,5	rfsu-2,5	rfsu+2,5
land supply	-0.05	0.04	-2.20	2.00	-0.71	0.63
land rental rate	0.17	-0.16	33.75	-27.20	12.10	-10.20

The scale of the land supply changes depends on the current position of the country on the land supply curve and shape of the curve. The agricultural land supply decreases slightly when the country in the consideration uses only small part of the available agricultural land. Canada is an example of this situation. Situation is very different when county is using almost all available agricultural land like North Africa. In this case, the agricultural land supply changes are large; this is also true for the real land rental rate changes.

North Africa and Rest of the Former Soviet Union use similar percentage of the agricultural land (97.1% and 95.2% respectively), however, the land supply curve for North Africa is much more steeper than for Rest of the Former Soviet Union. As the result, reaction of the land supply on the asymptote change is much higher for North Africa than for Rest of the Former Soviet Union.

The agricultural land supply and the real land rental rate changes do not lead to large production grow rate changes compared with the results obtained for the estimated land supply curve. The absolute differences between percentage change of the aggregated agricultural production with shifted asymptote and with the estimated asymptote are lower than corresponding differences between the agricultural land use. As a result, land productivity increases when the land asymptote is reduced and decreases when the asymptote increase. These yield changes are higher for countries where the agricultural land is scarce.

Table 2: Simulation results with the shifted asymptote of the land supply curve: difference between percentage change of the aggregated agricultural production, land use and yield calculated with shifted asymptote and with the estimated asymptote.

	can-2,5	can+2,5	naf-2,5	naf+2,5	rfsu-2,5	rfsu+2,5
land supply	-0.05	0.04	-2.20	2.00	-0.71	0.63
production	-0.03	0.03	-1.10	0.93	-0.25	0.22
Yield	0.02	-0.01	1.10	-1.07	0.46	-0.41

6. Conclusions

The paper shows that the empirical agricultural land supply curve derived from detailed biophysical data concerning land use and associated land productivity is consistent with the proposed conceptual model. The use of the biophysical data makes it possible the parameterization of the curve. In this way, the heterogeneity of land is taken in to account. As a result, the estimated land supply curve has different shape depending on biophysical characteristics of a region under consideration.

The simulation experiments shows that the shape of the land supply curve and the current position of the region on its land supply curve has very important impact on simulation results. The simulations for models with and without the agricultural land supply curve produce different results. When the agricultural land is endogenous, agricultural prices decrease and agricultural production and trade increase more than in the case of an exogenously determined agricultural land. Moreover, the implications for land scarce and land abundant countries are opposite. With endogenous land supply an increase in agricultural demand leads in land abundant countries to an expansion of agricultural land whereas this is not possible in land scarce countries. This implies in the former countries that the increase in the rental rate for land is less than with a fixed land supply. This gives these countries a comparative advantage, which leads to more exports and less imports. The reverse is true for land scarce countries. The introduction of an endogenous land supply curve has therefore important implications for analyses of the impact of agricultural and trade policy reforms as it changes the impacts for land scarce and land abundant countries.

Sensitivity analyses with regard to land supply function parameters show that changing of the asymptote of the land supply function leads to significant changes of land supply for countries when the agricultural land is scarce. However, the induced production changes are rather low. The aggregated agricultural production elasticity in respect of the asymptote change vary from 0.1 for countries where the agricultural land is abundant to 0.5 for countries where the agricultural land is scarce. It means that the simulation results concerning production development are rather robust with regard to the estimated land supply curve parameters.

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Appendix 1: Estimation results of the land supply curve

	Agricultural land used** (%)	land supply function flatness indicator: ρ	current real land rental rate indicator: r**	R square
can	8.8	20.7	3.4	0.97
usa	50.8	5.5	4.1	0.91
mex	65.0	2.7	5.2	0.97
rcam	51.8	5.1	3.9	0.99
brazil	32.4	9.8	6.2	0.99
rsam	49.6	9.1	5.8	0.99
naf	97.1	17.7	59.1	0.98
maf	53.9	9.3	6.5	0.99
saf	56.6	6.6	5.3	0.91
eu15	94.0	7.4	47.6	N.A.***
rweu	81.0	7.7	7.1	0.87
eu10	71.7	4.5	3.9	0.99
reeu	59.4	4.8	3.9	0.98
buru	61.5	3.7	3.1	0.99
rus	13.5	29.7	5.0	0.99
rfsu	95.2	0.4	374.7	0.99
turky	50.7	7.4	4.9	0.99
me	97.1	49.7	833.3	0.93
sas	60.0	3.5	5.4	0.98
kor	9.1	9.7	3.1	0.98
chi	73.0	2.9	16.0	0.99
ind	23.1	7.4	4.7	0.99
sea	74.2	6.0	5.2	0.99
oce	91.4	7.4	35.6	0.93
jap	79.7	3.7	3.4	0.95

[*] 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).
[**] Current real land rental rate indicator is a solution of the land supply function for the currently observed land supply.
[**] Land supply curve for EU15 was calibrated. Because of pro-nature policy, the agricultural land is scarce in the by EU. This is situation is not depictured by biophysical data, which hampers the possibility to use these data to estimate the land supply curve. Therefore we calibrated the land supply curve for EU using estimation results for Oceania. The use these results because the real land rental rate indicator "r" is relatively high compared with the "flatness" indicator "ρ" for Oceania and we expect the same for EU since both regions use similar percentage of potentially available agricultural land.

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,goats,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.