Land Use Modeling in
Recursively-Dynamic GTAP Framework*

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GTAP Working Paper No. 48
2008

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*Chapter 10 of the forthcoming book *Economic Analysis of Land Use in Global Climate Change Policy*, edited by Thomas W. Hertel, Steven Rose, and Richard S.J. Tol

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Abstract

The goal of this work is to investigate land-use change at the global scale over the long run – particularly in the context of analyzing the fundamental drivers behind land-use related GHG emissions. For this purpose, we identify the most important drivers of supply and demand for land. On the demand side, we begin with a dynamic general equilibrium (GE) model that predicts economic growth in each region of the world, based on exogenous projections of population, skilled and unskilled labor and technical change. Economy-wide growth is, in turn, translated into consumer demand for specific products using an econometrically estimated, international cross-section, demand system that permits us to predict the pattern of future consumer demands across the development spectrum. This is particularly important in the fast-growing, developing countries, where the composition of consumer demand is changing rapidly. These countries also account for an increasing share of global economic growth and greenhouse gas emissions. Consumer demand is translated into derived demands for land through a set of sectoral production functions that differentiate the demand for land by Agro-Ecological Zone (AEZ).

The paper devotes considerable attention to modeling the supply of land to different land-using activities in the economy. We address the issue of land mobility across different uses via sequence of successively more sophisticated models of land supply, beginning with a model in which land is perfectly mobile and undifferentiated, and ending with one in which land mobility across uses is governed by a nested Constant Elasticity of Transformation function. A soft link between our GE model and an intertemporal forestry model is included for better representation of forestry sector in GE model. To reflect the real world fact that deforestation represents an important source of land supply in the face of high demand, we also introduce the possibility of conversion of unmanaged forest land to land used in production. This is treated as an investment decision whereby new land is accessed only when present value of returns on land in a given region is high enough to cover the costs of accessing the new land. In equilibrium, the supply of land to each land-using activity adjusts to meet the derived demand for land. A set of projections for the long run supply and demand for land obtained with this model is a useful input to improving our understanding of land-related GHG emissions in the future.

JEL codes C68, R14, Q24
Keywords: land use, climate change policy, baseline, general equilibrium, agro-ecological zones

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1. Introduction and motivation

Changes in land use and land cover represent an important driver of net greenhouse gas (GHG) emissions and are a key part of any long run GHG emissions scenario. Currently, agricultural activities generate the largest share, 58%, of the world's anthropogenic non-CO2 emissions (84% of nitrous oxide (N2O) and 47% of methane (CH4)) and make up roughly 14% of all anthropogenic greenhouse gas emissions (U.S. Environmental Protection Agency (US EPA), forthcoming).[1] At the same time, forestry offers considerable scope for carbon sequestration; yet most models of climate change policy have thus far failed to fully take into account the role of land use and land use change in determining changes in net GHG emissions as a result of mitigation efforts. A large part of the problem has been the difficulty in appropriately modeling the derived demand and supply for land in the long run. Hence the focus of this chapter.

In this work, the GTAP-Dyn (Ianchovichina and McDougall, 2001) dynamic general equilibrium (GE) model of the global economy is modified and extended to investigate long-run land-use change at the global scale. For this purpose, we identify the most important drivers of supply and demand for land from 1997 to 2025. A better understanding of this interaction is critical for the long run analyses of the environmental implications of land use and land use change. We begin with an analysis of consumption behavior in the presence of economic growth, since it is the demand for food and forestry products that drives much of the long run demand for

[1] Agricultural sources of NO2 emissions include manure management, agricultural soils, field burning of agricultural residues, and prescribed burning of savannas. These activities are also sources of CH4 emissions. Main sources of CH4 in agriculture are manure management and rice cultivation.

land. Depending on the location of this demand, and the nature of the production undertaken on this land, the pattern of international demands can have important implications for the emissions of greenhouse gases from agriculture and forestry. We then turn to an analysis of the scope for accessing new lands, and converting land from forestry to agriculture, and vice versa.

Examples of other large scale simulation models that investigate the tradeoffs between different land use decisions are the Forest and Agriculture Sectors Model (FASOM) of Adams *et al*. (1996), the Future Agricultural Resource Model (FARM) of Darwin (1995), D-FARM of Ianchovichina *et al*. (2001), and the modified global trade and environment model (GTEM) of Ahammad and Mi (2005). FASOM is a dynamic optimization model that explores allocation of land between agriculture and forestry in the United States. FARM (Darwin, 1995) is a global computable general equilibrium model which is a modified version of the GTAP model. In this model, land is differentiated in six classes, distinguished by the length of the growing season. Land owners allocate land among uses on the basis of a constant elasticity of transformation (CET) function. D-FARM (Ianchovichina *et al*., 2001) extends the FARM model to allow dynamic adjustments over time. The model of Ahammad and Mi (1996) is an extension of GTEM to allow modeling land use changes and associated GHG emissions. Following Darwin (1995), it differentiates land by the length of growing season and utilizes a CET function to model allocation of land across uses. Different from FARM, the allocation of land is a multistage decision process, governed by nested CET functions.

Building on the existing approaches to modeling land use, particularly that of FARM, D-FARM and GTEM, the contribution of this chapter is three-fold. First of all, we incorporate into a recursive dynamic general equilibrium model, a very flexible, non-homothetic demand system that permits changes in the patterns of consumer demand to determine the long run derived demand for land. Second, in response to our initial model projections, we incorporate a soft link between the GE model and forestry model for better representation of forestry sector in GE model. Third, we introduce an investment decision by which land owners consider the conversion of unmanaged forests to commercial forestry or agricultural land.

For purposes of this work, the standard demand structure of GTAP –Dyn model is modified. We introduce an international cross-section, demand system that permits us to predict the pattern of future consumer demands, particularly in the fast-growing, developing countries that account for an increasing share of global economic growth – as well as greenhouse gas emissions. The production structure of land using sectors and specification of land supply are also modified. The later issue is addressed via a sequence of successively more sophisticated models of land supply. We start from assumption that land is perfectly mobile across uses and then gradually restrict mobility of land, introducing Agro-Ecological Zones (AEZs) and nested model of land supply. Our approach is motivated by the findings in the existing literature on land use that land quality and land rents play an important role in determining how landowners allocate land among uses (see Choi *et al*. (2006) for a literature review).

While the introduced features offer what appears to be a quite realistic representation of the individual determinants of land supply and demand, the resulting baseline land rental changes in forestry and grazing appear excessively large. Further analysis suggests that this is driven by the following limitations of the model: the lack of forestry input-augmenting productivity growth in forestry processing sectors and, to some extent, by the absence of unmanaged land that can be brought into commercial production when the derived demand for land is high. Therefore, these issues are subsequently addressed.

Any decision regarding forestry production is always a forward looking decision. Unlike crops and, to some extent, livestock, growing a tree takes a very long period of time, and optimal decisions regarding the timing of forestry harvesting could be modeled only in a forward looking framework. To improve the representation of the forestry sector in a dynamic recursive model, like GTAP-Dyn, a link with forestry dynamic forward looking model is required. We iterate between GTAP-Dyn and Global Timber Model of Sohngen and Mendelson (2006) to determine forestry input-augmenting productivity growth in forestry processing sectors in GTAP-Dyn. Using the rate of unmanaged forest access predicted by the Global Timber Model, we introduce the possibility of conversion of unmanaged forest land to land used in production when demand for cropland, pasture or commercial forestland is high, and land rents are high enough to cover cost of access of unmanaged land.

The chapter is organized in five sections. The modeling framework, structure of consumer demand and production sectors, as well as baseline assumptions are discussed in section two. Sections three is devoted to various issues in modeling land supply. The projected baseline derived demand for land and comparison of alternative supply-side specifications are analyzed in section four. Summary of the results and discussion of limitations are presented in section five.

2. Modeling Framework and Baseline Assumptions

Dynamic General Equilibrium Model

Projections of future global economic activity are undertaken using a modified version of the dynamic GTAP model (Ianchovichina and McDougall, 2001). The dynamic GTAP model is a multi-sector, multi-region, recursive dynamic applied general equilibrium model that extends the standard GTAP model to include international capital mobility, endogenous capital accumulation, and an adaptive expectations theory of investment. The distinguishing feature of the model is its disequilibrium mechanism for determining the regional supply of investments. This mechanism consists of adjustment of the expected rate of return toward actual rate of return within each region and adjustment of the regional expected rate of return toward the global rate of return to capital. These lagged adjustment mechanisms, as well as the mechanism determining the composition of capital and allocation of wealth are parameterized according to econometric estimation documented in Golub (2006).

In order to facilitate long run projections of the sort desired for climate change policy analysis, the GTAP-Dyn has been modified. The usual assumption of fixed savings rates has the unwelcome implication that as economies with high savings rates, like China, grow, there is a "glut of global savings" and, as a result, investments and capital in the world. Because of excessive amount of capital, rates of return to capital are not stationary in the long run. Therefore, in this work we adopt a new approach to the evolution of savings over time (Golub and McDougall, 2006) in which the theoretical structure of GTAP-Dyn is modified such that the wealth to income ratio in each region is stabilized at region specific level. Thus the savings rate becomes an endogenous function of the ratio of wealth to income. This approach is motivated by the balanced growth theory which implies that in steady state, regional income, wealth and savings share the same rates of growth.

Structure of Consumer Demand

The specification of consumer demand is critical for any long run GE growth model. As economies become richer and per capita incomes grow, the income elasticities of demand will determine demands for different products. These changing consumer demands, together with resource constraints will translate into changing production patterns. Thus, specification of consumer demand is an important issue in assessing climate change policies, since it influences the scale and location of each production activity and, hence, associated GHG emission levels. For example, changes in demands for staple crops, livestock products, processed foods and forestry products will determine changes in derived demand for land in each of these activities, land cover, non-carbon dioxide GHG emissions and forest carbon sequestration.

In the choice of demand system for our analysis we follow Yu *et al*. (2002) where the properties of a demand system desirable for long run projections are identified. First, the demand system should be internationally comparable to be used in the global economy projections. Second, the demand system should be consistent with economic theory and should satisfy usual economic restrictions such as adding-up, symmetry and homogeneity. Consistency with economic theory guarantees that budget shares stay non-negative and sum to one in the long run projections involving very large changes in income. Third, the utility function underlying the demand system should be non homothetic to allow changes in the budget shares as income rises. This is especially important for projections of demand for staple food for which budget shares declines as income rises. Finally, the demand system should be very flexible and allow adjustment not only in average budget shares, but also adjustment in marginal budget shares, i.e. fraction of extra dollar spent on food. The adjustment in marginal budget shares is necessary for a non-monotonic path of income elasticities. This permits, for example, income elasticities of staple foods − necessities at low income level − to fall as income rises.

As recommended by Yu et al., we adopt an implicit directly additive demand system (AIDADS) developed by Rimmer and Powell (1996). The AIDADS demand system is rank 3, meaning that it is very flexible in its ability to represent the non-homothetic demand for consumer goods. Furthermore, it has been shown to outperform competing demand systems in the prediction of observed demands – particularly demand for food – across a wide range of income levels (Cranfield *et al*., 2003). From the point of view of determining the long run demand for land in crops, livestock and forestry, the most important feature of this demand system is the fact that the average and marginal budget shares for these (and other) products varies with the level of real, per capita income.

We adopt the AIDADS estimates offered by Reimer and Hertel (2004). We subsequently calibrate the model to each of the 11 regions in our aggregation[2] using the approach outlined by Golub (2006). With a complete demand system in hand for each region in our aggregation, we are in a position to project the pattern of per capita, national consumer demands in all 11 regions, in the year 2025. The impact of income growth on the pattern of consumer expenditure can be nicely illustrated by shocking income per capita by growth in this variable over the 1997-2025 period assuming constant prices for all goods and services. In this illustration, projections of per capita income are exogenous and based on the GTAP baseline (Walmsley *et al*., 2000). Table 1 reports the 1997 and projected 2025 expenditure shares for 10 aggregate commodities in the AIDADS system at constant prices in each of the 11 regions. Note that these shares vary relatively little for Australia and New Zealand (ANZ), High Income Asia (HYAsia), North America (NAM) and Western Europe (WEU) – the high income and slow growing (in terms of per capita income) regions. These regions are characterized by slightly increasing budget shares for services (wholesale, financial, housing and others) and corresponding decreasing budget

[2] The choice of aggregation scheme is driven by our focus on the derived demand for land due to income growth. The 78 regions of the GTAP 5.4 data base (Dimaranan and McDougall, 2002) are aggregated to 11 regions according to the mapping reported in Appendix Table A1. This aggregation, while parsimonious, represents a broad spectrum of income levels and development across regions.

shares for other commodities. In contrast, budget shares in low income and rapidly growing regions, represented by China and South Asia (SAsia) in our aggregation, change quite a bit over the projections period. In these regions budget shares for food products decline significantly, especially in China. The share spent on textile and apparel products declines slightly, and shares spent on manufactured products and different types of services grow quite strongly over the baseline. The other five regions in our aggregation are relatively poor, but have more moderate (ASEAN, Economies in Transition (EIT)) or low (Latin America (LAM), Middle East and North Africa (MENA), Rest of the World (ROW)) *per capita* growth rates. While budget shares spent on food products are large initially, they decline very little over the 1997-2025 period. Similar to high income slow growing regions, these regions are characterized by slightly growing budget shares for services and small decline in budget shares for other commodities.

Of course all of these demands represent consumer demands. Not land demands. To get to the derived demand for land, we must first consider how these consumer demands are met. This takes us to the supply side of the model – in particular the sectoral production functions.

Production Structure

The supply side of this model begins with the standard GTAP model (Hertel, 1997) production functions. These are constant returns to scale, nested CES functions, which first combine primary factors into composite value-added, and imported and domestic intermediate inputs into composite intermediates, before aggregating these composites into an aggregate output. There are 17 production sectors in each region. The 17 produced goods are then combined into 10 consumed goods, according to the mapping reported in Appendix Table A2, using fixed proportions. Some of the 10 consumed goods are composites of several produced goods. For example, the consumed composite MeatDairy consists of ruminants, non-ruminants, processed ruminants and processed non-ruminants. While consumed quantities of the composites grow at the same rate because of fixed proportion assumption, prices of the composites can diverge as economy grows and relative prices change.

In keeping with our interest in the derived demand for land, we modify the standard GTAP production structure in the forestry, crops and livestock sectors. In the forestry sector, we allow for effective substitution between land and other value added inputs (labor and capital) at the national level, based on predictions from the Global Timber Model (Sohngen and Mendelsohn, 2006). Specifically, we observe that changes in management intensity permit substantial changes in forestry output per unit of land. Accordingly, we increase the elasticity of substitution between land and other value added inputs from 0.2 – standard GTAP model magnitude of the elasticity of substitution in value added for natural resource extraction sector – to 1.0, a value suggested by the work reported by Hertel *et al*. (this volume) where the authors explore the sensitivity of management input to carbon price changes. Note that Ronneberger *et al.* (this volume) also increased this substitution elasticity to assure convergence between economic and biophysical models in their coupling procedure.

In the livestock sectors we permit producers to vary the intensive margin of ruminant livestock production. In particular, we permit substitution amongst feedstuffs, and between feedstuffs and land.[3] Therefore, as land rents rise over the baseline projections period, provided TFP growth in agriculture is sufficient to keep crop prices flat or declining (as has been the case historically), producers make greater use of feedlots and intensify their livestock production practices. This phenomenon has proven to be very important in the evolution of livestock

[3] We set the elasticities of substitution between feed and land, and between feedstuffs to 0.75.

production – both in the US and overseas (e.g., China) and is captured in our model via the substitution of purchased feedstuffs for land in the national production function for livestock.

In crop production, we allow substitution between land and fertilizers to reflect the fact that producers will use more fertilizers to increase yields per hectare as land prices rise under the pressure of increasing derived demand for land. In the choice of the elasticity of substitution, we follow the approach outlined in Keeney and Hertel (2005).[4] The region specific elasticities of substitution between value added composite and intermediate inputs are set according to the values of the Allen partial elasticity of substitution between land and purchased inputs reported in OECD (2001). Then, using Allen partial elasticities of substitution between land and other farm-owned inputs, also reported in OECD (2001), we calibrate elasticity of substitution among value added inputs.

As household income rises over the projections period, consumers demand not only a greater quantity of food, but also higher quality food. A recent study of China suggests that "…the demand for quantity diminishes as income rises, and the top tier of Chinese households appear to have reached a saturation point in quantity consumed of most food items. Most additional food spending by this emerging middle class of consumers is spent on higher quality or processed foods and meals in restaurants." (Gale and Huang, 2007). These current trends in China repeat ones observed earlier in higher per capita income countries. The fraction of the average consumer dollar spent on food which actually goes to farmers has been continually declining over the past century (Wohlgenant (1989); Economic Research Service (ERS), US Department of Agriculture (USDA) (2006)). For this reason, we introduce the possibility of

[4] Unlike Keeney and Hertel (2005), we do not model substitution among non-farm purchased intermediate inputs in crops.

substitution between farm and marketing inputs in food processing – in effect allowing the food marketing system to boost the non-agricultural content of food products. For the aggregation used in our land use model, three sectors seem suitable for introduction of this type of substitution: processed ruminants (PrRuminants), processed non ruminants (PrNRuminants) and processed food (PrFood). The values for these elasticities of substitution are taken from Wohlgenant (1989) and range from 0.35 for pork to 0.96 for dairy products.[5]

Baseline Assumptions

The starting point of our simulation is the world economy in 1997, as depicted in the GTAP v.5.4 data base. In our simulations from 1997 to 2025, labor force, population and productivity growth are all exogenous to the model. Projections of labor force (skilled and unskilled labor) growth rates for 1998 – 2025 are taken from Walmsley *et al*. (2000). The historical real GDP and population growth rates for 1998-2004 period are constructed using World Development Indicators database. The real GDP path for 2005 − 2025 is driven by our assumptions about productivity growth in various sectors of the economy. Productivity growth rates in non-land using sectors are based on our assumptions about economy-wide labor productivity growth in each region, adjusted for productivity differences across sectors using estimates reported in Kets and Lejour (2003). For detailed description of the productivity growth in non-land using sectors the reader is referred to Hertel et al. (2006).

There are two land-using sectors: agriculture and forestry. Agriculture, in turn, combines crops, ruminants and non-ruminants. While non-ruminants are included in the discussion here, in

[5] A large part of our processed food sector (PrFood) is processed fruits and vegetables. Wohlgenant (1989) excludes this commodities from the reported results"...because of the wrong sign on the farm output variables". As a proxy for the elasticity of substitution in the processed food sector, we use the elasticity for “Fresh Vegetables” which equals 0.54.

the model the use of land by this sector is set to zero to reflect the fact that production of non-ruminants does not involve grazing land and is largely undertaken in confined settings, that are more nearly akin to factories than farms. For the three agricultural sectors, the projected productivity growth rates are taken from Ludena (2005).[6] These productivity growth rates take into account the productivity of all inputs, not just value-added. In the absence of better information, productivity growth rates in forestry are assumed to be equal to the average of productivity growth rates in crops and ruminants, weighted by the share of their output in total output of crops and ruminants. This is a "neutral" assumption that does not have an affect on the allocation of land between agriculture and forestry. The annual geometric average productivity growth rates in agriculture and forestry sectors are reported in Table 2.

It remains to discuss how we model technical change in forestry processing sectors – a key factor in determining the derived demand for land used in the forestry sector. According to our estimates, real output in the forest products industry in the U.S. increased by 3.8% per year since 1977, whereas the quantity of industrial roundwood harvested in the U.S. increased only by 1.2% per year over the similar period (Haynes, 2003). According to Haynes (2003), in United States production of wood, paper, and paperboard products per unit of industrial roundwood input increased by 35 percent in the past 50 years. This suggests that there has been strong forest input-augmenting technical change in manufacturing and other sectors.

Because this technical change in the forest-using sectors is not directly observable and is difficult to estimate, we adopt an indirect approach to this problem. We iterate between the

[6] In our baseline, we augment productivity growth rates in the three agricultural sectors, reported in Ludena (2005), by a common across regions factor "tfp-agriculture", which is chosen such that world crop price index moves closely with the price index of traded goods and services. Without such adjustment, the crop prices could rise by an implausible amount over the projection period, which would be in sharp contrast with historical evidence on falling crop prices. As it turns out, this adjustment factor is very small, and could be dropped altogether with little change in the findings.

GTAP-Dyn model and the Global Timber Model of Sohngen and Mendelsohn (2006) to determine the relative price of global forestry output. Given baseline GDP, population and AIDADS income elasticities, determining baseline timber consumption path, the Global Timber Model projects global price of forestry. In GTAP-Dyn, we target this price by endogenizing global forestry input-augmenting technical change in forestry processing which plays a key role in determining the long run demand for forest land, and hence land rents (see next section 4 for details).

3. Issues in modeling the supply of land

The focal point of this chapter is the way in which land supply is modeled in general equilibrium, and the implications for the long run use of land in the context of a baseline scenario. We consider two key aspects of land supply in particular: heterogeneity of land, and access to new lands. In this section we outline the conceptual issues associated with each of these challenges. We will then explore their implications in the context of a long run baseline for land use.

Heterogeneity of Land

We will explore the structure of the land market by employing a sequence of successively more complex representations of land supply, and investigating their implications for future patterns of land rents and land use. A natural place to begin with is the naïve assumption that land is like labor and capital inputs in the GE model – homogeneous and perfectly mobile across crops, livestock and forestry in the medium run. In this case, there is a single land rental rate per region that is equated across all uses.[7] Therefore, when the derived demand for land in one sector (e.g., forestry) increases, a substantial shift in land is required in order to re-equilibrate the system. A model operating under such assumptions will overstate the potential for heterogeneous land to move across uses.

A natural way to overcome this heterogeneity problem is to disaggregate the land endowment –much as is done with labor (e.g., disaggregating into skilled and unskilled labor) in CGE models. We do this by bringing climatic and agronomic information to bear on the problem – introducing Agro-Ecological Zones (AEZs) data base (Lee *et al*., 2005).[8] This data base enhances the standard GTAP global economic data base by disaggregating land endowments into 18 AEZs. These AEZs represent six different lengths of growing period (6 x 60 day intervals) spread over three different climatic zones (tropical, temperate and boreal). Following the work of the Food and Agriculture Organization (FAO) and International Institute for Applied Systems Analysis (IIASA), the length of growing period depends on temperature, precipitation, soil characteristics and topography (see also Part II of this book). This approach evaluates the suitability of each AEZ for production of crops, livestock and forestry based on currently observed practices, so that the competition for land within a given AEZ across uses is constrained to include activities that have been observed to take place in that AEZ. Indeed, if two

[7] In the standard GTAP model, land is assumed not to move between agriculture and forestry, and it is imperfectly mobile within agriculture.

[8] Another modification of the standard GTAP data base undertaken in this work is an adjustment of the cost share of land in forestry sector. In the standard GTAP data base, the land share in forestry is unrealistically small – about 7% of value added. This share of land in forestry was been chosen to give a reasonable degree of aggregate supply response in the forestry sector (see Hertel and Tsigas, 2002). However, it has no firm basis in the direct measurement of land rents. This could be improved by combining estimates of per hectare land rents in forestry with Global Timber Market and Forestry Data and forestry hectares estimates obtained with Global Timber Model (Sohngen *et al*.1999). Gouel (2006) used this method to calculate the world average cost share of land in forestry. We use his estimate – world average cost share of 0.39 – to adjust the cost share of land in forestry in the data base.

uses (e.g., citrus groves and wheat) do not presently appear in the same AEZ, then they will not compete in the land market.

From the point of view of the general equilibrium model, the key dimension of the land use data base is the economic importance of land in each AEZ and each activity. Table 3 summarizes land rental shares for cropping, livestock and forestry activities, within 6 AEZs, in the 11 regions (we aggregate over the climate dimension of the AEZs for purposes of this chapter). Thus, the shares within any given column sum to one across uses, for any given AEZ/region. The boldface row in each regional block reports the share of total land rents in a given AEZ in total regional land rents (summed across all AEZs).

From this table, we see that AEZ1 (very short growing period) in ANZ, WEU and ROW is dominated by livestock grazing activity, while extensive cropping dominates in South Asia, Latin America and MENA. In AEZ1 forestry is relatively large component of land rents only in EIT. Cropping activity tends to be economically dominant in AEZ2 for China, South Asia, NAM, LAM, EIT and MENA, forestry is relatively important in WEU, whereas grazing activities dominate in ANZ. On the other hand, cropping activity dominates in all regions, except ANZ, in more productive locales: AEZ3 – AEZ6. However, importance of forestry is gradually rising from AEZ3 to AEZ6 in many regions. And it becomes economically quite important in AEZ6 (the longest growing period) in ANZ, NAM, EIT and ROW.

It is also important to look at the pattern of land rents within a given country, aggregated across AEZs (final column of Table 3). Cropping activity dominates ruminants and forestry in terms of economic value in all regions. In China, cropping activity accounts for an estimated 85% of total land rents in forestry and agriculture. This figure is much lower in Australia/New Zealand, and Europe. Forestry dominates ruminants in many regions including, China, HYAsia, ASEAN, NAM, WEU, MENA and ROW, while the ruminants sector is economically more important in SAsia and LAM. Forestry and ruminants are almost equally important, as measured by estimated land rents, in ANZ and EIT.

Table 3 gives us some insight into the importance of disaggregating AEZs in a particular region, since the elasticity of land supply to each land using activity depends on these land rent shares. In the extreme, if the entry for a given activity in a given AEZ is zero, this activity will not compete in the land market at all. For example, a rise in the price of forest products will have no impact on the land market in AEZ1 in China. On the other hand, small, but unimportant uses have more scope to grow than dominant ones. For example, rising beef prices in China will have a large positive impact on percentage growth of grazing land in AEZ6. By contrast, activities which already dominate land rents in a given AEZ, such as crops in China's AEZ4 and AEZ5, have little room to expand – and the land supply elasticity will be very low. Whereas a rise in relative crops prices may generate a significant increase in acreage devoted to crops in AEZ1, there is very little scope for expansion at the extensive margin of the higher AEZs in China. Of course, the activity/AEZ variation would be much greater if crops were further disaggregated into paddy rice, cotton, wheat, etc in the model, making the presence of AEZs even more important.

Despite the rather coarse grouping of land into AEZs, there is still considerable heterogeneity within these units, and this, in turn, is likely to limit the mobility of land across uses within an AEZ. In addition, there are many other factors, beyond those reflected in the AEZs, that limit land mobility. These include costs of conversion, managerial inertia, un-measured benefits from crop rotation, etc. A natural way to constrain land mobility within an AEZ is via the Constant Elasticity of Transformation (CET) frontier. This is the approach taken in the standard GTAP model (Hertel, 1997), and it is effective at restricting land mobility.[9] The mobility of land across uses is governed by the CET parameter, or the elasticity of transformation, which is non-positive. In this specification, the absolute value of the CET parameter represents the upper bound (in the case of a tiny rental share) on the elasticity of supply to a given use of land in response to a change in its rental rate. The lower bound on this supply elasticity is zero (the case of a unitary land rental share). If the CET parameter is close to zero, then the allocation of land across uses is nearly fixed and unresponsive to changes in relative returns to land in different activities. If the CET parameter is large in absolute magnitude, then allocation of land is very sensitive to disparities in relative returns across land using activities, and land is very mobile across uses.

In a final variant of the land supply model, a nested, multi-stage, optimization structure is introduced which allows better representation of the land transformation possibilities across uses. This follows the approach first proposed in Darwin *et al*. (1995) and then further developed in Ahammad and Mi (2005). Owners of the particular type of land (AEZ) first decide on the allocation of land between agriculture and forestry to maximize the total returns from land. Then, based on the return to land in crop production, relative to the return on land used in ruminant livestock production, the land owner decides on the allocation of land between these two broad types of agricultural activities.[10] These allocations are governed by CET functions. At each stage in the decision making process, the CET parameter increases, reflecting the greater sensitivity to relative returns amongst crops and livestock than between forestry and agriculture – where the allocation decision can be irreversible in the near term.

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[9] A key difference between this variant of the model and the standard GTAP model is that land is assumed to be mobile between agriculture to forestry.

[10] Currently there is only one crop commodity in the model. Though not modeled in this work, the nested structure can be expanded to allow the allocation of land to various crops.

We calibrate the elasticity of transformation of land between agriculture and forestry to econometric estimates. Based on data for U.S. Midwestern forests, Choi (2004) estimates the own price supply elasticity of land to forestry to be 0.516. Sohngen and Brown (2006) report an average land supply elasticity for different types of forests of 1.48. Using initial forestry revenue shares in total land rents in each AEZ/region, we calibrate the CET transformation parameter such that initial supply elasticities are in the range between these two econometric estimates. Specifically, we choose a CET parameter of -1.5 so that the maximum supply elasticity is just under 1.5. [11] The elasticity between crops and livestock is set to -3 – twice larger by absolute magnitude, reflecting the relatively easier conversion of crop land to grazing (as opposed to conversion of agricultural land to forestry and vice versa).

Having introduced AEZs into the model, we must also determine how products produced on different AEZs compete. The most natural approach would be to have a different activity for each AEZ/product combination, with the resulting outputs (e.g., wheat) competing in the product markets. If like products produced on different AEZs are perfect substitutes, then a single price will prevail. If the production functions are similar, and the firms face the same prices for nonland factors, then land rents in comparable activities must also move together. This assumption can be introduced into the model in a variety of ways. The first is to incorporate separate production functions for each AEZ/product combination. With as many as 6 AEZs, this results in a great proliferation of sectors and dimensions in the model which is a problem – particularly for dynamic analysis of global issues. An alternative is to retain a single, national

[11] In earlier work by Golub et al. (2006) value of -0.25 for the CET transformation parameter between forestry and agriculture was used. The smaller absolute magnitude assumes less sensitive land supply to changes in relative returns to land. In this work larger parameter is used to reflect new econometric estimates of Sonhgen and Brown (2006). We also think that larger magnitude of the CET parameter is plausible in the long run scenarios – as opposite to static one like in another chapter of this book “The Role of Land Use in Determining the Economy-wide Cost of Greenhouse Gas Abatement” by Hertel et al. – to reflect greater flexibility of land allocation in the long run.

production function for each commodity, but to introduce the different AEZs as inputs to this national production function. With a sufficiently high elasticity of substitution in use,[12] the return to land across AEZs, but within a given use, will move closely together. This approach is taken here.[13]

Access to New Lands

The second key issue in land supply that we explore in this chapter has to do with access to new lands. In North America, 75% of forest lands are estimated to be currently inaccessible, and therefore not employed in commercial production. In Australia and New Zealand, this figure is above 90% (Global Timber Market and Forestry Data Project, 2004). This represents a substantial source of commercial land, some of which could reasonably be expected to come into use if land rents were to rise sufficiently to bring them into production.

A land owner's decision to add new land to production possesses the two main features of an investment decision. First, the conversion of unmanaged land today yields a stream of future benefits from production undertaken on this land. Second, conversion of unmanaged land is costly because it requires building roads and other infrastructure. Thus, the initial outlay of resources required to access the land must be weighed against future benefits. To model access of unmanaged land as an investment decision, we follow approach described in the Gouel and Hertel (2006) and briefly summarized here.

The price of land today reflects the present value of future benefits generated by production activities on this land. In the context of our model, land owner's benefits from

[12] In this model, the elasticity of substitution among AEZs in production is set to 20.
[13] See the related discussion in Chapter "The Role of Land Use in Determining the Economy-wide Cost of Greenhouse Gas Abatement" of this book by Hertel et al.

holding a land are measured by land rents. With myopic expectations for both the land rents and the rate of return (the only option available in our recursive dynamic model) the price of land can be expressed in terms of the present value of ordinary annuity:

$$P = \frac{Landrent}{r} \tag{1}$$

where P denotes the price of one hectare of forestland that can be converted to land used by one of three land using activity, *Landrent* is the average (across uses) annual land rent generated in a given period, and r is the net rate of return that investors expect to earn over that same period.[14] Because access of new land requires an initial outlay of resources, represented by access costs C, the net present value of accessing new land is:

$$NPV = -C + \frac{Landrent}{r} \tag{2}$$

The marginal costs of accessing new land are expected to rise as more land is accessed and less land is left unmanaged, holding prices of production factors fixed or rising.[15] The marginal hectare of land is accessed when net present value of the decision to access is zero, which is reflected in equality of access cost of the marginal hectare to present value of benefits it provides:

$$C = \frac{Landrent}{r} \tag{3}$$

Thus, the higher land prices generated under pressure from consumer demand for crops, livestock and forestry attract more unmanaged land into the production process. But, new land is accessed only when value of land in a region is high enough to cover the costs of access, which

[14] The rate of return is net of depreciation, which is zero for land asset. Thus, net rate of return and rate of return on land are equal.
[15] The access activity is modeled as a production function, where capital and unskilled labor are production inputs and accessed hectares of unmanaged forests are output.

increase as less land is left unmanaged. Gouel and Hertel (2006) assume that the marginal access cost function is convex in the share of accessed forest in total forest. Therefore, as the share of accessed forest increases, the cost of accessing an additional hectare rises. The costs of access become infinite as the last hectare of inaccessible land is approached. These effects can be modeled with the following functional form for access costs:

$$C(h_{t+1}) = -\alpha.\ln\left(\frac{\bar{h} - h_{t+1}}{\bar{h}}\right) + \beta\,, \tag{4}$$

where $\bar{h}$ is the total forest area, and h the accessed forest area, so $\bar{h} - h$ is the remaining inaccessible forest land. Parameter α determines the long run elasticity of access costs $\sigma(h)$ with respect to cumulatively accessed hectares:

$$\sigma(h) = \frac{\alpha}{C(h)} \frac{1}{\left[\frac{\bar{h}}{h} - 1\right]}\,, \tag{5}$$

which eventually becomes infinite as we exhaust the remaining inaccessible land, i.e. $(\bar{h} - h) \to 0$. Parameter β reconciles observed cumulatively accessed hectares with the current access costs, implied by the current level of price of land in each region.

Following Gouel and Hertel (2006), we parameterize the access cost function in each region by assuming that the elasticity of access costs with respect to cumulative accessed hectares in Australia and New Zealand – the region with the lowest share of accessible forests (Table 4) – is equal to the share of accessible forests, that is $\sigma(h) = 0.066$. Then, each region's α is calibrated such that it would have a very elastic supply of land –very low sensitivity of access costs with respect to cumulatively accessed forestland – if they were to have the same inaccessible share of forest land as recently observed in Australia and New Zealand

(1-0.066=0.934). This assumption fixes ratio of α to access costs $C(h^*)$, existing in a region when share of inaccessible forest was equal to current one in Australia and New Zealand:

$$\sigma(h^*)(\frac{\bar{h}}{h^*}-1)=\frac{\alpha}{C(h^*)} \tag{6}$$

Using the formula for access costs,

$$C\left(h^*\right)=-\alpha.\ln\left(\frac{\bar{h}-h^*}{\bar{h}}\right)+\beta \ . \tag{7}$$

Expressions (6) and (7) together with (4), describing the relationship between current cost of access and current cumulatively accessed hectares, allow us to determine α and β.

The problem with the access cost function (4) is that it leads to unrealistically high rate of access due to the lack of short run constraints. To moderate the rate of access, Gouel and Hertel (2006) modify access cost function (4) by appending a term that is quadratic in the annual rate of access:

$$C\left(h_{t+1}\right)=-\alpha.\ln\left(\frac{\bar{h}-h_{t+1}}{\bar{h}}\right)+\beta+\gamma.\left(\frac{h_{t+1}-h_t}{h_t}\right)^2 \tag{8}$$

where parameter λ governs the size of adjustment costs (a near term phenomenon). Thus, the access cost function (4) can be considered as the long run equilibrium in which $\gamma = 0$ so that the "adjustment cost" term drops out.

Having the long run access cost function calibrated, we need to determine the size of the adjustment cost parameter γ . We determine γ by targeting decadal rate of access of unmanaged forests predicted by the Global Timber Model (Sohngen and Mendelson, 2006) in the first 10 years of our simulation. The access cost function parameters for each region, along with the data required to determine them, are reported in Table 4. The calibrated γ s are very large, thereby ensuring that in model simulations the rates of access are quite stable.

The access cost functions are specified at the regional level, thereby augmenting regional AEZs proportionally, where the proportionate additions are based on the AEZ's current share of accessible forests in the total regional accessible forests. The SAGE land cover data, consistent with GTAP data base definitions of regions and production activities (Lee et al., 2005), is used to determine land endowments and calculate initial period costs of accessing unmanaged land. We refer to the Global Timber Model (Sohngen and Mendelson, 2006) to determine the regions without inaccessible forest land. In Table 4, regions with no inaccessible forests remaining are High Income Asia, South Asia and Western European Union.

4. Analysis

In this section we first present baseline projections of land use changes from 1997 to 2025 and then compare results from the sequence of models of land supply. Our baseline model is the most complex one, including the nested structure of land supply, the soft link with Global Timber Model to determine the time path of forestry prices, and access to new lands through the conversion of unmanaged land to land used in production. All other models discussed here may be viewed as special cases of this baseline model. And by comparing them to the baseline, we are able to gain insight into the limitations of approaches that omit one or more of the baseline model features.

Baseline

We start from the consumer demand side of the model, as this is the main driver of the demand for land. Behavior of the AIDADS budget shares, projected with the GE model, is very similar to that observed in Table 1. However, now, with prices endogenous, consumption depends on substitution as well as income effects. Table 5 reports the changes in consumer demand for the land-using sectors. As population and income rise, consumer demands for crops, livestock and forestry products rise in all regions, with the strongest increases in China, followed by South Asia (Table 5). Considering three sectors at global scale, the strongest growth in demand is predicted for forestry products, which reflects rising demands for furniture, construction and paper products.

Consumer demand and growth in sectoral productivity, as well as availability of land, determine prices of output in the land using sectors. The changes in market and global price indices of output, relative to the price index of world trade, are shown in Table 6. The global price index for crops is flat over the projections period[16] while the global price index of ruminants increases by a very modest amount (Table 6). The global forestry price is determined through iteration with Global Timber Model (see discussion above) and increases at 0.8% per year. This modest, positive rate of growth is consistent with what had been observed historically (Sohngen *et al.*, this volume). To target this slow rate of price increase, the forestry input-augmenting technical change is introduced. In our baseline simulation, the forestry input processing technology is improved at annual rate of 4.2%. This is quite a high rate of technical progress and will require continued strong innovation in the forest products using sectors.

[16] This follows by assumption (see earlier footnote). However, it is nearly true in our model, even without this calibration of global agricultural TFP growth.

Prices for forestry output rise in all regions, except Western European Union, where prices decline very slightly due to relatively strong TFP growth coupled with slow overall economic growth (Table 6). The growth rate for the crops composite varies considerably by region. In regions with slow-growing demand and relatively rapid TFP growth in crops (as in the Americas and Europe), crops prices fall over the baseline. On the other hand, in regions with high demand growth (China and South Asia) or low (even negative) TFP growth (ASEAN and High Income Asia), the composite crop price is rising. Prices for ruminants rise in all regions except for High Income Asia, North America and Latin America, where growth in consumer demand is weak relative to productivity improvements.

Stronger consumer demand for crops, ruminants and forestry translates into increased demand for land. Note that in the baseline the land endowment is not fixed, but rather rises in regions where unmanaged land is available and can be brought into production when land prices are high. When calibrating the adjustment cost parameters associated with the access cost function for unmanaged forests, we target decadal rate of access predicted with the Global Timber Model. The rate of access is defined as hectares accessed per decade divided by the initial forestland accessed. These rates, as well as decadal and annual average rates of access obtained in simulation with GTAP-Dyn, are shown in Table 7. For the first decade of the simulation, the rates in GTAP-Dyn are similar to ones in the Global Timber Model (due to our calibration approach). Thereafter, access rates rise a bit due to the increased demand for land, as well as declining opportunity costs of accessing new land since the rate of return to capital falls in later periods in all regions, except Economies in Transition.[17] The highest rate of access for

[17] Rates of access predicted with the Global Timber Model are very stable as well. In the forward model, rates of access tend to decline as prices stabilize over long time horizon.

new lands is in Australia and New Zealand, where the share of accessible forests is very low and accessing new lands is cheap (Table 4); this is followed by Latin and North America.[18]

Access to new lands for use in agriculture and forestry is driven by rising land prices in those sectors, which are themselves a function of the land rental rates in the land-using sectors and the discount rate. Cumulative and annual growth rates in land values are presented in Table 8. Projected growth in land valuation is highest in South Asia, where consumer demand is strong, and the aggregate land endowment is fixed. In High Income Asia, the value of land used in agriculture and forestry (not urban land) is declining, signaling a strong incentive to convert these lands to other uses (although we do not model this possibility). This declining value of land is explained by negative TFP growth in crops and forestry, and relatively low TFP growth rate in ruminants (Table 2), combined with weak consumer demand. Among regions where access to new lands takes place, the rise in the value of land is highest in Australia and New Zealand, followed by North America and China.

Table 8 also reports changes in the rate of access to non-commercial, forested lands. This access rate rises in all regions where such lands are available, except for EIT. The largest growth in the access rate is 74%, in Middle East and North Africa. This sounds like a large number, until we recognize that the initial rate of access is very low (just 0.02%: Table 7, column 5)[19]. As a result, over the entire period from 1997 to 2025, total accessed forestland expands only to 0.75% in the MENA region (Table 8, total accessible forest land, cumulative growth rate). In contrast, from 1997 to 2025, total accessed forestland in Australia and New Zealand expands by 46%. With relatively moderate growth in forest hectares accessed per year (57%), the 46% expansion

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[18] As discussed before, we assume that no unmanaged forests are left in High Income Asia, South Asia and Western European Union.

[19] The initial annual rate of access is defined as hectares accessed over initial year divided by the initial total accessible forestland.

of accessed forests is explained by a very high initial access rate (1% in Australia and New Zealand, see Table 7). Among regions where access takes place, the growth in value of land is the slowest in Economies in Transition. The slow growth in value of land is explained by relatively slow growth in land rents and, unlike other regions in the model, *increasing* expected returns to capital. This together with rising wage rates for capital and labor, the two inputs required to access new lands in the region, results in a decline in hectares accessed per year (-2%). The initial annual access rate in Economies in Transition is moderate 0.2% (Table 7). Together with declining hectares accessed per year, total accessed forestland expands by 4.6% over the projections period (Table 8).

Figure 1 summarizes access activity measured by the share of accessible forests in total forestland in the initial period (1997). It shows that in Middle East and North Africa very little unmanaged forests are left in the beginning, and accessed forests expand only marginally. On the other hand, there is a large scope for expansion in Australia and New Zealand and the Economies in Transition. From 1997 to 2025, the shares of accessible forests in total forestland increase by the largest amount in Latin America, followed by Australia and New Zealand and North America. In Economies in Transition, expansion of accessed forests is tiny because of slow increase in land value and rising prices of production factors required to access new lands.

Newly accessed land augments the total endowment of land employed in production in each AEZ (in proportion to the AEZ's share of accessible forests in the total regional accessible forests), but only in AEZs where unmanaged forestland is present. Cumulative increase in production land by AEZ and total for each region are shown in the lower part of Table 8. Thus, the bottom panel of Table 8 shows that total land employed in production expands in Australia and New Zealand, but only in AEZ3-AEZ6. In AEZ1 and AEZ2, production land cannot expand because of absence of forestry. Total land in production expands the most in Latin America, followed by North America. In Australia and New Zealand, growth in accessed forestland is large (45%), however land employed in production expands only by 0.2% due to the relatively small share of accessible forests in total land employed in the region (Table 9). In contrast, in Latin America a relatively large increase in total accessible forests (33%), in fact, translates into large increase in land employed in production (10%) because initial share of accessible forests in total production land is high (0.3 in Table 9).

Projected cumulative changes in the demand for land in different sectors and regions are presented in Table 10. These changes are a result of the redistribution of land across sectors as well as the enlarged land endowment. In Australia and New Zealand, North America, Latin America and Western Europe − exporters of agricultural products − land used in commercial forestry production declines, while agricultural lands expand. Within agriculture, cropland expands and land in grazing contracts, except for AEZ6 of Australia and New Zealand and Latin America, where relatively large increases in AEZ land in production is observed (Table 8) and both, crop and grazing, lands expand over the projections period. In the Economies in Transition, Middle East and North Africa, South Asia and High Income Asia, land in forestry expands and agricultural land declines, and, within agriculture, land moves to the ruminants sector.

In ASEAN with only AEZ3 – AEZ6 available, land within agriculture moves to the ruminants sector. Both forestry and agricultural lands expand in AEZ4 and AEZ5 (recall unmanaged land can be converted to either of these activities). In AEZ6 of ASEAN, where forestry is economically quite important (Table 3), forestry expands while land used in agriculture declines. In China, land in forestry expands in all AEZs except AEZ2 where grazing land is relatively more important and strong returns to ruminant production result in agriculture bidding land away from forestry. In Rest of the World, forestry expands and agricultural land declines in all AEZs except the largest AEZ5 dominated by agriculture, where both forestry and agricultural lands expand. Overall, the baseline results suggest a strong move towards increased commercial forestry activity in response to increased demand for forest products worldwide in developing regions, including ASEAN, South Asia and the Rest of the World – three regions which have experienced extensive deforestation in the past few decades.

Figures 2a-2c show global maps of revenue share-weighted changes in land use in crops, ruminants and forestry respectively. The revenue share-weighted changes allow us to evaluate, and compare across regions, the economic importance of land use changes. Expansion of cropland is most important in Australia and New Zealand, followed by Americas and Europe, while the percentage growth in grazing land is largest in China – a region where this represents overall a relatively smaller claim on land in the base period. Expansion of grazing land is also important in Economies in Transition, South Asia, ASEAN, and Middle East and North Africa. Expansion of commercial forestland is important in Economies in Transition, High Income Asia, ASEAN and Middle East and North Africa.

Determining the Relative Importance of Alternative Supply-side Specifications

Having the main features of the baseline in hand, we now explore the implications of alternative assumptions made with respect to the specification of land supply. Following discussion in section 4 of this chapter, we start from a very simple model where land is homogenous and perfectly mobile across uses, and then successively restrict mobility of land. Throughout this exercise, we will focus our attention on the implications for land use and land prices.

The features of the six models are summarized in Table 11. We start from the simplest possible model 1, where land is perfectly mobile, and then gradually introduce features to limit mobility of land across uses. Based on the results obtained with the most highly structured land supply (model 4), the model is then linked to Global Timber Model to improve forestry representation (model 5). In model 6, the possibility of conversion of unmanaged forests to land used in production is introduced. Model 6, our baseline model, includes a nested structure of land supply, a link with Global Timber Model through the time path of forestry output prices, and the possibility of conversion of unmanaged land to land used in production. Results of models 1-5 are compared to this baseline model (model 6). To facilitate comparison, productivity growth in the land using sectors is held constant across six models and fixed at the levels of the baseline model 6 (recall Table 2). The productivity growth in forestry processing in model 5 is also fixed at the levels of model 6 to evaluate effect of the introduction of the possibility of conversion of unmanaged land to land used in production.

Projected changes in total consumption and production of crops, ruminants and forestry in all regions are presented in Tables 12a and 12b, respectively.[20] Here, the cumulative growth rates obtained from simulations with Models 1-5 are expressed as ratios of growth in the model of interest to corresponding growth in model 6. For example, Table 12a shows that ratio of cumulative growth in consumption of ruminants in ANZ predicted with model 1 is only one third (0.33) of cumulative growth predicted with the baseline model 6. In Table 12b, cumulative growth in production of forestry in NAM predicted with model 1 is not only more than 16 times

[20] Note, because 17 produced goods are aggregated to 10 consumption goods, direct correspondence between Tables 12a and 12b could be established only for "crops" (see Table 2b). Produced good "ruminants" is part of the consumed aggregate good "MeatDairy", and produced good "forestry" is part of the consumed aggregate good "Mnfcs" (manufactured goods). Thus, consumer demands for ruminants and forestry are driven by the demands for meat/dairy and manufactured goods, respectively.

larger by absolute magnitude than the one predicted by the baseline model 6, but also has opposite sign. In the baseline production of forestry declines due to the strong forest input-augmenting technical change. However, this feature is not present in model 1, which predicts a large expansion of forestry output in NAM and all other regions, relative to baseline.

When presenting the results for land use change, we concentrate our attention on China, South Asia and Western Europe. These three regions are characterized by very different patterns of economic growth and land endowments. Economic growth is rapid in China and South Asia, but slow in Western Europe. However, 38% of forest land in China is unmanaged forests, while there is none available for conversion in South Asia and Western Europe.

Projected changes in demand for land in land using sectors in the three regions are presented in Tables 14a and 14b. With the nested CET structure, the land owner first allocates land between agriculture and forestry, and then between crops and ruminants. When presenting projected changes in land use, we follow this structure. Table 14a shows distribution of land between agriculture and forestry and Table 14b shows changes within agriculture. When land is treated as perfectly mobile across uses (model 1 and model 2) or mobility is restricted by the non-nested CET (model 3), the decisions about allocation of land among three sectors is taken simultaneously – nothing is reported for agriculture in Table 14a. When land is considered as a homogenous endowment (model 1), only one AEZ-generic growth rate appears in the tables.

Now return to tables 12a and 12b. Consumption and production projected with model 1 and model 2 are almost identical. Thus, the introduction of AEZs does not make any difference for these aggregate outcomes. With perfect mobility of land across uses, land rents in different sectors are always equated within AEZ. In light of the fact that different AEZs substitute readily in a national production function, the land rents across AEZs, but within a given use, will also move together. Thus, in model 2 land rents move together across sectors and AEZs, as in model 1 (Table 13).

Projected changes in land use are also similar across models 1 and 2 (Tables 14a and 14b). With land perfectly mobile across uses (and total land employed in production fixed), in China, South Asia and Western Europe land moves to that sector with the most rapidly growing consumer demand –forestry. In South Asia, forest land increases in expense of crops and ruminants sectors. In China, where rates of growth in demand for forestry and ruminants are much higher than for crops and TFP growth is much stronger in ruminants then in crops, land moves from crops to forestry, and also to ruminant production. In Western Europe, where consumption patterns are very stable and TFP growth in ruminants is much slower than in crops, land in the ruminant sectors contracts and moves to forestry and crops.

When comparing land use projected with models 1 and 2, note that the economic importance of a sector in a specific AEZ determines whether magnitude of change predicted with model 2 is larger or smaller than the one predicted with model 1. Thus, the forestry sector is very small in AEZs 1-4 in South Asia (Table 3) and therefore has great potential to expand without excessively bidding up land rents in that AEZ. In fact, projected changes of land use in forestry in these AEZs are larger than in model 1. In AEZs 5 and 6, where forestry is relatively important, expansion of forest land bids up land rents very quickly and is therefore smaller than in model 1.

Model 3 introduces restrictions on the mobility of land across uses within a given AEZ through a CET function. This gives rise to substantial changes in supply, and hence in relative prices and, therefore consumption. This phenomenon is most striking in the case of ruminants production. Whereas previously there was a strong tendency (outside of China) to shift land out of grazing and into crops and/or forestry production, this kind of reallocation is no longer so easy in the presence of finite acreage response elasticities. With more land being retained in ruminant production, yet the same rate of technical change, prices are accordingly lower and consumption is higher. On the other hand, consumption of crops and forest products is lower. Note also that intermediate use and international trade smooth out the production differences resulting in relatively more uniform changes in consumption across regions (Table 12a). In fact, ruminant consumption is nearly identical to baseline from model 3 onwards, indicating that the CET specification is a key feature of the full baseline model.

With the CET in place, the allocation of land across uses is much less responsive to changes in relative returns to land in different activities and, thus, land rental differentials across sectors persist. Table 13 shows that, with exception of Australia and New Zealand, introduction of CET leads to higher land rents in forestry (comparing models 2 and 3), because growth in demand for forestry is the strongest among three land using sectors worldwide. In China and South Asia, growth in TFP and consumer demand translates into stronger growth in land rents in ruminants sector compared to crops. In China, increase in land rents in crops, predicted with model 3, is even smaller than the one predicted with models 1 and 2. In contrast, in Western Europe where TFP growth in crops is higher than in the ruminants sectors, land rents in crops rise stronger than in ruminants.

With restricted mobility of land across uses, projected changes in land use in China are smaller with model 3 (Table 14a and 14b), however direction of changes is very similar to ones projected with model 2. Forestland and grazing land expands in all AEZs and crop land contracts, but the magnitude of changes is smaller than with model 2. As with models 1 and 2, forest land expands in South Asia. In contrast to models 1 and 2, however, grazing land expands. Both, forestry and grazing land expand at the expense of cropland, which contracts much faster in each AEZ compared to model 2. Similar to model 2, grazing land declines in Western Europe in all AEZs, with changes being smaller than in model 2. Crop land, however, also contracts in AEZs 4 and 5 giving more scope for expansion of land in the forestry sector.

In model 4, the nested CET structure is introduced, whereby the land owner first allocates land between agriculture and forestry, and then between crops and grazing. This modification has very little effect on production patterns (Table 12b), and no effect on consumption. Changes in land use are similar to ones projected with model 3, but in most cases smaller because of more limited mobility of land between agriculture and forestry (Tables 14a and b). And this more limited mobility further increases divergence of land rents across uses (Table 13).

Does this divergence in land rents make sense? Are the projected rates of growth in overall land rents plausible? By way of comparison, it is useful to consider growth in land rents over the past 100 years in the US. In 1900, the average value of agricultural land and buildings was just $20 per acre. By 2000, this had risen to $1,050 in constant dollars –an increase of 52 times or 4% per year (NASS, USDA, 2007). Contrast this with the projected annual growth rate in land rents of 6.78% and 6.03% in crops and livestock, respectively, in North America for 1997-2025 period. The projected rates seem high, especially if we take into account that North America grows slowly over the projection period.

In light of this concern for excessive growth in land rents, we turn to two additional aspects of the long run modeling of land use that we believe are required in order to obtain realistic projections. The first of these has to do with technical change in the forestry using sectors. In models 1-4, we model technical change in forestry processing sector as labor augmenting – as with all the non-land using sectors. This ignores the strong technological improvement in forestry processing sectors observed in the past (recall the discussion of this point in section 2 of this chapter). In model 5, we introduce such forestry input-augmenting technical change in forestry processing, allowing it to adjust endogenously in order to let the model track the price path suggested by the Global Timber Model. Comparison of the production patterns in models 4 and 5 shows huge drop in output of forestry sector (logs) after introduction of the forest product-augmenting technical change (Table 12b). Fewer logs are needed to produce the final goods demanded by consumers. At the same time, with lower prices for the final goods, consumption of these goods increases. The technical change also frees some of the forest land that now may be used to produce more ruminants and crops. As land becomes less “scarce”, output prices in the land using sectors decline, leading to larger consumed quantities of crops and ruminants, as well, in most of the regions (Table 12a).

Forestry input-augmenting technical change reduces pressure on land rents in forestry, as well as in the other land using sectors. Land rents, projected with model 5, are much smaller, especially in forestry. They are also less divergent across uses in all regions except Australia and New Zealand where forestry output projected with model 5 drops below baseline (Table 12b).

Introduction of forestry input-augmenting technical change in forestry processing significantly affects projected land use changes (Table 14a). In China and South Asia, forestland grows only by very small amount in most AEZs, or even contracts slightly in AEZ2 of China, where strong growth in ruminant land demand outbids forestry. Within agriculture, land continues to expand in the ruminants sector, where returns to land are higher (Table 13), at the expense of crop land. In Western Europe’s agricultural sectors, crops outbid the other uses of land and forestry land contracts in all AEZs.

While land rents grow more slowly in model 5 than in previous models, they still grow at a real rate of 7 or 8 percent per year in some regions. This raises the question of whether previously inaccessible land might be accessed to reduce growth in land rents. Certainly the investment theory laid out above would suggest that this kind of a rise in land rents would encourage individuals to invest in roads, infrastructure and deforestation in order to expand the commercial land base. And access to new land is indeed part of the baseline model (6) from which results are reported in Tables 12 – 14. Recall that we calibrate the access cost functions to be initially relatively elastic in those regions with lots of inaccessible land, and inelastic in those regions on the verge of exhausting their inaccessible land (Table 4, column 8). Also, we set the adjustment cost parameters in order to broadly replicate the same rate of access in the first decade as that predicted by the Global Timber Model. As a result, the adjustment cost terms are quite high and access rates are relatively stable. As a consequence, moving from model 5 to model 6 will only make a large difference if: a) the access rate in a region is high initially and b) the initial accessed forest area is large, relative to total land in production, in the same region. These two conditions hold only in Latin America and North America. In Australia and New Zealand access rates are high, however initial accessible forest area is tiny comparing to total production land. Thus, introduction of this last feature changes projections of land use and land rents only slightly.

Projections obtained with model 6 suggest slightly higher consumer demand for crops in all regions. Compared to model 5, this is achieved mostly through expansion of output in Latin and North America, where new access takes place, and reduction of output in Western Europe (Table 12b). Growth rates in land rents are further reduced in all sectors and regions (Table 13). In China, expansion of land used in production changes land use patterns. When more land is available, forest land expands in all AEZs, except AEZ2. Within agriculture, land continues to be shifted into higher returns ruminant production, at the margin. However, the decline in cropland is smaller than predicted with model 5. In South Asia and Western Europe, where no unmanaged forests are available, the pattern of land use change is very similar to one predicted with model 5. The expansion of production land in all other regions smoothes changes in land use in South Asia and Europe. In South Asia, with highest returns to land in forestry, forestland grows and agricultural land declines, as in model 5, but at slower rate. In Western Europe, where returns to agricultural land rise faster than to forestland, agricultural, more specifically cropland, expands in expense of forests.

5. Summary and Evaluation

An important component of global GHG emissions is related to land use. Yet our ability to predict long run changes in global land use remains limited. In this chapter we develop a model designed explicitly to project patterns of land-use change at the global scale over the long run based on fundamental supply/demand drivers. We start from a dynamic GE model that predicts economic growth in each region of the world, conditionally on a scenario of productivity changes, and modify it in order to capture the most important determinants of supply and demand for land. Because forestry plays an important role in the competition for land and future path of land-use related GHG emissions, and because a recursive GE model is unable to capture forestry dynamics, we also link the GE model with forward-looking Global Timber Model in order to establish a future price path for forest products.

The most important driver of the demand for land is consumer demand, which we model with econometrically estimated, international cross-section, AIDADS demand system. This demand system is very flexible in representing changes in the consumption bundle as incomes rise, which is particularly important in the fast-growing developing countries. The specification of consumer demand influences the scale and location of each land-using production activity and, hence, associated GHG emission levels. We then introduce recent empirical estimates and forecasts of technological change in the agricultural sectors to account for the influence of technology on the demand for land. Technical change in forestry processing sectors is another key factor in determining demand for land used in forestry sector and outcomes of the competition for land between forestry and agriculture, and this is determined through the soft link with the Global Timber Model.

Input substitution is also important in determining sectoral demand for land, which we incorporate through possibility of intensification in crops, livestock, forestry and food processing sectors. We allow substitution between land and fertilizers in crops, and substitution amongst feedstuffs, and between feedstuffs and land, in livestock production, in order to reflect the empirical evidence that agricultural production tends to intensify in the face of rising land rents. In forestry, we permit substitution between land and other value added inputs to reflect sensitivity of output per unit of land with respect to changes in management intensity, predicted by the Global Timber Model. In food processing, we introduce substitution between farm-based products and marketing inputs. These intensification possibilities reduce pressure of the growing consumer demands on land.

Consumer demand is translated into the derived demands for land through a set of production functions. Equilibrium land rents are determined by equating these demands to land supply, and we focus considerable attention on how the latter should be modeled, through a sequence of successively more sophisticated models of land supply. We begin from very simple model where land endowment is fixed, homogenous and perfectly mobile, and end with one (our baseline model) which realizes that land endowments are heterogeneous, can be expanded by converting unmanaged land into production land, and where mobility of land across uses is restricted by a nested CET function within each land type.

In the baseline model, as population and per capita income grow and consumption patters change, the strongest growth in consumer demand for land-based products is predicted in rapidly growing China and South Asia. Comparing three land-using sectors globally, the strongest growth in consumer demand is predicted for forestry, fueled by increasing demand for furniture, housing and paper products. Increasing consumer demand for crops, livestock and forestry products translates into increased demand for land, which is reflected in land values. When land values are high enough to justify investment in the access to new lands, unmanaged forestland can be converted to production land. Thus, in the baseline, the land endowment is not fixed and expands in regions where unmanaged forests are available. When introducing the decision to access unmanaged forests, we draw, again, on the Global Timber Model, by targeting rates of access of unmanaged forests, predicted by the forestry model. Driven by higher land values, production land expands in all regions except High Income Asia, South Asia and Western Europe where no unmanaged forests are available. The largest expansion is projected in Latin America (9.96%), followed by North America (4.47%), with global production land expanding by 2.4%.

The redistribution of land across sectors under pressure of changes in relative land rents, as well as the expansion of land employed in production through new access, combine to result in land use changes by AEZ. In Australia and New Zealand, North America, Latin America and Western Europe, land used in forestry production declines and agricultural land expands. Within agriculture in these regions, more land is used in crop sector and less in livestock production. In all other regions of the world, including ASEAN, South Asia, and the Rest of the World –three regions which have experienced extensive deforestation in the past – our model predicts expansion of land employed in commercial forestry and contraction of agricultural land in response to increased demand for forest-based products worldwide.

Analysis of the sequence of models of land supply reveals that introduction of the Constant Elasticity of Transformation function to restrict mobility of land across uses within AEZs is critical for determining relative costs of production in each land using sector, and thus for consumption and production patterns in all regions of the model. The forestry input-augmenting technical change is critical in moderating the growth in land demands over the baseline, thereby freeing land for cropping and grazing activities. In some regions, like Western Europe, this changes the land use patterns leading to expansion of agricultural land in expense of forestland. The possibility of accessing new lands further reduces land rents in all land using sectors and regions, and smoothes changes in land use in the regions where access does not take place.

It remains to discuss the sensitivity of the baseline to uncertain model parameters, as well as to evaluate our overall results in light of historical evidence as well as common sense. Since we build up our estimates of the time path of land rents from fundamental drivers of supply and demand and not from time trends, perhaps the best overall method of model validation is to simply look at the rate of growth of land rents in the model. These vary by region, and they only reflect conditions in agriculture and forestry. So, for example, in High Income Asia, where consumer demand is weak and TFP rates of growth in these sectors are very slow or negative, land rents are flat. However, we expect residential, commercial and recreational demands for land to grow strongly, thereby supporting land rents in agriculture and forestry as well (if only due to the expectation of profits from future conversion of land to these uses). The growth rates in China's land rents range from 5 to 6% per year and do not seem out of line with recent experience in that country. If anything, these may be on the low side. However, once again we must distinguish between growth in land rents due to agriculture and forestry uses vs. that due to growth in the demand for land by other sectors which is not treated here.[21]

Perhaps most surprising is the very strong growth in land rents in the agricultural exporting regions Australia/New Zealand and North America (4 – 8% per year). Strong TFP growth – particularly in the crops sectors – supports an expansion of these activities. These growth rates are generally higher than those observed over the long term in North America (4% per year over the last century). But there are some reasons to believe that the economic fundamentals may be in place to support this. In addition to the strong projected TFP growth, and strong economic growth in the natural resource scarce Asia region, the US (and hence North America) will have to begin repaying its debts in the future. And our dynamic GE model takes this into account – showing the region moving into a substantial trade surplus by the end of the projections period. This bodes well for export-oriented sectors such as agriculture and could presage a higher rate of growth in agricultural and forestry land rents.

We can also compare projected changes in land use with historical changes. Unfortunately, we do not presently have data that document changes in land use by AEZ/region. However, the FAO (FAOSTAT, 2004) provides information on historical changes in land employed within agriculture. These data suggest that agricultural land in South America expanded by 14% from 1975 to 2003 (a comparable length of time to our baseline). Our baseline suggests that this trend will continue with agricultural land expanding from 2.2% in AEZ1 to

[21] It is assumed in the model that only crops, ruminant livestock and forestry compete for land, while all other sectors do not use land.

20.6% in AEZ6 (Latin America, Table 10). Within agriculture, historical data show that land expanded much more in cropping activity (22%) than in grazing (12%). Our projections for crop sector suggest continuing trend with cropland expanded from 7.8% in AEZ1 to 24% in AEZ6 over next 28 years. Projections for livestock depart from the trend suggesting a decline in grazing land driven by more intensification in livestock production. The changes projected for North America, however, are very different from the historical trend. FAO reports that from 1975 to 2003 agricultural land use declined, equally in crops and livestock sectors, by 4%, while our projections suggest large decline in grazing land, but expansion of cropland driven by growth in exports. Of course, if historical trends were always accurate predictors of the future, there would be no need for economic models! In light of the recent expansion in crops production in the US, the recent historical trend in that region may indeed be reversed.

Taking into account the fact that this book focuses heavily on methodology and the current state of the art in modeling land use in general equilibrium, we close the chapter by discussing those aspects of this work that we feel most uncomfortable with, and which are in greatest need of attention in subsequent work. First consider the issue of parametric uncertainty. While there are many parameters in the model that play a role in determining the long run pattern of land use, there is one that we single out here for special attention, both because it is important and we know relatively little about it, and because it is fundamentally amenable to econometric investigation. This is the elasticity of substitution between feedstuffs and land in the livestock sector. In our simulations, we assume a value of 0.75 – this is comparable to the elasticities of substitution amongst feedstuffs in livestock production documented in other studies (Keeney and Hertel (2005), Peeters and Surry, 1997). Yet we intend for this parameter to capture a broader set of changes – in particular the scope for intensification of livestock production. Over time, as land rents rise, relative to feed prices, we expect to see more feedlots and a general intensification of livestock production. This is a key feature of the evolving global livestock industry and it is important for the determination of land use. For example, when we reduce this possibility by cutting the elasticity of substitution to 0.2, more land is required to meet the growing consumer demands for ruminant livestock. In this simulation, grazing land expands in all regions, except Australia and New Zealand, at the expense of forest land. Forest land expands only in Economies in Transition and High Income Asia. Thus, our findings about the potential increase in commercial forests in ASEAN, South Asia and the Rest of the World are very sensitive to the assumption about intensification in livestock production. On the other hand, setting the elasticity to substitution to some higher value, would lead to smaller expansion of grazing land in regions where baseline projects expansion of land employed in livestock (like China), and larger decline of grazing land in regions where baseline predicts its contraction (like Australia and New Zealand). Future research efforts should be focused on estimating this parameter using historical data on the livestock industry.

The second major area of concern relates to the use of Constant Elasticity of Transformation (CET) functions to restrict land mobility across uses, within AEZs. This is a popular device in CGE models. It successfully permits these models to be calibrated to estimated land supply elasticities. However, it prevents us from tracking physical hectares as they move from one use to another. This is due to the fact that the CET function, true to its name, *transforms* hectares in one use to hectares in another use. And these uses have different values. Higher valued land is deemed more productive. The fundamental constraint in the CET production possibility frontier for land in a given AEZ is *not* expressed in terms of individual hectares, but rather in terms of *effective* hectares – that is productivity-weighted hectares. Since land is assumed to be paid the value of its marginal product, these are also land rent-weighted hectares. Thus, the fundamental constraint on the CET function is that the land rental share-weighted quantities in each use sum to the total change in AEZ hectares available. This is why, whenever we seek to compare changes in land use, we weight the quantity changes by their value in use. However, this creates a rift between the physical world and the economic model which can pose problems when attempting to relate model results back to the physical environment. Therefore, tractable alternatives to the CET specification would be most desirable.

Finally, we do not believe the present implementation of the land use component of this model is sufficiently detailed. While the 11 region/6 AEZ/crop-livestock-forestry breakdown does yield some interesting heterogeneity across AEZs, in future work, we would like to use a much larger number of AEZs as well as more crops in order to capture the heterogeneity of land use across AEZs. We believe that the cost of doing so would be relatively small, as long as we retain the assumption of a single, national production function detailed in this chapter. So, for example, reducing the Length of Growing Period in each AEZ from 60 to 20 days would seem to make good sense. This would considerably enrich the physical detail of the ecological constraints on production in the model at relatively low cost.

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Table 1. Beginning, and projected end-of-period budget shares, assuming constant prices, based on exogenous income and population growth in the baseline

Region	Year	Growth in per capita income	Crops	Meat Dairy	OthFood Bev	Text Appar	Hous Utils	WR Trade	Mnfcs	Trans Comm	Fin Service	Hous OthServ
ANZ	1997		0.01	0.03	0.09	0.03	0.04	0.24	0.09	0.09	0.03	0.35
	2025	102%	0.01	0.02	0.07	0.03	0.04	0.25	0.08	0.09	0.04	0.38
China	1997		0.20	0.16	0.12	0.09	0.02	0.10	0.14	0.06	0.04	0.08
	2025	512%	0.04	0.13	0.06	0.10	0.03	0.15	0.18	0.09	0.09	0.13
HYAsia	1997		0.03	0.02	0.08	0.04	0.05	0.24	0.10	0.10	0.03	0.31
	2025	96%	0.01	0.02	0.07	0.03	0.05	0.26	0.09	0.10	0.04	0.34
ASEAN	1997		0.09	0.07	0.12	0.06	0.04	0.12	0.17	0.08	0.06	0.21
	2025	126%	0.05	0.06	0.09	0.05	0.04	0.13	0.16	0.08	0.08	0.26
SAsia	1997		0.24	0.12	0.08	0.09	0.02	0.11	0.08	0.12	0.03	0.12
	2025	195%	0.11	0.10	0.04	0.10	0.02	0.14	0.10	0.16	0.05	0.18
NAM	1997		0.01	0.02	0.05	0.03	0.05	0.20	0.10	0.07	0.10	0.37
	2025	78%	0.00	0.02	0.04	0.03	0.05	0.21	0.09	0.07	0.11	0.39
LAM	1997		0.05	0.08	0.13	0.08	0.05	0.16	0.16	0.12	0.03	0.14
	2025	88%	0.03	0.07	0.10	0.08	0.05	0.18	0.15	0.13	0.04	0.17
WEU	1997		0.01	0.05	0.06	0.04	0.05	0.22	0.14	0.10	0.12	0.21
	2025	106%	0.01	0.04	0.05	0.04	0.05	0.23	0.13	0.09	0.14	0.23
EIT	1997		0.05	0.13	0.13	0.04	0.08	0.10	0.13	0.10	0.06	0.18
	2025	157%	0.03	0.10	0.09	0.04	0.09	0.12	0.13	0.11	0.08	0.23
MENA	1997		0.09	0.08	0.12	0.06	0.04	0.15	0.12	0.11	0.03	0.19
	2025	57%	0.06	0.07	0.11	0.05	0.04	0.17	0.12	0.11	0.03	0.23
ROW	1997		0.10	0.09	0.14	0.05	0.03	0.19	0.11	0.10	0.06	0.13
	2025	57%	0.07	0.08	0.12	0.05	0.04	0.21	0.11	0.10	0.07	0.15

Note: These calculations assume constant prices and are based on exogenous income and population growth in the baseline. Projections are obtained using GAMS and based on projected income per capital growth calculated using GTAP baseline (Walmsley *et al*., 2000)

Table 2. Annual Average Total Factor Productivity Growth Rates in Agriculture and Forestry Sectors

	TFP, % per year			
Region	Crops	Rumin.	NonRumin.	Forestry
ANZ	1.42	0.56	0.92	1.11
China	1.63	3.66	6.70	1.75
HYAsia	-0.13	0.56	0.92	-0.05
ASEAN	-0.13	-0.83	3.47	-0.18
SAsia	1.13	1.57	3.35	1.23
NAm	1.42	0.56	0.92	1.15
LAm	1.00	1.64	4.94	1.13
WEU	1.42	0.56	0.92	1.10
EIT	1.95	0.65	2.49	1.51
MENA	0.47	-0.11	-0.04	0.31
ROW	1.14	0.80	0.15	1.08

Note: The TFP growth rates are different from the rates reported in Ludena (2005) by common across agricultural sectors and regions adjustment factor. The factor is chosen such that world crop price index moves closely with the price index of traded goods and services. Also, we depart from Ludena (2005) assuming that crops TFP in HYAsia is equal to one in ASEAN, much slower than in the other industrialized regions.

Table 3. Land earnings by sector and AEZ for 11 regions of the model

Regions	Sectors	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	All Sector
ANZ	Crops	0.23	0.45	0.66	0.66	0.51	0.20	0.46
	Ruminants	0.77	0.55	0.33	0.28	0.08	0.18	0.26
	Forestry	0.00	0.00	0.003	0.06	0.41	0.62	0.28
	AEZ	***0.03***	***0.13***	***0.18***	***0.14***	***0.24***	***0.27***	***1.00***
China	Crops	0.40	0.81	0.88	0.89	0.92	0.82	0.85
	Ruminants	0.60	0.16	0.08	0.07	0.01	0.01	0.04
	Forestry	0.00	0.03	0.04	0.04	0.07	0.17	0.11
	AEZ	***0.01***	***0.06***	***0.12***	***0.11***	***0.19***	***0.51***	***1***
HYAsia	Crops	0	0	0.68	0.81	0.87	0.78	0.83
	Ruminants	0	0	0.05	0.04	0.06	0.06	0.05
	Forestry	0	0	0.27	0.15	0.07	0.16	0.12
	AEZ	***0***	***0***	***0.01***	***0.38***	***0.47***	***0.14***	***1.00***
ASEAN	Crops	0	0	0	0.94	0.91	0.77	0.82
	Ruminants	0	0	0	0.04	0.06	0.05	0.05
	Forestry	0	0	0	0.02	0.04	0.17	0.13
	AEZ	***0***	***0***	***0***	***0.18***	***0.16***	***0.67***	***1.00***
SAsia	Crops	0.67	0.69	0.81	0.76	0.67	0.73	0.76
	Ruminants	0.30	0.30	0.15	0.16	0.10	0.08	0.16
	Forestry	0.03	0.02	0.04	0.09	0.24	0.19	0.08
	AEZ	***0.03***	***0.12***	***0.42***	***0.29***	***0.11***	***0.04***	***1.00***
NAM	Crops	0.36	0.63	0.50	0.75	0.69	0.51	0.63
	Ruminants	0.59	0.30	0.12	0.10	0.08	0.02	0.12
	Forestry	0.05	0.07	0.39	0.15	0.23	0.46	0.25
	AEZ	***0.03***	***0.10***	***0.13***	***0.36***	***0.15***	***0.23***	***1.00***
LAM	Crops	0.61	0.62	0.62	0.73	0.66	0.74	0.70
	Ruminants	0.34	0.26	0.26	0.22	0.22	0.18	0.21
	Forestry	0.05	0.12	0.12	0.05	0.12	0.08	0.09
	AEZ	***0.03***	***0.06***	***0.09***	***0.24***	***0.22***	***0.35***	***1.00***
WEU	Crops	0.12	0.05	0.25	0.47	0.49	0.56	0.43
	Ruminants	0.88	0.32	0.25	0.25	0.25	0.31	0.25
	Forestry	0.00	0.64	0.50	0.28	0.26	0.13	0.32
	AEZ	***0.00***	***0.03***	***0.19***	***0.45***	***0.29***	***0.04***	***1.00***
EIT	Crops	0.18	0.70	0.76	0.73	0.70	0.51	0.73
	Ruminants	0.07	0.16	0.10	0.11	0.18	0.09	0.12
	Forestry	0.74	0.14	0.13	0.16	0.12	0.40	0.15
	AEZ	***0.00***	***0.17***	***0.35***	***0.43***	***0.05***	***0.00***	***1.00***
MENA	Crops	0.48	0.71	0.54	0.73	0.81	0.00	0.62
	Ruminants	0.26	0.18	0.09	0.05	0.03	0.00	0.17
	Forestry	0.25	0.11	0.38	0.21	0.16	0.00	0.21
		0.27	***0.44***	***0.16***	***0.13***	***0.00***	***0.00***	***1.00***
ROW	Crops	0.21	0.35	0.76	0.72	0.75	0.50	0.66
	Ruminants	0.46	0.39	0.16	0.06	0.13	0.14	0.12
	Forestry	0.34	0.26	0.09	0.22	0.12	0.35	0.22
	AEZ	***0.01***	***0.02***	***0.07***	***0.27***	***0.35***	***0.29***	***1.00***

Note: The land earnings shares are based on GTAP Land Use Data Base, Release 1.0, December 2005, with revised land rents in forestry (see footnote 8 in the text).

Table 4. Access Cost Function Parameters

Region	Initial average land rent, 1997 $US/ha	Initial expected rate of return, % per year	Initial price of land, or cost of access, 1997 $US/ha	Total forestland, 1000 ha	Share of accessible forests	Decadal rate of access	Initial elasticity of access costs	Access costs function parameters		
								α	β	γ, E+6
1	2	3	4	5	6	7	8	9	10	11
ANZ	9	13.39	64	31,464	0.066	0.137	0.066	59.342	59.481	4.312
China	60	13.30	450	168,448	0.622	0.013	0.833	227.901	228.438	575.872
HYAsia	530	13.81	3835	37,079	1	0				
ASEAN	140	14.11	990	188,379	0.346	0.010	0.371	693.236	694.870	785.716
SAsia	160	13.47	1190	66,111	1	0				
NAm	73	13.07	558	973,828	0.255	0.042	0.263	430.332	431.346	65.944
LAm	46	13.27	347	916,710	0.342	0.099	0.366	244.034	244.609	19.742
WEU	147	13.27	1107	201,891	1	0				
EIT	23	12.69	182	1,134,790	0.208	0.017	0.213	147.116	147.463	26.522
MENA	31	13.47	232	12,017	0.892	0.002	2.553	71.796	71.966	1313.986
ROW	14	13.36	106	547,646	0.583	0.005	0.745	56.494	56.627	1417.678

Table 5. Projected Growth Rates in Consumption and Production of Crops, Ruminants and Forestry, from 1997 to 2025

Sector	Growth rate	ANZ	China	HYAsia	ASEAN	SAsia	NAM	LAM	WEU	EIT	MENA	ROW
							Consumption					
Crops	cumulative, %	30	184	10	62	126	30	61	29	79	108	99
	annual, %	1	4	0	2	3	1	2	1	2	3	2
Ruminants	cumulative, %	61	883	78	105	200	92	113	55	169	144	120
	annual, %	2	9	2	3	4	2	3	2	4	3	3
Forestry	cumulative, %	120	1244	136	207	472	106	91	90	188	169	177
	annual, %	3	10	3	4	6	3	2	2	4	4	4
							Production					
Crops	cumulative, %	388	88	-28	4	110	253	161	125	94	32	138
	annual, %	6	2	-1	0	3	5	3	3	2	1	3
Ruminants	cumulative, %	82	637	38	46	201	106	153	39	142	50	128
	annual, %	2	7	1	1	4	3	3	1	3	1	3
Forestry	cumulative, %	-13	73	20	72	339	-5	80	32	94	44	139
	annual, %	-0.5	2	1	2	5	0	2	1	2	1	3

Table 6. Projected Global and Market Annual Average Percent Changes in Prices of Output in Land Using Sectors Relative, from 1997 to 2025

Sector	Price index of global exports, % per year	Market indices, % per year										
		ANZ	China	HYAsia	ASEAN	SAsia	NAM	LAM	WEU	EIT	MENA	ROW
Crops	0.00	0.24	1.95	1.10	1.76	2.21	-0.01	-0.03	-0.50	-0.13	0.42	0.15
Ruminants	0.07	0.82	0.47	-0.13	2.55	2.09	-0.20	-0.59	0.18	0.26	0.93	0.22
Forestry	0.80	1.23	2.64	0.68	1.10	1.31	1.21	0.12	-0.006	0.49	1.20	1.20

Note: Price indices reported in the table are relative to price index of global exports.

Table 7. Access Rates

Region	Projected Decadal Access Rates, % per decade			GTAP-Dyn Initial Access Rate, % per year	GTAP-Dyn Projected Annual Average Access Rate, % per year
	Global Timber (first decade of simulation)	GTAP-Dyn 1998-2007	GTAP-Dyn 2016-2025		
1	2	3	4	5	6
ANZ	13.70	14.00	14.80	1.29	1.35
China	1.30	1.40	1.47	0.13	0.14
ASEAN	1.00	1.23	1.42	0.10	0.13
NAm	4.20	4.36	5.40	0.41	0.48
LAm	9.90	10.22	11.03	0.95	1.01
EIT	1.70	1.70	1.55	0.17	0.16
MENA	0.20	0.21	0.33	0.02	0.03
ROW	0.50	0.51	0.58	0.05	0.05

Note: Rate of access is defined as hectares accessed per decade divided by the initial (1997 and 2015 in columns 3 and 4, respectively) forestland accessed and multiplied by 100 to convert into percentages. Regions not shown in the table are assumed to have already exhausted inaccessible forest lands.

Table 8. Value of Land and Access of New Lands

Variable	ANZ	China	HYAsia	ASEAN	SAsia	NAM	LAM	WEU	EIT	MENA	ROW
Value of land											
cumulative growth, %	603.74	361.32	-11.09	138.46	611.81	393.84	273.02	119.03	107.00	113.62	343.88
annual growth, %	7.22	5.61	-0.42	3.15	7.26	5.87	4.81	2.84	2.63	2.75	5.47
Forest hectares accessed every year											
cumulative growth, %	57.37	18.23		50.39		52.03	48.31		-2.00	73.63	23.33
annual growth, %	1.63	0.60		1.47		1.51	1.42		-0.07	1.99	0.75
Total accessible forestland											
cumulative growth, %	45.73	4.07		3.76		14.29	32.68		4.56	0.75	1.53
annual growth, %	1.35	0.14		0.13		0.48	1.01		0.16	0.03	0.05
Land employed in production											
Cumulative grwoth, %											
AEZ1	0	0.01	-	-	0	0.54	0.65	0	0.06	0.003	0
AEZ2	0	0.23	-	-	0	6.86	3.62	0	1.79	0.02	0.01
AEZ3	0.01	1.02	0	-	0	9.81	4.49	0	1.83	0.07	0.04
AEZ4	0.18	1.03	0	0.74	0	2.77	4.89	0	0.36	0.07	0.37
AEZ5	2.07	1.22	0	0.93	0	2.99	8.77	0	0.76	0.32	0.70
AEZ6	2.62	1.11	0	1.43	0	3.94	17.75	0	1.06	-	1.05
Total	0.20	0.63	0	1.26	0	4.47	9.86	0	1.08	0.03	0.33

Note: "-" indicates that specific AEZ is not present in a region. HYAsia, SAsia and WEU have no inaccessible land and, thus, no access activity. Cumulative growth of land employed in production in these regions is zero. In ANZ, there is no forestry in AEZ1 and AEZ2, so production land cannot expand. In AEZ1 of ROW, all available forests are accessed initially.

Table 9. Share of Accessible Forests to Total Land Employed in Production in the Initial Period

AEZ type	ANZ	China	HYAsia	ASEAN	SAsia	NAM	LAM	WEU	EIT	MENA	SSA
AEZ1	0.00	0.0021			0.01	0.04	0.02	0.52	0.01	0.00	0.00
AEZ2	0.00	0.06			0.03	0.48	0.11	0.93	0.39	0.02	0.01
AEZ3	0.0002	0.25	0.80		0.15	0.69	0.14	0.74	0.40	0.10	0.03
AEZ4	0.0040	0.25	0.83	0.20	0.23	0.19	0.15	0.52	0.08	0.09	0.24
AEZ5	0.05	0.30	0.72	0.25	0.38	0.21	0.27	0.43	0.17	0.43	0.46
AEZ6	0.06	0.27	0.79	0.38	0.63	0.28	0.54	0.62	0.23		0.69
Total	0.0044	0.16	0.78	0.34	0.18	0.31	0.30	0.60	0.24	0.03	0.22

Table 10. Cumulative Growth Rates in Demand for Land in Land Using Sectors

Agro-Ecological Zones	ANZ	China	HYAsia	ASEAN	SAsia	NAM	LAM	WEU	EIT	MENA	ROW
Forestry											
AEZ1	0.0	0.0			5.9	-38.7	-32.1	0.0	6.2	6.9	4.6
AEZ2	0.0	-0.1			6.1	-39.4	-29.0	-9.2	29.2	9.6	4.5
AEZ3	-66.8	4.3	32.2		7.4	-32.7	-28.5	-17.5	30.9	6.9	3.5
AEZ4	-66.2	5.0	41.0	15.0	6.8	-42.5	-29.9	-21.8	27.5	9.4	2.9
AEZ5	-58.9	7.9	46.7	14.4	6.0	-41.1	-25.8	-22.1	28.4	10.7	3.9
AEZ6	-46.3	7.1	39.5	12.6	6.7	-35.8	-20.9	-23.1	18.5		3.7
Agriculture All											
AEZ1	0.0	0.0			-0.2	2.0	2.2	0.0	-18.9	-2.4	-2.4
AEZ2	0.0	0.2			-0.1	8.7	7.4	10.9	-3.1	-1.3	-1.6
AEZ3	0.2	0.9	-13.4		-0.3	23.6	8.2	7.3	-3.2	-4.2	-0.3
AEZ4	2.9	0.8	-8.1	0.4	-0.7	6.8	6.5	3.1	-5.5	-2.6	-0.4
AEZ5	30.7	0.7	-4.0	0.4	-1.9	9.7	12.6	2.7	-3.5	-1.7	0.3
AEZ6	55.8	-0.2	-8.5	-1.0	-1.6	20.6	20.6	1.3	-11.7		-0.4
Crops											
AEZ1	53.0	-35.2			-5.8	29.1	7.8	20.3	-27.3	-7.9	5.6
AEZ2	32.6	-13.6			-5.6	19.9	12.1	32.6	-10.0	-4.5	4.5
AEZ3	17.7	-6.9	-16.5		-3.2	30.4	12.9	13.9	-7.7	-6.4	1.6
AEZ4	18.5	-5.6	-10.5	-2.1	-3.9	10.2	10.2	6.8	-10.3	-3.6	0.5
AEZ5	38.9	-0.6	-7.2	-3.0	-4.2	12.7	16.7	6.3	-10.8	-2.3	1.9
AEZ6	96.3	-1.2	-11.9	-4.7	-3.4	21.9	24.0	5.1	-17.0		2.1
Ruminants											
AEZ1	-17.2	21.1			11.9	-26.9	-8.8	-8.9	0.9	7.3	-6.1
AEZ2	-28.3	61.5			12.2	-32.1	-5.2	0.4	24.8	11.3	-7.1
AEZ3	-36.3	74.1	27.1		15.0	-26.1	-4.5	-13.8	28.0	9.1	-9.6
AEZ4	-35.9	76.4	36.3	53.3	14.2	-37.6	-6.8	-19.2	24.4	12.2	-10.6
AEZ5	-24.8	85.8	41.2	51.9	13.8	-36.2	-1.2	-19.5	23.7	13.8	-9.4
AEZ6	6.2	84.6	34.1	49.3	14.8	-31.0	4.9	-20.4	15.1		-9.2

Table 11. Main Features of Six Consecutive Models of Land Supply

Model	Features
Model 1	Perfect mobility of land across uses, no AEZs
Model 2	Perfect mobility of land across uses within AEZ
Model 3	Land mobility across uses according to non-nested CET within AEZ
Model 4	Land mobility across uses according to nested CET within AEZ
Model 5	Land mobility across uses according to nested CET within AEZ, forestry-augmenting technical change in forestry processing
Baseline (Model 6)	Land mobility across uses according to nested CET within AEZ, forestry-augmenting technical change in forestry processing, access of unmanaged land

Table 12a. Cumulative Growth Rates in Consumption of Crops, Ruminants and Forestry, Projected with 6 Consecutive Models

Model	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAm	WEU	EIT	MENA	ROW
Model 1					*relative to baseline*						
Crops	1.02	1.00	0.65	0.89	0.99	0.83	1.00	1.01	0.93	1.11	1.01
Ruminants	0.33	0.57	0.31	0.36	0.66	0.92	0.63	0.48	0.87	0.77	0.45
Forestry	0.99	1.01	0.98	0.98	0.94	0.95	1.07	1.01	1.03	1.15	1.06
Model 2					*relative to baseline*						
Crops	1.01	1.00	0.65	0.89	0.99	0.83	1.00	1.01	0.93	1.11	1.01
Ruminants	0.34	0.57	0.31	0.36	0.66	0.92	0.63	0.48	0.87	0.77	0.45
Forestry	0.99	1.01	0.98	0.98	0.94	0.95	1.07	1.01	1.03	1.15	1.06
Model 3					*relative to baseline*						
Crops	0.83	0.93	0.50	0.85	0.94	0.80	0.86	0.88	0.89	0.94	0.95
Ruminants	0.96	1.01	1.01	0.99	0.98	0.96	0.95	0.98	0.97	0.97	0.97
Forestry	0.96	0.95	0.98	0.94	0.92	0.96	0.97	0.98	0.97	0.96	0.92
Model 4					*relative to baseline*						
Crops	0.83	0.93	0.56	0.87	0.94	0.81	0.87	0.88	0.91	0.94	0.95
Ruminants	0.96	1.01	1.01	1.00	0.99	0.96	0.95	0.99	0.97	0.97	0.98
Forestry	0.96	0.94	0.98	0.94	0.90	0.96	0.97	0.98	0.96	0.96	0.90
Model 5					*relative to baseline*						
Crops	0.96	0.99	0.91	0.98	0.99	0.93	0.92	0.98	0.99	0.99	0.99
Ruminants	0.99	1.00	1.00	1.00	1.00	0.99	0.96	1.00	1.00	1.00	1.00
Forestry	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00
Baseline Model 6, %											
Crops	30	184	10	62	126	30	61	29	79	108	99
Ruminants	61	883	78	105	200	92	113	55	169	144	120
Forestry	120	1244	136	207	472	106	91	90	188	169	177

Note: The cumulative growth rates obtained from simulations with Models 1-5 are expressed as ratios of growth in the model of interest to corresponding growth in Model 6.

Table 12b. Cumulative Growth Rates in Production of Crops, Ruminants and Forestry, Projected with 6 Consecutive Models

Model	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAM	WEU	EIT	MENA	SSA
Model 1						*relative to baseline*					
Crops	1.13	1.02	1.13	-4.42	1.05	0.92	0.94	1.11	0.79	0.99	0.83
Ruminants	0.63	0.97	0.12	0.38	0.76	0.88	0.70	0.56	0.86	0.67	0.62
Forestry	-3.37	3.91	6.59	5.41	1.57	-16.70	2.69	4.93	3.22	2.86	2.32
Model 2						*relative to baseline*					
Crops	1.12	1.02	1.13	-4.38	1.05	0.92	0.94	1.11	0.79	0.99	0.83
Ruminants	0.63	0.97	0.12	0.38	0.76	0.88	0.70	0.56	0.86	0.67	0.62
Forestry	-3.44	3.91	6.59	5.39	1.57	-16.68	2.69	4.94	3.22	2.86	2.32
Model 3						*relative to baseline*					
Crops	1.03	0.95	1.09	-3.59	0.96	0.93	0.89	1.09	0.89	1.06	0.85
Ruminants	1.00	0.97	0.92	0.64	0.96	0.95	0.89	1.00	0.95	0.99	0.92
Forestry	-4.50	3.54	5.63	4.90	1.64	-16.44	3.23	6.04	2.56	2.92	2.27
Model 4						*relative to baseline*					
Crops	0.99	0.97	1.06	-2.73	0.97	0.93	0.88	1.07	0.92	1.07	0.86
Ruminants	0.97	0.97	0.94	0.71	0.96	0.95	0.89	0.99	0.97	1.00	0.93
Forestry	-5.59	3.40	4.80	4.62	1.62	-16.58	3.59	6.50	2.16	2.89	2.25
Model 5						*relative to baseline*					
Crops	1.01	1.01	0.96	0.86	1.00	0.98	0.90	1.05	1.01	1.07	1.01
Ruminants	0.99	0.99	1.00	0.98	1.00	0.98	0.93	1.04	1.00	1.01	1.00
Forestry	1.12	0.98	1.05	1.03	1.01	1.45	0.85	1.07	1.02	1.02	1.01
Baseline Model 6, %											
Crops	388	88	-28	4	110	253	161	125	94	32	138
Ruminants	82	637	38	46	201	106	153	39	142	50	128
Forestry	-13	73	20	72	339	-5	80	32	94	44	139

Note: The cumulative growth rates obtained from simulations with Models 1-5 are expressed as ratios of growth in the model of interest to corresponding growth in Model 6.

Table 13. Cumulative and Annual Growth Rates in Land Rents in Crops, Ruminants and Forestry

Model	Sector	Rate of growth	ANZ	China	HYAsia	ASEAN	SAsia	NAM	LAM	WEU	EIT	MENA	ROW
Model 1	All sectors	cumulative, %	714	463	5	160	538	510	332	168	190	151	419
		annual, %	8	6	0	3	7	7	5	4	4	3	6
Model 2	Sector												
	All sectors	cumulative, %	713	463	10	156	538	509	332	167	193	148	419
		annual, %	8	6	0	3	7	7	5	4	4	3	6
Model 3	Crops	cumulative, %	814	422	3	132	574	532	353	182	176	147	438
		annual, %	8	6	0	3	7	7	6	4	4	3	6
	Ruminants	cumulative, %	643	529	16	176	612	419	329	156	210	157	425
		annual, %	7	7	1	4	7	6	5	3	4	3	6
	Forestry	cumulative, %	618	575	47	244	693	566	371	219	296	200	567
		annual, %	7	7	1	5	8	7	6	4	5	4	7
Model 4	Crops	cumulative, %	814	411	-2	126	566	527	352	179	160	141	426
		annual, %	8	6	0	3	7	7	6	4	3	3	6
	Ruminants	cumulative, %	645	516	10	167	603	415	328	154	191	151	413
		annual, %	7	7	0	4	7	6	5	3	4	3	6
	Forestry	cumulative, %	569	684	75	334	773	604	409	260	361	241	669
		annual, %	7	8	2	5	8	7	6	5	6	4	8
Model 5	Crops	cumulative, %	706	331	-22	93	548	446	315	124	106	93	330
		annual, %	8	5	-1	2	7	6	5	3	3	2	5
	Ruminants	cumulative, %	555	429	-11	124	586	351	294	103	130	103	314
		annual, %	7	6	0	3	7	6	5	3	3	3	5
	Forestry	cumulative, %	265	349	4	119	589	262	207	84	157	110	339
		annual, %	5	6	0	3	7	5	4	2	3	3	5
Model 6	Crops	cumulative, %	670	315	-25	88	542	408	269	115	101	88	319
		annual, %	8	5	-1	2	7	6	5	3	3	2	5
	Ruminants	cumulative, %	527	411	-14	118	580	321	249	96	124	98	303
		annual, %	7	6	-1	3	7	5	5	2	3	2	5
	Forestry	cumulative, %	244	334	0	117	581	233	176	76	149	107	327
		annual, %	5	5	0	3	7	4	4	2	3	3	5

Note: The growth rates across AEZs (models 2-6) are very similar in each sector. Because of this, average across AEZs growth rates are reported.

Table 14a. Cumulative Growth Rates in Demand for Land in Agriculture and Forestry

Region	AEZ	Land using sector	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
China	AEZ1	Agriculture		0.00	0.00	0.00	0.00	0.01
		Forestry	97.52					
	AEZ2	Agriculture				-2.38	0.03	0.24
		Forestry		105.66	85.10	73.66	-1.32	-0.13
	AEZ3	Agriculture				-3.64	-0.08	0.89
		Forestry		115.12	93.44	76.98	2.19	4.30
	AEZ4	Agriculture				-4.46	-0.13	0.84
		Forestry		115.40	93.78	76.58	2.86	5.01
	AEZ5	Agriculture				-7.01	-0.40	0.72
		Forestry		117.84	96.12	76.05	5.45	7.89
	AEZ6	Agriculture				-15.76	-1.06	-0.18
		Forestry		92.33	75.12	59.69	4.92	7.08
Sasia	AEZ1	Agriculture				-1.41	-0.18	-0.17
		Forestry	49.80	59.30	51.69	43.80	6.19	5.91
	AEZ2	Agriculture				-0.84	-0.11	-0.10
		Forestry		60.37	52.93	44.76	6.37	6.09
	AEZ3	Agriculture				-2.19	-0.33	-0.32
		Forestry		57.66	54.36	44.74	7.63	7.38
	AEZ4	Agriculture				-4.45	-0.68	-0.66
		Forestry		53.52	49.81	41.16	7.07	6.83
	AEZ5	Agriculture				-11.24	-1.96	-1.90
		Forestry		41.03	38.54	31.69	6.17	5.98
	AEZ6	Agriculture				-9.41	-1.66	-1.61
		Forestry		44.55	42.64	34.84	6.85	6.65
WEU	AEZ1	Agriculture		0.00	0.00	0.00	0.00	0.00
		Forestry	27.15					
	AEZ2	Agriculture				-26.82	11.06	10.93
		Forestry		23.03	21.47	18.04	-9.29	-9.17
	AEZ3	Agriculture				-14.88	7.45	7.32
		Forestry		24.69	30.19	28.47	-17.88	-17.54
	AEZ4	Agriculture				-6.95	3.18	3.13
		Forestry		28.59	39.07	38.56	-22.20	-21.79
	AEZ5	Agriculture				-6.19	2.80	2.75
		Forestry		29.09	40.03	39.62	-22.54	-22.12
	AEZ6	Agriculture				-3.10	1.30	1.28
		Forestry		32.47	44.83	44.46	-23.53	-23.10

Table 14b. Cumulative Growth Rates in Demand for Land in Crops and Ruminants

Region	AEZ	Land using sector	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
China	AEZ1	Crops	-15.42	-33.15	-31.74	-31.71	-34.69	-35.21
		Ruminants	54.66	21.93	19.21	19.19	20.82	21.11
	AEZ2	Crops		-14.62	-14.21	-14.09	-13.52	-13.63
		Ruminants		55.72	49.81	49.94	59.98	61.46
	AEZ3	Crops		-10.69	-10.35	-9.99	-7.59	-6.86
		Ruminants		62.88	56.56	57.10	70.95	74.12
	AEZ4	Crops		-10.58	-10.19	-9.70	-6.40	-5.63
		Ruminants		63.09	56.84	57.60	73.15	76.41
	AEZ5	Crops		-9.61	-9.10	-8.07	-1.71	-0.63
		Ruminants		64.85	58.73	60.45	81.82	85.75
	AEZ6	Crops		-20.15	-18.85	-16.52	-2.09	-1.25
		Ruminants		45.63	41.73	45.70	81.13	84.60
Sasia	AEZ1	Crops	-4.06	-1.20	-6.82	-6.67	-5.73	-5.79
		Ruminants	-4.80	-2.68	9.76	9.95	11.78	11.94
	AEZ2	Crops		-0.54	-6.06	-5.97	-5.49	-5.56
		Ruminants		-2.03	10.66	10.78	12.06	12.23
	AEZ3	Crops		-2.22	-5.18	-4.88	-3.19	-3.22
		Ruminants		-3.69	11.69	12.07	14.79	15.01
	AEZ4	Crops		-4.79	-7.98	-7.37	-3.84	-4.24
		Ruminants		-6.21	8.40	9.14	14.01	14.24
	AEZ5	Crops		-12.53	-14.90	-13.25	-4.27	-4.24
		Ruminants		-13.85	0.25	2.21	13.51	13.79
	AEZ6	Crops		-10.35	-12.38	-10.93	-3.38	-3.35
		Ruminants		-11.70	3.21	4.94	14.57	14.85
WEU	AEZ1	Crops	1.46	39.16	21.67	21.31	21.29	20.34
		Ruminants	-39.26	-16.38	-9.53	-9.36	-9.36	-8.92
	AEZ2	Crops		-2.90	-15.31	-11.86	33.76	32.60
		Ruminants		-41.65	-37.03	-34.14	-0.04	0.36
	AEZ3	Crops		-1.58	-9.23	-9.46	14.29	13.89
		Ruminants		-40.86	-32.51	-32.35	-14.59	-13.80
	AEZ4	Crops		1.50	-3.04	-3.49	7.02	6.82
		Ruminants		-39.01	-27.91	-27.89	-20.02	-19.16
	AEZ5	Crops		1.89	-2.37	-2.80	6.51	6.32
		Ruminants		-38.77	-27.41	-27.37	-20.41	-19.53
	AEZ6	Crops		4.56	0.98	0.73	5.30	5.13
		Ruminants		-37.17	-24.92	-24.74	-21.31	-20.43

Figure 1. Managed forests as share of initial total forestland

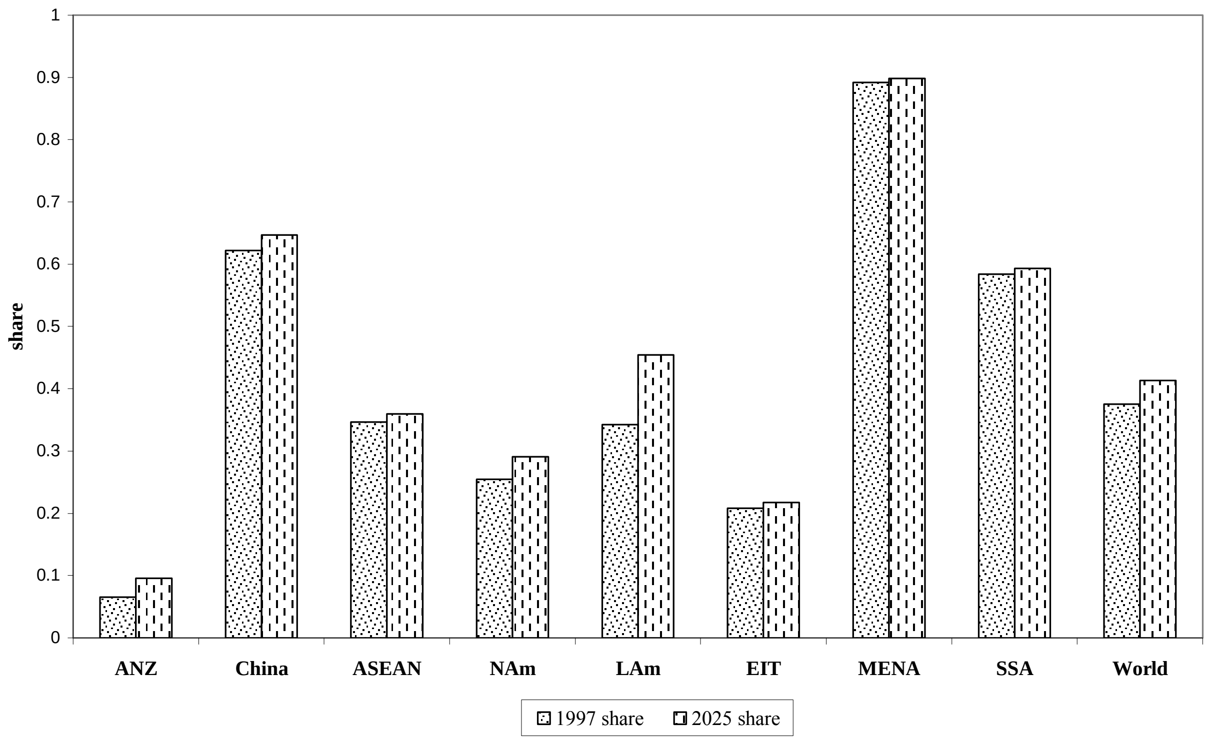


Figure 2a. Revenue Share Weighted Changes in Land Used in Crop Sector in a given AEZ*country

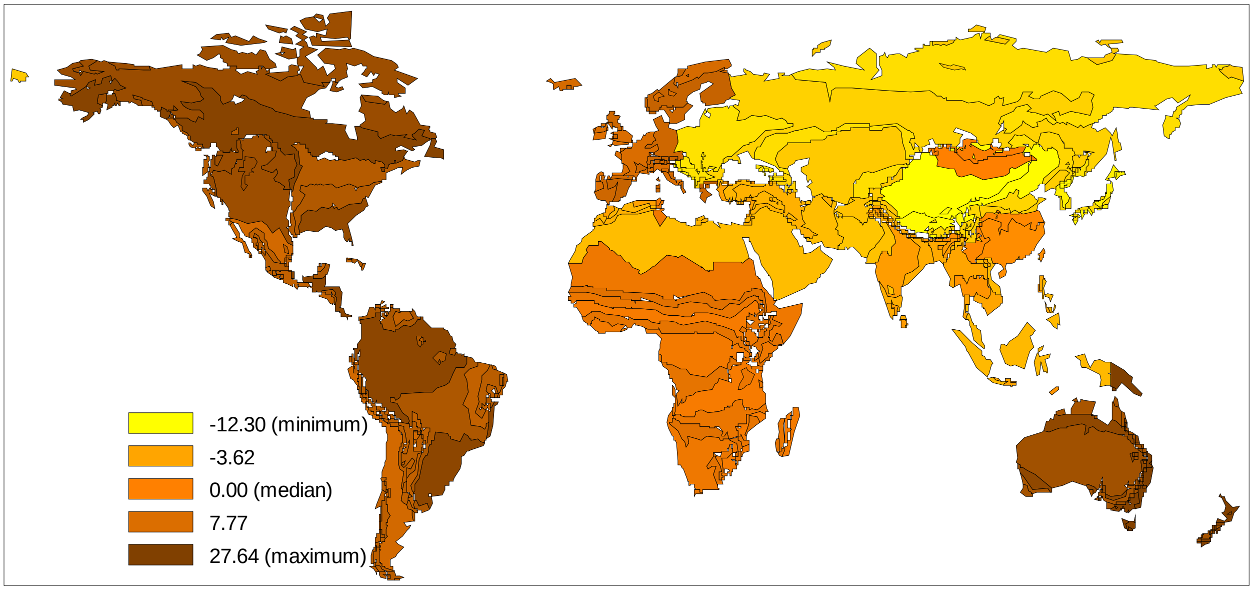


Figure 2b. Revenue Share Weighted Changes in Land Used in Ruminants Sector in a given AEZ*country

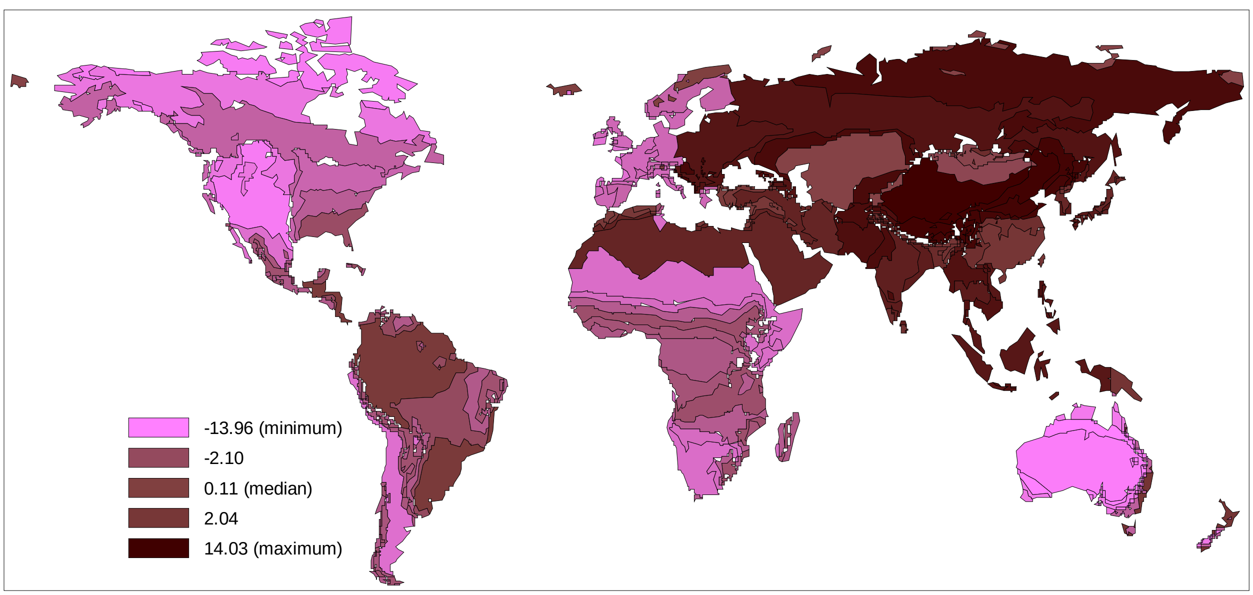
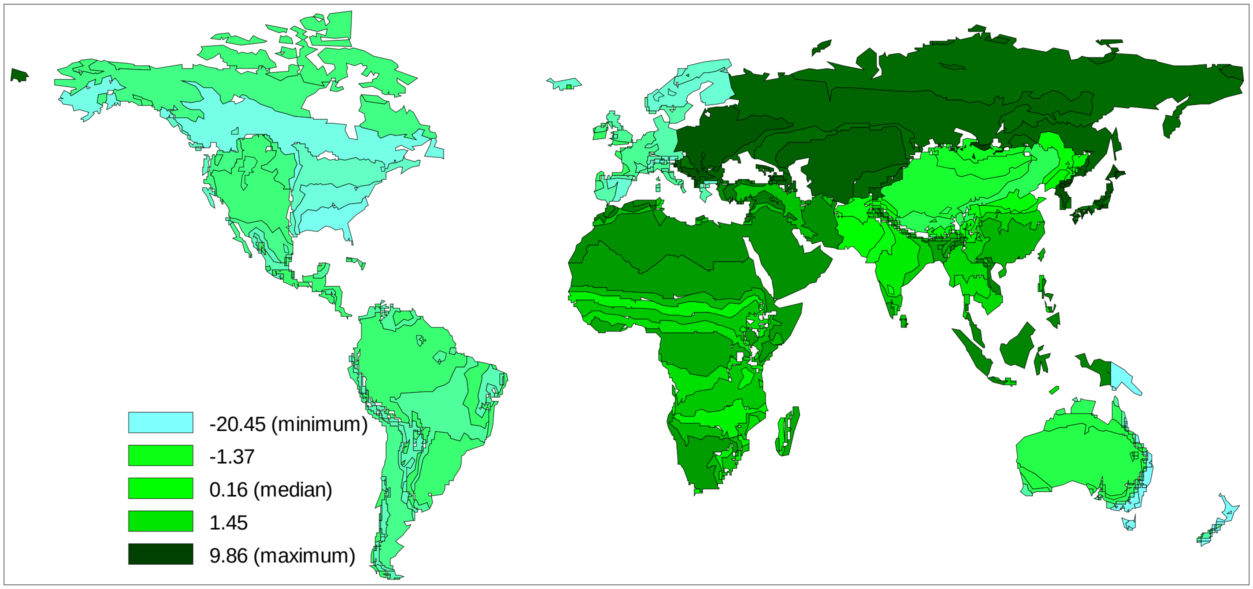


Figure 2c. Revenue Share Weighted Changes in Land Used in Forestry Sector in a given AEZ*country



Appendices

Table A1. Aggregation of GTAP regions

Region	GTAP regions
Australia and New Zealand (ANZ)	Australia, New Zealand
China (CHN)	China
High Income Asia (HYAsia)	Hong Kong, Japan, Korea, Taiwan
Association of Southeast Asian Nations (ASEAN)	Indonesia, Malaysia, Philippines, Singapore, Thailand, Viet Nam
South Asia (SAsia)	Bangladesh, India, Sri Lanka and the rest of South Asia
North America (NAM)	Canada, United State
Latin America (LAM)	Mexico, Central America and Caribbean, Colombia, Peru, Argentina, Brazil, Chile, Uruguay, Venezuela and the rest of Andean Pact.
Western European Union Europe (WEU) except Turkey	Austria, Belgium, Denmark, Finland, France, Germany, United Kingdom, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, Switzerland and the rest of EFTA
Economies in Transition (EIT)	Albania, Bulgaria, Croatia, Czech Republic, Hungary, Malta, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Cyprus, Russian Federation and the rest of former Soviet Union
Middle East and North Africa (MENA)	Turkey, the rest of Middle East, Morocco, the rest of North Africa
The Rest of the World (ROW)	Botswana, the rest of SACU, Malawi, Mozambique, Zambia, Zimbabwe, the rest of Southern Africa, Tanzania, Uganda, the rest of Sub-Saharan Africa, the rest of the World

Table A2. Mapping between 17 produced and 10 consumed goods

Produced good	Consumed good	Produced good	Consumed good
Crops	Crops	TransComm	TransComm
Ruminants	MeatDairy	FinService	FinService
NonRuminants	MeatDairy	HousOthServ	HousUtils
PrRuminants	MeatDairy	Forestry	Mnfcs
PrNRuminants	MeatDairy	Fisherie	MeatDairy
PrFood	OthFoodBev	Utilities	HousUtils
TextAppar	TextAppar	Petroleum	TransComm
Mnfcs	Mnfcs	Construction	HousUtils
WRtrade	WRtrade		