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Forestry in MAGNET

A new approach for land use and forestry modelling

WOt-werkdocument 320

G.B. Woltjer

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For quality of life

Forestry in MAGNET

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Abstract
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This report discusses improvements of MAGNET in order to improve the analysis of land use change and forestry dynamics. In the standard approach only a difference is made between agricultural land, non-used land that can be potentially used for agriculture, and land that never can be used for agriculture. In the new approach different other land cover types like built-up area and forestry are distinguished. Also the symmetry requirement of the old model is replaced by a more sophisticated mechanism where stylized facts that forest land is normally converted into grassland, and grassland into cropland can be acknowledged. Next to this the forestry sector is implemented as a sector where land use and harvest of the land are not directly coupled. An explicit function is included that acknowledges that deforestation generates a once and for ever production of wood and other forestry products.

Keywords: general equilibrium model, forestry, deforestation, land supply.

A comprehensive summary of this working document can be found in WOt-paper 22 (2013): Woltjer, G.B. *Modellering van verandering van grondgebruik en bosbouw in een algemeen evenwichtsmodel.* (in Dutch)

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Preface

This report is the result of a combination of two projects: a WOT project on forestry in MAGNET of 2011 and a Knowledge Base project of 2012. It discusses the theoretical background and empirical implementation of a new approach to forestry and land use in the MAGNET model. This approach not only solves some problems in the old approach but also opens the way towards the use of empirical information on the dynamics of forestry and deforestation in the model.

Geert Woltjer

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Summary

Background

The combination of the land supply curve and a constant elasticity of transformation (CET) function is one of the corner stones of the global general equilibrium model MAGNET. The land supply curve describes the relationship between agricultural land area and average land rentals. The CET function describes how allocation of agricultural land over different sectors changes depending on changes in relative rentals earned in the different activities. The use of this combination with the parameterization normally used generates some results that are not very plausible. For example, increase in demand for cropland reduces the rentals on grassland and forestland, and in general it seems that agricultural land supply expands too much when demand for land increases. In other words, the model gives too much expansion on the extensive margin, and not enough expansion on the intensive margin.

Another problem is the symmetry in the CET function. Switching from grassland to forestland is as easy as switching from forestland to grassland. Another disadvantage of the land supply curve-CET approach is that it is not able to differentiate between different types of non-agricultural land use. Forest land, built-up area, savannah grassland are all handled in the same way. For all these reasons a new approach to land modelling has been explored.

Other modelling approaches

In order to get an overview of other approaches for land use modelling in general equilibrium models, two studies have been evaluated in some detail. First, the study by Ferreira and Horridge (2012) on Brazil introduces the concept of the land transition matrix. Second, a study by Gurgel *et al.* (2007) introduces the idea that land transition towards higher value land use types requires investment.

In this report a first attempt is made to model land cover change in a fundamentally different way than the land supply curve with CET approach. The basic concept is the land transition matrix that describes the transition flows from one land cover type to another. The idea is that relative prices do determine the size of these flows, where the flows may regress to 'normal' flows in the long run. This creates much more flexibility into the system. The approach creates also the possibility to differentiate between a lot of land cover types, making it potentially possible to have different transitions from one land cover type to another. It provides also the opportunity to include empirical information on the dynamics of land cover changes into the land modelling system. For example, the growth of built-up area may be determined completely by population and welfare growth, instead of the price mechanism.

The new approach provides the opportunity to include a specific handling of forestry. Forestry has been handled in the new land transition approach by including some characteristics of the forestry sector into the model. The production of the forestry sector has two sources: harvesting of commercial forests, and cleaning of forest land for conversion into other types of land. The combination of the two sources implies that in periods with a lot of land conversion from natural forests to other land use types the supply of timber wood is higher than normal.

The rent on forest is split into a rent on forest harvests, that is the rent really earned during production (as it is in the standard GTAP model), and a rent that is paid for using land for growing forests (as it is in the standard MAGNET approach if forestry land is included). This decouples land use for forestry and harvests of forests. This is intuitively much better given the long time that it takes before a forest can be harvested. For the moment the two rents are directly coupled in the model, and the rents on forestry determine through the land transition functions the amount of commercial forest land.

A growth function of forests, at this moment a fixed amount per km^2, describes how forest capital increases over time, while the harvests reduce the amount of forest capital. Some substitution possibilities in the demand for forestry products have been introduced in the construction industry and the investment goods sector.

At this moment parameters for the forestry module and the land transition module are introduced in an ad hoc manner. The approach provides the opportunity to fill the parameters with numbers based on empirical information, as far as available.

Potentially, the land transition matrix approach could be extended with the idea that conversion towards higher value land use types require an investment by adding an investment flow related with the land transition in the same manner that we add a timber land flow related with some land transitions.

Three simulation experiments

Discussion of three simulation experiments finish this report in order to get an idea of the behaviour of the new transition matrix based land use approach compared with the standard land supply curve CET approach. A baseline experiment, a historical simulation experiment and a biofuel experiment suggest that the new land supply performs in a more plausible manner than the old land supply approach. Livestock land use develops more like we have seen in the past, while the experiment with the biofuels directive shows that land price behaviour is more plausible. Nevertheless, also in the new approach an increase in biofuel production leads to extensification of livestock production in the short run. The background is in the segmentation of the labour and capital market; the realism of this mechanism requires further investigation.

A historical simulation covering about the last ten years provides the opportunity for comparison of the simulation results with empirical data from FAO. The results suggest that the new land supply approach mirrors better historical land cover change patterns in Brazil than the old land supply approach. We have to be aware that the results of both the old and the new land supply approach depend also on the parameters chosen, so the discussion on the advantages and disadvantages of both methods requires further investigation. Nevertheless, the results of the new approach seem to be promising, and the new approach seems to provide opportunities to put more empirical content in the land allocation module of MAGNET.

The next steps in developing the new land use and forestry module is to include more empirical information in the coefficients and the equations. The system, as it has been designed now, is quite open for this.

Samenvatting

Achtergrond en aanleiding

Dit werkdocument bespreekt verbeteringen in het algemene evenwichtsmodel MAGNET die nodig waren om de analyse van grondgebruiksveranderingen en de dynamiek van bosbouw en ontbossing beter te kunnen analyseren. De combinatie van de grondaanbodcurve en de constant elasticity of transformation (CET)-functie vormden de hoeksteen van de landmodule in MAGNET.

De grondaanbodcurve beschrijft de relatie tussen de oppervlakte agrarische grond en de grondpacht. De CET-functie beschrijft hoe de agrarische grond over verschillende sectoren wordt verdeeld. Als dit systeem wordt gebruikt, leidt dit bij de parameterwaarden die normaal in het model worden gebruikt soms tot verrassende, weinig plausibele resultaten. Zo leidt een toename van de vraag naar akkerland tot een daling van de prijs van grasland en bosgrond. Ook lijkt een toename in de vraag naar agrarische producten in het model vooral te leiden tot uitbreiding van landbouwgrond, en in veel mindere mate tot intensivering.

Een ander probleem is de symmetrie in de CET-functie die grond over de verschillende sectoren verdeelt. Volgens de CET-functie is omzetting van grasland in bosgrond even gemakkelijk als de omzetting van bosgrond in grasland. Een ander nadeel van de grondaanbodcurve CET-benadering is dat er geen onderscheid wordt gemaakt tussen verschillende soorten niet-agrarisch grondgebruik. Zo worden bosgrond, bebouwde grond en savannes op dezelfde manier behandeld. Vanwege al deze redenen wordt er in dit werkdocument een nieuwe benadering ontwikkeld om grondaanbod en bosbouw te modelleren.

Alternatieve benaderingen voor modellering

In hoofdstuk 3 wordt er een overzicht gegeven van twee studies waar alternatieve benaderingen voor grondgebruikmodellering in algemene evenwichtsmodellen worden gebruikt. De eerste studie van Ferreira en Horridge (2012) introduceren voor Brazilië het concept van de grondtransitiematrix. De tweede studie, van Gurgel *et al.* (2007), introduceert het idee dat grondtransities van grond van lagere waardes naar hogere waardes investeringen vergt.

In hoofdstuk 4 wordt het literatuuroverzicht in hoofdstuk 3 als inspiratiebron gebruikt voor een nieuwe benadering van de modellering van grondgebruik in MAGNET. Het fundamentele concept is de grondtransitiematrix die de transitie van het ene type grondgebruik naar het andere beschrijft. Het idee is dat de omzetting van de ene soort grondgebruik in de andere mede bepaald wordt door relatieve grondprijzen, waarbij de stromen die op deze wijze gegenereerd zijn geleidelijk tot normale waarden teruggaan als de grondprijzen niet verder veranderen. Dit maakt het systeem zeer flexibel. De benadering geeft ook de mogelijkheid om onderscheid te maken tussen verschillende soorten niet-agrarisch grondgebruik. Hierdoor kan specifieke empirische informatie over sommige grondgebruiksvormen gemakkelijker in het model worden ingebracht. Zo wordt als voorbeeld de oppervlakte bebouwde grond volledige bepaald door bevolkingsgroei en groei van nationaal inkomen, en is de prijs van bebouwde en agrarische grond hier een resultante van.

De nieuwe benadering van grondgebruik geeft de mogelijkheid om de specifieke karakteristieken van bosbouw in het model te verwerken. De productie van bosbouwproducten bestaat uit twee fundamenteel verschillende bronnen. De eerste is het oogsten van hout van commerciële bossen, de tweede is de eenmalige oogst van hout die ontstaat doordat natuurlijk bos wordt omgezet in landbouwgrond. Dit impliceert dat in perioden met veel ontbossing het aanbod van timmerhout groter is dan normaal.

De pacht voor bossen en bosbouw wordt gesplitst in de nieuwe modelleringssystematiek. Als er hout gekapt wordt, ontstaat er een winst per hectare gekapt bos die als beloning voor de natuurlijke hulpbron 'bos' kan worden gezien. De pacht die wordt betaald voor het in gebruik houden van commerciële bosgrond is daar slechts indirect aan gerelateerd. Deze pacht zit gewoon in de dynamiek van de grondtransitiematrix verwerkt. Dit ontkoppelt de beslissing over het gebruiken van grond voor bos en de beslissing om bossen te kappen, hetgeen beter aansluit bij het feit dat er tientallen jaren zitten tussen het moment dat een bos wordt geplant en dat het wordt gekapt om hout en andere bosbouwproducten te verkopen.

Een groeifunctie van kapitaal in de bosbouwsector beschrijft hoe het bosbouwkapitaal toeneemt als gevolg van jaarlijkse groei van de bossen, en afneemt doordat bossen worden gekapt. Ook zijn er voor de voltooiing van de modellering van de bosbouwsector substitutiemogelijkheden voor de vraag naar bosbouwproducten in het model ingebouwd. Op dit moment worden de parameters voor de bosbouwsector en de grondtransitiematrices op een ad hoc wijze gekalibreerd. De benadering geeft echter de mogelijkheid om specifieke empirische informatie in het model te verwerken. In principe kan het concept van de grondtransitiematrix worden uitgebreid met een investeringsfunctie die expliciet maakt dat het veranderen van grondgebruik van lager naar hoger gewaardeerde grond kosten met zich meebrengt. Dit is nu nog niet gedaan.

Simulatie-experimenten

Drie simulatie-experimenten besluiten dit werkdocument. De drie experimenten laten zien hoe de nieuwe op de grondtransitiematrix gebaseerde benadering van grondaanbod zich verhoudt tot de standaard grondaanbodcurve CET-benadering. Een baseline scenario, een historische simulatie en een biobrandstoffenexperiment suggereren dat de nieuwe benadering zich beter gedraagt dan de oude benadering van grondaanbod. Grondgebruik in de veehouderij in Brazilië ontwikkelt zich meer zoals we in de laatste tien jaar hebben gezien, terwijl bij een toename van gebruik van gewassen voor biobrandstoffen het gedrag van de grondprijzen plausibeler is. Toch leidt ook in de nieuwe benadering een toenemend gebruik van biobrandstoffen op de korte termijn nog steeds tot enige extensivering van de veehouderij. Dit gebeurt omdat meer kapitaal en arbeid worden ingezet in de akkerbouw. Of dit overeenkomt met de werkelijke dynamiek in de landbouw, vergt nader onderzoek.

Een historische simulatie van de laatste tien jaar geeft een eerste vergelijking van modelresultaten met data van de FAO. We nemen Brazilië als voorbeeld. Een eerste analyse suggereert dat de nieuwe benadering van het grondaanbod de ontwikkeling in Brazilië beter beschrijft dan de oude benadering. Hierbij moet de kanttekening worden geplaatst dat de resultaten van beide benaderingen ook afhangt van de manier waarop de parameters zijn gekalibreerd. Niettemin lijkt de nieuwe benadering veelbelovend, niet het minst omdat het veel makkelijker is om empirische informatie in de parametrisering van de nieuwe grondallocatiemodule in te brengen. Dit is de volgende stap voor de verdere ontwikkeling van de nieuwe grondgebruik en bosbouw module in MAGNET.

Het is een uitdaging om beschikbare kennis, zowel kwalitatief als kwantitatief, in de vergelijkingen en coëfficiënten van de nieuwe grondgebruiksmodule in te brengen. Het ontwerp van de nieuwe module geeft alle mogelijkheden hiertoe.

1 Introduction

In 2010 a start has been made to include forestry into MAGNET. The approach and data used by Lee *et al.* (2009) is implemented, where forestry land use is defined and forestry land is included in the CET nesting structure for land (Walker and Woltjer, 2011). This required relatively minor changes in the model, but was not neither satisfactory from an empirical nor from a theoretical point of view. In 2011 and 2012 the implementation of forestry has been improved and the result is summarized in this report.

The first line of improvement is the land supply approach, where an alternative for the combination of a land supply curve with CET land allocation structure is developed. The CET approach has not very plausible outcomes and is also not very satisfactory from a theoretical point of view. As an alternative a land transition matrix approach has been developed that is inherently dynamic in character, and creates much more flexibility in distinguishing different land cover types.

The second line of improvement is in forest dynamics. Forestry production requires a long period of time, something that is not consistent with the current CET approach used in MAGNET. For this reason, the decision to harvest forestry products is separated from the decision to expand or reduce forestry land, although both are related with forest land rent developments. Furthermore, forest production is related explicitly to deforestation: if forest land is converted into grassland or cropland, the cutting of the forest generates an extra supply of forestry products.

A third improvement is on the demand side for forestry products. If the price of forestry products increases, demand will be reduced by substituting with other commodities like plastics and metals. This substitution is explicitly taken into account for capital goods and construction.

In order to show the behaviour of the new land supply and forestry demand system under different conditions three scenarios will be analysed. This shows the logic of the system. The approach developed in this report doesn't include a lot of empirical evidence yet, but it opens the door to including empirical information on land transition and forestry dynamics in an easier and more plausible manner.

The structure of the report is as follows. First, the problems with the standard land supply and CET approach will be discussed in Chapter 2. Then the two main alternatives developed in the literature will be investigated (Chapter 3). The new approach, developed in Chapter 4, takes lessons from these two approaches. The introduction of forestry supply and demand consistent with the new land allocation system is introduced in Chapter 5. Finally, Chapter 6 discusses a baseline, a historical simulation and a biofuels scenario where the simulation results with the old land supply approach is compared with those of the new one.

2 Problems with the old land supply approach in MAGNET

2.1 Old land supply with CET implementation

The standard approach in MAGNET was a combination of a land supply function for all agricultural land and a nested CET function to distribute agricultural land over different land uses. When forestry was introduced in this approach, forestry was just considered as a part of agricultural land that could substitute with cropland and grassland according to a CET function.

2.1.1 The land supply curve

The land market in standard GTAP is extended in MAGNET with an explicit land supply function. The basic idea is that supply of agricultural land depends on average land price. This land price is calculated as a weighted average of land prices for different land uses. An increase in agricultural land price either implies less urban land use, or less land use for nature. The asymptote is defined as the maximum amount of land that is available for agriculture, and it seems plausible that land price increases when agricultural land use increases. This idea behind the land supply function is illustrated with the land supply curve in Figure 2.1.

The land supply curve shows that if the land rental rate, i.e. the price of land, increases, the amount of land that will be taken into cultivation rises. When a lot of unused land is still available, the land supply curve is about horizontal. In the curve of Figure 2.1 an increase in demand from D1 till D1' generates a large increase in land use from Q1 till Q1', and a small increase in rental rate from P1 till P1'. In a country where current land use is nearer to the asymptote, an increase in demand from D2 till D2' generates a small increase in agricultural land use from Q2 till Q2', and a relatively large increase in land rental price from P2 till P2'. In this manner the effect of an increase in land demand on land use depends on the scarcity of land in a country.

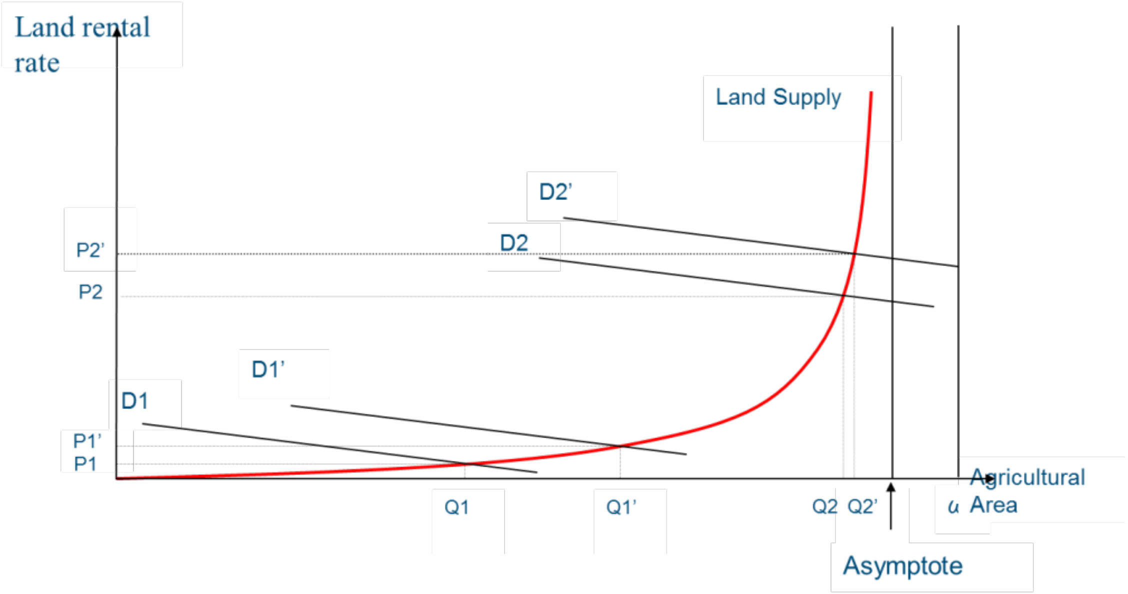

Figure 2.1: The land supply curve

It is not easy to find a good foundation for the land supply elasticities used to calibrate the land supply curve. The calibration of the land supply elasticity function was originally based on the land productivity as defined in the land use model IMAGE (MNP, 2006). The idea was that in first instance land with high land productivity would be used and when land use would expand less and less productive land would be taken into production. This idea was not consistent with what determined land allocation in IMAGE. In IMAGE grids are defined for 0.5 x 0.5 degree spatial resolution, about 50 x 50 km, and for each grid cell IMAGE calculates suitability based on a very rough indicator function. Suitability is the sum of indexed suitability between 0 and 500 for population density, distance to main water infrastructure, and a random factor, with land productivity having a negligible influence. It adds an indicator between 0 and 1 to the calculated suitability, where cells with land productivities of less than 10% of the maximum are not included in the land allocation procedure. This implies that there are enormous differences in land productivities of cells with the same suitability. Land is allocated from highest to lowest land suitability, starting from the current land allocation.

Knowing that the suitability values in IMAGE have not much to do with land prices, a much easier approach for calibration of the land supply function was developed. The function was simplified. Two basic logical requirements form the starting point: the elasticity of land supply is zero when land supply equals the amount of available land, and approaches infinity when land use approaches zero. The function was calibrated on one other point: when 50% of available land is used, we assumed that the price elasticity of land supply equals 4, but by changing a parameter this could be easily adjusted.

Information about suitability may be used to derive a land supply function for MAGNET. But this is a risky business. For suitability only an ordinal scale is required, while land price is a cardinal scale. By weighting the different elements in calculating the suitability index, some cardinality is also implied. For example, with a population density index of 500 an increase of 1 in distance to infrastructure is assumed to have the same effect as the increase of 1 in distance to infrastructure with a density index of 200. So, the better the suitability index in IMAGE is based on a correct and statistically estimated function, the better will be the cardinal properties of the index.

2.1.2 Allocation of agricultural land with a nested CET function

The standard version of GTAP represents land allocation in a constant elasticity of transformation (CET) structure (left side of Figure 2.2) assuming that the various types of land use are imperfect substitutes.

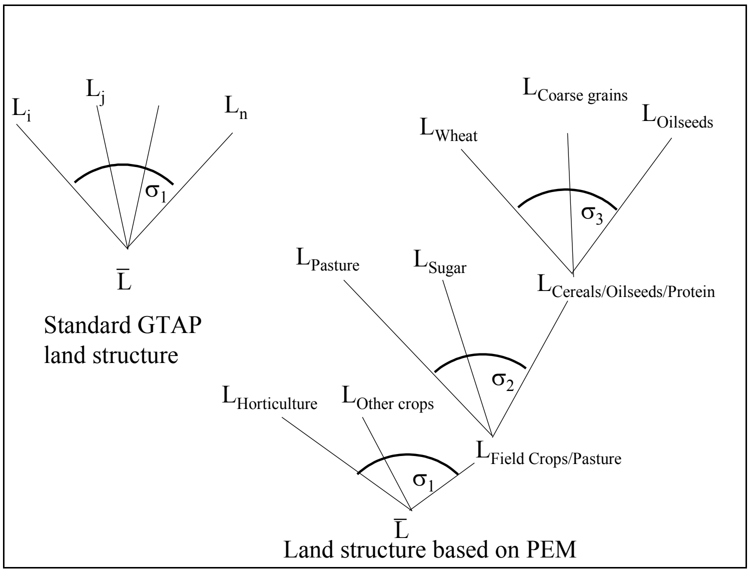

Figure 2.2:
Land allocation tree in MAGNET

This simple land use allocation structure with equal substitution elasticities between all land uses is extended by creating a nested three-level CET-structure that takes into account that the degree of substitutability differs between types of land using the elasticities from the OECD Policy Evaluation Model (Huang *et al.*, 2004) in a nested three-level CET structure (right part of Figure 2.2). In this structure it is assumed that for example wheat and oilseeds are easier to substitute than horticulture and field crops, i.e. that $\sigma3 > \sigma2 > \sigma1$.

The basic approach with the PEM nesting structure has been generalized for MAGNET to the possibility to create all types of nesting CET structures. One of the nesting structures used includes also forestry as a sector, where the top nest substitutes between crops, livestock and forestry. Based on estimates from Purdue university this CET elasticity was set at 0.2, i.e. a very low value. But even for the other elasticities normally values less than 1 are used.

2.2 Rationale for the CET approach

The rationale for the CET functional form may be interpreted in three ways (see for the first two Baltzer and Kløverpris, 2008: 20-1). First, different types of land have different productivities for different products. If the land is allocated more or less optimally to the different sectors, a change in allocation implies that the expanding sector has to use less productive lands, while the sector that reduces its land use may get rid of land with a lower than average productivity. As a consequence, a switch of production will generate an increase in the number of hectares needed.

Second, an increase in variety of production implies more opportunities for crop rotation, and therefore a higher land productivity. Although this may be the case for substitution between crop products, this cannot be defended for substitution between grassland and cropland.

Third, practice shows that farmers do not switch to different crop types immediately. A change in crop may require some investment or at least some adjustment in production processes. Especially changes between grassland and cropland may require adjustments in the production process. Uncertainty and adjustment costs will delay this process, even if productivities may not be involved. To the extent that this dynamic process is relevant, a dynamic formulation of land adjustment would be required, implying that in the short run the effect of differences in rent between different sectors generate only small adjustments in land allocation, while after a long time the elasticity of transformation may be almost infinity. The combination of the lines of reasoning above would imply a lower elasticity of transformation in the short run than in the long run.

In the current implementation technological opportunities do not depend on the share of land used for this product. Demand is determined by relative price, and it is assumed that relative price of a specific use of land increases with the share of land used by this product. This is consistent with the first two arguments, and it could be consistent with the adjustment cost argument in the short run. But in the long run it is not, because then price would go back to its original value.

2.3 Problems with the land supply CET approach

The consequence of the CET approach with the land supply curve is that an increase in crop land demand as a consequence of for example a biofuels policy results in lower prices for grassland and forest land. The explanation of this is as follows. When demand for cropland rises, this implies that the share of cropland in total agricultural land use increases, and according to the CET function this requires that the relative price of cropland rises compared with the price of other agricultural land like forest land and pasture land. On the other hand, the supply of total land is determined by the land supply curve that describes a relationship between land use and the average price of land. If land supply is infinitely elastic, the average price of land will not change when land supply has to increase. If the average price of land is not changing, a relative price increase of cropland requires a price decrease in grassland and forestland. The reduction in land price generates extensification of land use for grassland and forestland. It is obvious that the land supply curve is normally not perfectly elastic, but even at relatively small elasticities of land supply, the perverse behaviour of forest and grassland rentals emerges.

The effect described above is reinforced by the MAGNET implementation of the labour and capital market. It is assumed that labour and capital are distributed according to a CET function between agricultural and other sectors. This implies that when demand for labour and capital in agricultural sectors rises, the relative wage and capital cost in agriculture rises compared with that of other sectors. Because agriculture will not influence the average wage and capital cost in the economy, this implies that the cost of capital and labour in agriculture rises, and therefore capital and labour are becoming more expensive relative to land. This generates a substitution process away from capital and labour into more use of land. Because of the small elasticity of substitution between labour, capital and land in MAGNET the effect will not be very strong, and normally the increase in prices in cropland will be larger than the increase in labour and capital cost. But for grassland, with already a declining tendency of land cost, the increase in labour and capital cost reinforces the extensification process of grassland and forestland. In the dynamic formulation of the labour and capital market the effect vanishes in the long run.

2.4 A solution for part of the problems

From the description of the problem with the current land supply approach in MAGNET follows already one possible solution: to make land supply less elastic. This approach is for example used in Laborde and Valin (2012), and may be easily implemented. By doing this alone, this will imply large increases in land price that are not very plausible. Insight in the normal process of intensification may help to solve part of this issue. When substitution between land and fertilizer is assumed a large part of the price increase may be taken away by using more fertilizer as a consequence of higher land prices. A very important question remains what the substitution elasticity between land and fertilizer is in different regions of the world, depending on current fertilizer use. So, the possibility of substitution between fertilizer and land in combination with less elastic land supply solves part of the problem, but will in many cases still generate very large increases in land price.

Another and additional approach to the problem could be the idea that an increase in prices for crops generates or speeds up technological change in the sectors involved. For example, if more biofuels are demanded and the price of the biofuel crops increases, the productivity of land increases by using more advanced technologies. This approach is taken by Golub and Hertel (2012), but the empirical foundation is very weak. The opinion of the referees is used as the most important argument to take this assumption on board. It helps to increase the intensification of land use above the one with fertilizer-land substitution, and it reduces land use effects as a consequence of biofuel policies. Nevertheless, it remains doubtful to what extend the process happens in the real world.

2.5 A former alternative land supply approach in MAGNET

Some years ago already a new land supply approach has been implemented in MAGNET. The basic idea was that land supply elasticities should depend on the amount of land available for conversion, where a differentiation could be made between different land cover types, like natural forest, natural pasture, savannah, built-up area and other land. The line of reasoning was that land conversion towards agricultural land depends on the price of agricultural land, where the elasticity is different for different land uses. For example, in most countries the supply elasticity is about zero for built-up area:

```
Equation qland1_Build (all,i,Buildland) (all,r,NEWLAND_REG)
              qland(i,r)=  0.6*pop(r)+0.05*qgdp(r);
```

Where:

- qland is the percentage change in the quantity of land cover
- pop is the percentage change in population
- qgdp is the percentage change in real GDP

In this equation the coefficients 0.6 and 0.05 are chosen ad hoc, but this can be based on empirical information. The supply of forest land has some exogenous factors (qforestexo) and depends on the real price of agricultural land compared with in this case the price index of GDP:

```
Equation qland1_forest (all,i,forestland) (all,r,NEWLAND_REG)
             qland(i,r)=qforestexo(r)-landsupel(i,r)*(pagri(r)-pgdp(r));
```

Where:

- landsupel is the land supply elasticity, i.e. a parameter
- pagri is the percentage change in the price of agricultural land
- pgdp is the percentage change in the price of GDP

Agricultural land is what is left over, where CET or perfect competition assumptions (the last by the way not assuming that prices are the same, but that the percentage change in land price is the same for all agricultural land use types) distributes between different types of land. The perfect competition assumption prevents the perverse effects in the standard MAGNET land supply approach, while defining elasticities based on available land, and not automatically calibrated, made it easier to introduce relative small elasticities of land supply.

In summary, the alternative land supply approach in MAGNET was able to solve part of the problems in the standard land supply approach by reducing supply elasticities and increasing CET elasticities, but remained founded on the same basic assumptions. The alternative land supply approach made it easier to differentiate between different types of land that were transferred into agricultural land.

2.6 Conclusion

An important problem of the land supply approach in MAGNET is that it generates extensification of land use when for example demand for crops as a consequence of biofuel policies increases. A solution that reduces the land supply elasticities, increases intensification possibilities by introducing a substitution possibility between land and fertilizer, and an endogenous technology effect of higher crop prices, may all reduce the problem.

3 Alternative approaches to land supply in CGE models

Within CGE models two alternative approaches to land supply can be found. Both approaches use a type of transition matrices between different types of land cover.

3.1 Ferreira and Horridge (2012)

First, Ferreira and Horridge (2012) evaluate the transition between different types of land use in a period of time in million hectares, and assume that this change will continue in the future if land rents do not change.

Table 3.1: A land transition matrix for Brazil (1996–2005, million hectares).

Brazil	**Crop**	**Pasture**	**Planted Forest**	**Unused**	**Total 1996**
Crop	59.2	1.6	0.0	2.0	62.9
Pasture	5.0	153.0	0.4	2.1	160.5
Planted Forest	0.0	0.9	3.6	0.1	4.7
Unused	0.1	3.7	0.6	619.0	623.4
Total 2005	64.3	159.2	4.6	623.3	851.5

Source: Ferreira and Horridge, 2012

In Table 3.1 we see that in Brazil more than 59 million ha remained cropland, that 5 million hectare was transferred from pasture towards cropland, 0.9 million ha went from planted forest to pasture and 3.7 million ha went from unused land to pasture. We see that also some cropland was changed into pasture or unused land. So, although land transition is a two-way process, the overruling transition is from natural forests and unused land to pasture, and from pasture to crops. In modelling the transitions over time, the following formula describes the process:

$$S_{pqr} = \mu \, L_{pqr} P_{qr}^{\alpha} \, M_{qr}$$

Where:
- S is change in land use (as % current use)
- P is the land rent per ha
- L is the current land transition
- M is a shifter
- μ is a shifter to keep total land use the same.

Ferreira and Horridge (2012) use the standard CET approach to model substitution within crops and livestock sectors.

To summarize the idea behind the formula is simple: the change in the land transition flows depends on change in relative prices of the different land cover types. So, the big difference compared with the standard MAGNET land supply approach is that it is *not the level* of land use that is determined by relative prices, but the *change* in land use.

3.2 Gurgel *et al.* (2007)

Also Gurgel *et al.* (2007) apply implicitly a land use transition matrix. They focus on one line of causation, i.e. from natural forest to planted forest, pasture and cropland, where at each stage the rent on the type of land increases. They assume that 1 ha of land of one type is converted to 1 ha of another type, and through conversion it takes on the productivity level of the average for that type for that region. In equilibrium the marginal conversion cost of land from one type to another should be equal to the difference in value of the types. The conversion requires investment, i.e. an investment commodity that produces new land with a higher rental value, and, for forest land, timber wood.

Gurgel *et al.* (2007) assume that the higher value land types are produced by an investment goods sector that is using production inputs like labour, capital and transport, just as if a normal good is produced. The revenue per unit of output is equal to the difference in land price, which is derived from the differences in land rent in the database. The production function they use is illustrated in Figure 3.1. One hectare of land of type gg is transferred in land of type g plus when the original land is natural forest also timber wood. For this transformation process, not only capital, labour, energy and other intermediate inputs are required, but also a fixed production factor in case of natural forest or natural grass to be converted. This fixed factor is calibrated based on the speed of conversion of the original sectors in the past:

> “The OLSR version requires an elasticity of substitution between the fixed factor and other inputs represented in Figure 3.1. We parameterize it to represent observed land supply response in the 1990s to present. Underlying this response may be increasing costs associated with specialized inputs, timing issues in terms of creating access to ever more remote areas, and possible resistance to conversion for environmental and conservation reasons that may be reflected in institutional requirements and permitting before conversion.”

Although the story behind this fixed factor is nice, it introduces a factor that is difficult to grasp in the model and is not less ad hoc than the elasticities used in the Ferreira and Horridge approach.

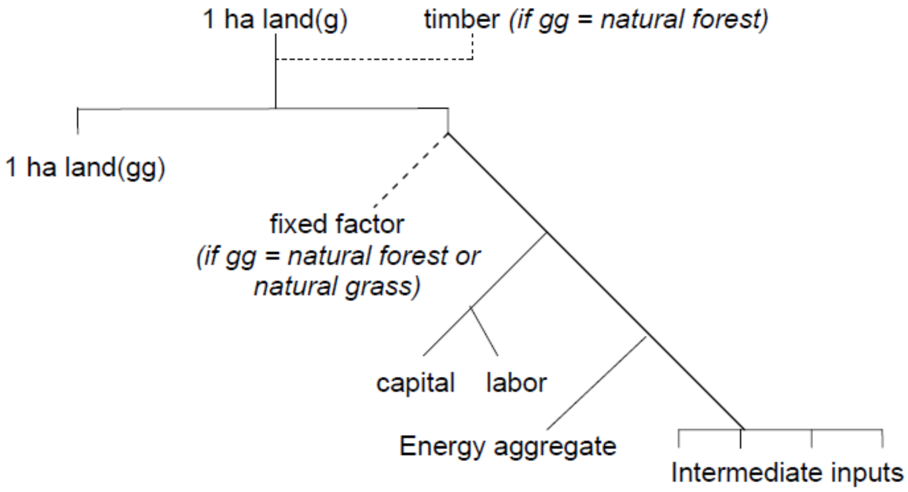

Figure 3.1: Structure of land transformation function (Source: Gurgel et al., 2007)

3.3 Conclusion

Both Ferreira and Horridge (2012) and Gurgel *et al.* (2007) work explicitly or implicitly with a land transition matrix. For Ferreira and Horridge the speed of transition is determined by the relative rents on different types of land, while Gurgel *et al.* model the transition of land with lower rents towards land with higher rents much more explicitly as an investment that is produced by a specific sector. This difference is less than it seems, because of the fixed production factor that Gurgel *et al.* introduce to be able to calibrate the model. So, in the end both approaches depend on calibration of transition probabilities, where Gurgel includes explicitly that higher value land requires some investment. These ideas form the foundation of our new approach to land supply.

4 A new approach to land supply in MAGNET

4.1 Introduction

The need for a new approach in MAGNET is derived from the lack of plausibility of some of the outcomes when the standard land supply CET approach to land transition is used, wishes to improve the empirical foundation, and the wish to be able to include forestry dynamics more explicitly in the model. The explicit introduction of forestry is discussed in Chapter 5.

The basic ideas underlying the new land supply approach are as follows. First, the land transition matrix is taken over from Ferreira and Horridge (2012), although instead of filling in the agricultural sectors through CET nests also movement between agricultural sectors is done through the land transition matrix. This solves the problem that the CET may create a decrease in land rents in sectors like forestry and livestock when the rent for crops increases. For the moment, we don't implement Gurgel *et al.* (2007)'s idea that land use change towards land types with higher rents is investment. Later we may adjust investment flows consistent with the elasticities in the land transition matrices, or determine land transitions partially by investment like in the international investment module in MAGNET.

4.2 The land transition matrix

The basic unit of analysis is land cover:

```
Coefficient (all,j,NEWLAND_CAT) (all,r,REG) LCOV(j,r)  #Land cover in km2#;
```

where the set NEWLAND_CAT includes all land use types, i.e. the land use included in the normal agricultural land demand in the standard model (LDEM) and the other land cover types like forestry and built-up area.

Land cover changes are defined as qland, i.e. the percentage change in land cover, where the price of land, LCOVPRICE, is updated by pland, i.e. the percentage change in the price of land for each land cover type.

The land transition matrix is defined consistent with the description in Section 3.1:

```
Coefficient (all,i,NEWLAND_CAT) (all,j,NEWLAND_CAT) (all,r,NEWLAND_REG) LANDTRANS(i,j,r)
        #Land transition from land type i to land type j in region r#;
```

NEWLAND_REG is just the set of all regions that apply the new land supply module instead of one of the old modules. The land cover change of a specific land cover category can be calculated as the sum of all land transitions from all land cover categories i towards land cover category j, minus all transition from land cover category j towards other land use categories:

```
Formula (all,i,NEWLAND_CAT) (all,r,REG)
            LCOVCHANGE(i,r)=sum{j,NEWLAND_CAT, LANDTRANS(j,i,r)-LANDTRANS(i,j,r)};
```

The basic idea behind the new land supply approach is that the transition from one type of land to another depends on the relative land rents:

```
Equation p_landtrans1
(all,i,NEWLAND_CAT) (all,j,NEWLAND_CAT) (all,r,NEWLAND_REG)
    p_landtrans(i,j,r)=   LANDELAST1(i,j,r)*(pland(j,r)-pland(j,r)) +p_ltransslck(i,r)
                   -(LANDTRANS(i,j,r)-LANDTRANSREF(i,j,r))*LANDREGR*100*time;

Equation p_ltransslck1 (all,i,NEWLAND_CAT) (all,r,NEWLAND_REG)
          sum{j,NEWLAND_CAT, LANDTRANS(i,j,r)*p_landtrans(i,j,r)}=0;
```

Where:

- P_landtrans(i,j,r) = percentage change of land from land category i to j as percentage of land use in land category i
- LANDELAST1(i,j,r) = parameter
- Pland(i,r)= rental price of land of category i in region r
- p_landtrans = a slack variable that guarantees that the sum of all land transitions is zero, i.e. that total land remains the same.
- LANDTRANSREF = the reference land transitions
- LANDREGR = fraction of convergence per year of the current land transition matrix towards the reference land transitions.

So, the percentage change of a land transition from i to j depends on the change in price, the long term equilibrium value of land cover transitions, and the speed with which the land transitions converge to the equilibrium value of land cover transitions, where the slack variable p_ltransslck guarantees that the sum of all changes in land cover equals zero, i.e. the total land cover remains the same. In other words, the land transitions are fuelled by changes in land prices, and regress towards a reference level in the long term. This creates a flexible dynamics in the land transition system, that starts from short term adjustments when the parameter LANDREGR is near 1 till very long lasting effects of changes in relative land prices.

Finally, the land transitions have to be converted towards changes in land cover:

```
Equation qland1 (all,j,NEWLAND_CAT) (all,r,NEWLAND_REG)
LCOV(j,r)*qland(j,r) =sum{i,NEWLAND_CAT:i NE j,
                                 (LANDTRANS(i,j,r)-LANDTRANS(j,i,r))*100*time+
                                   LANDTRANS(i,j,r)*p_landtrans(i,j,r) -LANDTRANS(j,i,r)*p_landtrans(j,i,r)});
```

So, the percentage change in land cover, qland, depends on the level of land transitions from i to j and from j to i (factor 100 is to make a percentage change, and the variable time just transfers the yearly flows in flows consistent with the time evolved), plus the changes in the land transition in the current calculation step in order to guarantee that the prices can determine changes in land cover directly.

In summary, the basic idea of the new land supply is that changes in relative rents of different land use types change the flows from one land use type into another, where the change in land cover of each land use type is the net effect of the change in all these flows. In the long run the net land transitions converge towards zero if the world would reach a steady state, where the parameter LANDREGR determines how fast this convergence is taking place. The ease of conversion of one land use type into another is determined by the price elasticities and the original land use flows. The logical relations can be made more sophisticated by determining the elasticities by formulas taking into account a number of other factors.

4.3 Investment cost related with land conversion

Gurgel *et al.* (2007) model the transition of one land type to another by an explicit production function producing a land transition investment good, but they need a magical fixed production factor to calibrate the function to empirical data. We will not do this here, but potentially the idea that investment is needed for land transitions can be implemented as follows. Implicitly some cost is involved, and this is represented in the difference in rent between different land use types (although the marginal, not the average rent, is the relevant factor, but for the moment we may follow the approach by Gurgel *et al.* (2007) and use the average rent difference as an approximation). The differences in land rents will be represented in differences in land prices, depending on the interest rate. This can be used to allocate some of the investment to the investment in land transition, making the cost of transition, that is basically an investment, explicit in the context of the model.

4.4 A specific role for built-up area

Built-up area may behave differently than normal land, because it is in many regions not determined by relative prices, but by regulation. Therefore, we have decided to give a specific treatment of built-up area, making explicit that it is related with the development of population and GDP, and making the implicit opportunity cost, i.e. the price, determined by the quantity.

```
Equation qland1_Build (all,i,Buildland) (all,r,NEWLAND_REG)
      qland(i,r)=a1*pop(r)+a2*qgdp(r);
```

Where

- a1 and a2 are parameters.
- pop is the percentage change in population
- qgdp is the percentage change in the volume of GDP

As a first approximation we use 0.9 for population and 0.05 for GDP, but it is obvious that all types of empirical information can be incorporated in this equation.

Also for other land there may be a problem, because we don't have an explicit rental for it. For this reason, we fix the price development of other land as equal to the price development of GDP, where the change in land cover of other land is determined by the elasticities in the land transition system and the price developments of other types of land:

```
Equation pland1_other (all,i,Otherland) (all,r,NEWLAND_REG)
   pland(i,r)=pgdp(r)-LSUPEL(i,r)*qland(i,r);
```

where pgdp is the percentage change in the price index of GDP. The term with qland is included to implement also the idea of the land supply curve into the new land transition approach, by the assumption that it becomes more difficult to transfer land of a specific type into agricultural land when less of this land is available. The land supply elasticity LSUPEL can be determined by every formula one wishes, or be set to zero, as is the default value at the moment.

4.5 Conclusion

With the concept of the land transition matrix we have developed a very flexible approach to land use changes. Empirical research is needed to fill in the original land transition matrix and to estimate the relevant elasticities. If more advanced information is available, either through econometric estimation, case study research or expert knowledge, this can be included in formulas for transition elasticities. The example with the formula for built-up area shows that the approach is also open for mechanisms that are not consistent with the pricing mechanism.

5 Forestry dynamics in MAGNET

5.1 Introduction

The new land transition matrix approach to land supply give the opportunity to include forests and forestry in a more realistic manner in the model. Forestry land is a very specific type of land in that it generates gradually capital in the form of wood, and then is harvested, losing all its value. The CET function normally used to allocate land to forestry seems not very appropriate in this context, because this function assumes a direct relationship between current forestry production and the area of forest land. For this reason, we split the forestry modelling in MAGNET in three stages: the first is a growth function of wood capital on the land. This is a process that just goes through time. The second is the decision to harvest the wood, either from natural forests, planted forests or forest plantations (although in the current implementation we don't differentiate between them yet). The third step is the decision to plant new forests.

Next to the supply side of the forestry sector there is also the demand side that has to be adjusted, i.e. when forestry products are becoming more expensive the model must have empirically relevant possibilities to substitute between forestry products and other products like plastics and metals.

5.2 The supply of forestry land and the growth of forestry capital

The first step is the growth of forestry capital. Each year the value of the wood on land in a forest increases. As a first approximation we assume that the yearly growth of wood on a km^2 of land is given per region. In a more sophisticated version this can be made dependent more explicitly on age structure of the forest, type of trees, climate, type of forest management (natural, planted, plantation) etc. Data for this are available in the GTAP land use database (Sohngren, 2007; Sohngren *et al.*, 2009). But for the moment we simply assume that on each km^2 of land grows a fixed amount of wood, and obviously if wood is produced this has to be subtracted from the added wood:

```
Equation p_Qwoodcap1 (all,r,NEWLAND_REG)
   QWOODCAP(r)*p_Qwoodcap(r)= WoodGrowth(r)*sum{i,Forestland,LCOV(i,r)}*100*time
              - sum{j,Forestry,FORESTPROD(j,r)}*100*time;
```

Where:
- QWOODCAP = quantity of capital in wood (i.e. tons of wood, or another measure. For the moment a fake number)
- P_Qwoodcap = percentage change of capital in wood
- WoodGrowth= yearly addition of QWOODCAP per km^2 of land cover
- FORESTPROD = production of forestry products in same dimension as QWOODCAP

Although it may be interesting from an accounting point of view to calculate the value of the wood quantity in the forests, it is not relevant for the model.

The production of forestry products has two important elements. The first is that land transition from forest land to another land use type implies a harvest of forest (although not always), and so we include the average wood revenues from this extra land. The second is just the optimal harvest of the current forestry stock, i.e. a percentage of the total forestry stock.

```
Equation  QOES1_NatRES_For (all,j,Forestry) (all,r,NEWLAND_REG)
 FORESTPROD(j,r)*qoesnatres(j,r)
        = sum{i,Forestland,sum{k,NEWLAND_CAT, AVWOODREV(r)*landtrans(i,k,r)*p_landtrans(i,k,r)}}
                         +optharvest*QWOODCAP(r)*p_Qwoodcap(r)
```

Where:

- qoesnatres(j,r) = percentage change in natural resource use in sector j.
- Forestland = set of forest land types, at this moment only one, but more is available in the GTAP database
- AVWOODREV = average wood production per km^2
- optharvest = fraction of total wood capital quantity that can be harvested with optimal harvest management

Logically, the harvest of wood will increase when the land rent on wood land increases, where a perspective on the future may be relevant in this decision. For the moment, we leave this element out.

When total availability of forestry resources that are harvested in the forestry sector is determined in this way, the output market for the forestry sector and the CES production function structure determine the rental price of the forest natural resource for the forestry sector. The land rent sec, i.e. the value of the land where forestry will be planted, is determined by the formulas on land use for forests.

Although the rent foresters will like to pay for new land may be different from the rent they get on the natural resource they use in producing forestry products, for the moment we assume that they change with the same percentage:

```
Equation pland1_FOR (all,l,ENDWN_COMM) (all,i,forestry) (all,r,NEWLAND_REG)
    pmes(l,i,r)=sum{k,forestland,pland(k,r)};
```

Where:

- pmes = the price of the natural endowment in forestry
- pland = percentage change in the price of land in forestry land

As long as the changes are gradual this seems to be sufficient as a first approximation.

5.3 The demand for forestry products

The GTAP database has a forestry sector, and we may investigate what is the demand structure in this database. Let us first have a look at the world wide destination of sales. Of the total production of forestry products, about 16% is sold to private households, and the rest is delivered to firms as intermediate deliveries. Less than 10% of forestry production is traded internationally.

More than 50% of intermediate deliveries of the forestry sector is delivered to the wood product (lumber) industry, and 10% to the paper industry. 6% of forestry products goes directly to construction, 6% to the chemical industry, and 10% is intermediate delivery for the forestry sector itself.

If we look at possibilities for substitution in the wood product industry, we see that also chemicals are used, as well as ferrous metals. But these are probably complements. So, within the wood product industry there are not many substitution possibilities. The wood products are delivered to the construction sector (35%) and the capital goods sector (14%), as well as to private consumers (10%). Here we have opportunities for substitution. About 3.5% of the production value of the construction industry is wood products, while the cost share of chemical, plastic and metal products is about 6%. These provide obvious possibilities for substitution. So, the solution to the substitution problem could be to include a CES nest with wood products, chemical products and metals. The same could be accomplished for the capital goods sector. Be aware that forestry is only 10% of the input of the wood product industry, so you need relatively large increases in prices of forestry products to have a significant influence on the demand for wood products.

In summary, at a first glance it seems that substitution possibilities for wood products are relatively small, where a relatively large price increase is needed before it has significant effect on demand. Further empirical investigation may deepen this insight and suggest for example other substitution possibilities in for example the paper industry with recycled paper, with energy sources for fire wood or in the wood industry. For the moment the CES nest structure as described above is included in MAGNET.

5.4 Initialization

5.4.1 Initialization of land transition data and parameters

The land cover is in first instance initialized (in the program MagnetAgg) in a very simple and symmetric manner, because in many cases the mechanism that is implemented is more important than the size of the initial flows, except for that the original transitions should not be too big:

```
Coefficient (all,i,NEWLAND_CAT) (all,j,NEWLAND_CAT) (all,r,REG)
  LANDTRANS(i,j,r) #Land transition from land type i to land type j#;
Formula (all,i,NEWLAND_CAT) (all,j,NEWLAND_CAT) (all,r,REG)
   LANDTRANS(i,j,r) = 0.001*min(LCOV(i,r),LCOV(j,r));
Formula (all,i,AGRLND_COMM) (all,j,AGRLND_COMM) (all,r,REG)
   LANDTRANS(i,j,r) = 0.01*min(LCOV(i,r),LCOV(j,r));
Formula (all,i,CROP_COMM) (all,j,CROP_COMM) (all,r,REG)
   LANDTRANS(i,j,r) = 0.1*min(LCOV(i,r),LCOV(j,r));
Formula (all,i,PASTURE_COMM) (all,j,PASTURE_COMM) (all,r,REG)
   LANDTRANS(i,j,r) = 0.05*min(LCOV(i,r),LCOV(j,r));
```

Where LANDTRANS(i,j,r) is the land transition from land cover type i to land cover type j, and LCOV is the land cover of type j. We take the minimum of each land cover type in each bundle. In general the transitions are very small (0.001), but within agriculture they are bigger (0.01, i.e. 1% of the land cover), and for crops they are bigger than that, i.e. 10% of the land cover, while between the different land using livestock sectors the initial land cover flows are also relatively high. This symmetric land transition matrix is also used as the reference land transition matrix, i.e. in the long run the transition flows converge to this matrix, where because of the symmetry the net change for each land cover category is zero.

For the initialization of the price elasticities of land transitions we have a comparable line of reasoning. Some examples are:

```
Formula (all,i,NEWLAND_CAT) (all,j,NEWLAND_CAT) (all,r,REG)
    EL_LANDTRANS(i,j,r)= 0.01;
Formula (all,i,AGRLND_COMM) (all,j,AGRLND_COMM) (all,r,REG)
    EL_LANDTRANS(i,j,r)= 0.15;
Formula (all,i,CROP_COMM) (all,j,CROP_COMM) (all,r,REG)
    EL_LANDTRANS(i,j,r)= 1;
Formula (all,i,Natforland) (all,j,Pasture_comm) (all,r,REG)
    EL_LANDTRANS(i,j,r)=
         300*min(1,3*LCOV(i,r)/sum{k,NEWLAND_CAT,LCOV(k,r)});
Formula (all,i,Pasture_comm) (all,j,CROP_COMM) (all,r,REG)
    EL_LANDTRANS(i,j,r)= 4;
Formula (all,i,NEWLAND_CAT) (all,j,Buildland) (all,r,REG)
    EL_LANDTRANS(i,j,r)= 1;
```

In general, the elasticities are low. Within agriculture a little bit higher and within crops and pasture even higher. But the main transitions are, according to some stylized facts, that transitions are from forest to pasture and from pasture to crops. So, for those relatively high elasticities are used. For the land transitions from natural forest land to pasture land a little bit more sophisticated formula is used that takes into account that the transition elasticities may be smaller when less natural forest is available.

Because the initial land transition matrix assumes no change in land use, this seems not very plausible. Information about current land use transitions is relatively scarce. For this reason, we calibrate the land transition matrix by running the model starting from the initial land transition matrix, and then using the transition matrix that is generated after a number of years where the process of land transition seems to be stabilized as the initial land transition matrix. This matrix may be compared with empirical data for countries where these data are available.

5.4.2 Initialization of forestry parameters

In order to initialize the values of the forest production without the relevant data, we scale QWOODCAP in such a manner that the quantity of wood grows with land cover of forests. This implies that the coefficient WoodGrowth equals 1. If we assume that forests grow for 30 years in a linear way before being harvested, the average wood value per km^2 is 15. This implies that forestry production, assuming linear growth of QWOODCAP and harvest after 30 years, is about 1/15 of QWOODCAP. This implies that the coefficient OptHarvest is 1/15. For the moment we don't initialize forestry production from deforestation, but this should be done in the future. The average wood revenue of converted land, assuming that this is just average forest land, would be 15. Because the quality of the forest will probably be lower than the average forestry land, we make 10 for AVWOODREV.

The initialization of parameters and coefficients is only done to show that the system is doing what it should do, and to have a starting point for rough ideas of what may happen with certain policies. It is obvious that all this a priori information should be changed to real world values when information is available.

5.5 A thought experiment

Let us do the following thought experiment. Assume that deforestation is not allowed anymore. This implies that the supply of wood from natural forests would be reduced. In that case either faster harvesting is required from both natural and planted forests, or demand for forestry products has to be reduced. Probably both will happen, and therefore we have to implement response functions for both. At the demand side the implementation is relatively easy: there must be defined CES substitution nests that allow for substitution between inputs from the forestry sector and other inputs. At the supply side it implies cutting trees at an earlier stage, or using the current harvest of trees in a more efficient manner. The first alternative has long term implications, because less forest will be available for later use, increasing the expected rent of new forest land. This implies that land rents for forests and forestry production depend on expectations about the future. To include these is a challenge for the future.

5.6 Transition of forest land

Transition of forest land should be determined by expected revenues of forest land in the future. This is related with current rents on forestry production, but has also to do with expectations on harvests of natural forest in the future, expected economic development, etc. When elasticities and dynamics are determined in the right way, change in forestry land will be determined automatically. How to incorporate these sophisticated issues requires further investigation.

5.7 Conclusion

Forestry has been included in MAGNET by including some characteristics of the forestry sector into the model. The production of the forestry sector includes two sources: harvesting of commercial forests, and cleaning of land for conversion into other types of land use. The combination of the two sources implies that in periods with a lot of land conversion from natural forests to other land use types the supply of timber wood is higher than normal.

The rent on forestry and forests is split into a rent on forest harvests, that is the rent really earned during production (as was the case in the standard GTAP model), and a rent that is paid for using land for growing forests. This decouples land use for forestry and harvests of forests, as is logic given the long time that it takes before a forest can be harvested. For the moment the two rents are directly coupled in the model, and the rents on forestry determine through the land transition functions the amount of commercial forest land.

A growth function of forests, at this moment a fixed amount per km^2, describes how forest capital increases over time, while the harvests reduce the amount of forest capital. Some substitution possibilities in the demand for forestry products have been introduced in the construction industry and the investment goods sector.

At this moment parameters for the forestry module are introduced in an ad hoc manner. The approach provides the opportunity to fill the parameters with numbers based on empirical information, as far as available. The new approach creates ample opportunities to enrich the model in this manner.

6 A baseline with a simple scenario as an example

In order to illustrate the behaviour of the new land supply approach, we compare a baseline and an international biofuel scenario for both the old and the new land supply approach. Both scenarios are the same, except for the land supply modelling. In interpreting the results, we must be aware that the results of both the old and the new approach depend a lot on how they are calibrated. The main advantage of the new approach is not its behaviour in these scenarios, but the flexibility to bring details in land cover change mechanisms in the model.

6.1 The baseline

To illustrate the effects of the new land supply and forestry module, we did run a baseline scenario. Table 6.1 provides the land use effects of the baseline with the new and old land supply curve for the world, the EU and Brazil. The new land supply approach shows less increase in agricultural area, but this depends on the calibration. What is more characteristic is that livestock area is not growing much on a worldwide scale: intensification has a more important role.

Table 6.1: Percentage change in agricultural land use

	World	World	EU27	EU27	Brazil	Brazil
	New land supply	Old land supply	New land supply	Old land supply	New land supply	Old land supply
Crops	4.9	9.2	-0.5	0.2	10.0	11.5
Livestock	-0.7	6.9	1.5	0.8	-0.4	5.7
Primary agriculture	1.3	7.7	0.1	0.4	2.3	7.2

Table 6.2: Percentage change in agricultural land prices

	World	World	EU27	EU27	Brazil	Brazil
	New land supply	Old land supply	New land supply	Old land supply	New land supply	Old land supply
Crops	142	120	13	7	23	16
Livestock	140	128	15	15	4	-9
Primary agriculture	148	124	13	9	25	13
Rice	171	115	21	29	14	-22
Wheat	102	79	13	7	22	11
Coarse grains	97	60	15	11	15	-5
Vegetable oils	133	121	18	19	38	44
Sugar cane/beet	138	123	16	14	19	6
Horticulture	154	110	12	-2	17	-2
Plans-based fibres	217	302	19	31	29	47
Other crops	120	139	15	10	21	9

Table 6.2 shows the relative prices of cropland and land for livestock. On a worldwide scale the difference is not much, although both are higher as a consequence of the current calibration of the model. For the EU we see much less differences between the price development of cropland and land for livestock. More significant is the difference between the prices of land for different crops. While in the old CET approach there are large differences that may generate even price decreases for some types of land use in a world of increasing land scarcity, the spread of land use price change is much less in the new land supply approach. Again, we must be aware that the difference is also determined by parameter calibration.

Related with the price behaviour of the different land use types, the amount of intensification differs between the new and old land supply approach. Especially livestock intensification is much higher in the new approach. The difference is large in a country like Brazil, but not happening in the EU (Table 6.3).

Table 6.3: Percentage change in land productivity

	World	World	EU27	EU27	Brazil	Brazil
	New land supply	Old land supply	New land supply	Old land supply	New land supply	Old land supply
Crops	58	52	16	14	50	46
Livestock	77	64	16	16	55	47
Primary agriculture	67	57	16	15	58	50

6.2 A biofuel scenario

In the baseline the biofuel share in transport fuels is assumed to remain stable. In order to investigate the effects of an increase in biofuel use, an international biofuel scenario has been defined, where it is assumed that the EU increases its biofuel share in transport from 3% till 5%, Canada from 1% till 3%, the USA from 2% till 10%, Brazil from 17% till 25%, China from 1% till 15%, South East Asia from almost nothing till 5%, and for Indonesia 10%, and that Oceania increases its biofuel share in transport till 3%. For the world as a whole this implies that the share of biofuels in transport increases from 0.27% till 0.87%.

When we analyse the effects of a biofuels directive on production of agricultural commodities, the two approaches generate roughly the same results. But if we are analysing the effect on land prices, significant differences emerge. Table 6.4 shows that in the old land supply approach the land price for livestock in Brazil is reduced, while in the new land supply approach it increases.

Table 6.4: A worldwide biofuels directive: percentage change in real land prices in Brazil in 2020

	New land supply	Old land supply
Crops	5.4	3.2
Livestock	0.3	-3.0

Surprisingly, the seemingly perverse effect of a biofuels directive on extensification of livestock in Brazil remains in 2020, although much less than in the old land supply system. The reason is that employment in agriculture is reduced less than in the baseline (1.8% reduction instead of 4% reduction), and therefore labour and capital in agriculture as a whole become more expensive. As a consequence, livestock farmers try to save on capital and labour that they need in the crop sector. In

2030 this effect is faded out, while with the old land supply approach the relative land price effects according to the CET function is still in (Table 6.5).

Table 6.5: A worldwide biofuels directive: percentage change land productivity in Brazil

		New land supply	Old land supply
2020	Crops	1.8	0.7
	Livestock	-1.0	-2.1
2030	Crops	1.6	1.0
	Livestock	0.0	-1.1

6.3 Simulating the past

In order to have a simple validation of the model, we made a simulation from 2001 till 2010. We used the standard data for calibration of the model, like GDP and population developments and FAO land productivity projections from 2001. Table 6.6 shows the results for one country, Brazil. Based on FAO the average yearly growth of crop land is 0.55%, and of pastureland -0.01%. The new land supply roughly catches this pattern, while the old land supply has much faster growth in pastureland, and also cropland, although the last may be a calibration issue.

Another issue is the stability of the results. While the new land supply approach gives a relatively small increase in land use in the period 2004-2007, this effect is much stronger in the old land supply approach. 2004-2007 is a year with fast GDP growth, both in Brazil and the rest of the world. The land saving technical change, that depends in these simulations partly on GDP growth, increases. The precise causes of the surprising fact that faster GDP growth in the world generates less increase in land use in Brazil requires further investigation.

Table 6.6: Yearly percentage change in land cover in Brazil

		2001-2004	2004-2007	2007-2010	2010-2012	2001-2010
New land supply	Crops	0.71	0.54	0.74	0.70	0.66
	Pasture	-0.12	-0.14	0.14	-0.11	-0.04
	Primary agriculture	0.10	0.04	0.30	0.11	0.15
Old land supply	Crops	0.85	0.54	1.21	0.81	0.87
	Pasture	0.30	0.15	0.69	0.36	0.38
	Primary agriculture	0.44	0.26	0.83	0.48	0.51

In summary, the short sketch of the validation exercise suggests that the new land approach gives better results for Brazil. Detailed analysis is required to get a better grasp on the fundamental causes of the dynamics in the model and to compare this as much as possible with historical evidence, both for Brazil and other regions of the world.

6.4 Conclusion

The simulation experiments in this chapter suggest that the new land supply approach performs in a more plausible manner than the old land supply approach. Livestock land use develops more like we have seen in the past, while the experiment with the biofuels directive shows that land price behaviour is more plausible, but in the short run nevertheless an increase in biofuel production leads to extensification of livestock production. The background is in the segmentation of the labour and capital market; the realism of this mechanism requires further investigation. Comparing simulation about the last 10 years with empirical evidence on land cover change suggests that the new land supply approach mirrors better historical land cover change patterns in Brazil than the old land supply approach.

7 General conclusion

This report discusses improvements of the modelling of land use change in the general equilibrium model MAGNET. In the standard approach a difference is made between agricultural land, non-used land that can be potentially used for agriculture, and land that never can be used for agriculture. In the new approach different other land cover types like built-up area and forestry are distinguished, while also the symmetry requirement of the old model is replaced by a more sophisticated mechanism where stylized facts that forest land is normally converted into grassland, and grassland into cropland can be acknowledged. Next to this the forestry sector is implemented as a sector where land use and harvest of the land are not directly coupled. An explicit function is included that acknowledges that deforestation generates a once and for ever production of wood and other forestry products.

The main advantage of the new approach is the possibility to include empirical information, both quantitative and anecdotal, in the modelling of land supply. Explicit functions that describe the dynamics of transformations of one type of land cover to another make the system more intuitive. The big challenge is to fill in the system with good information, and to calibrate the model in such a way that it explains historical patterns in land use change.

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