Modeling Land Supply and Demand in the Long Run

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Abstract

The goal of this paper is to improve modeling of the supply and demand of land in the GTAP framework to enhance suitability of the model for climate change policy analysis and, specifically, analysis of green house gas emissions driven by land use and land use change. On the demand side, we begin with a dynamic general equilibrium model that predicts economic growth in each region of the world, based on exogenous projections of population, skilled and unskilled labor force 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). In equilibrium, supply of land by AEZ to every land-using activity adjusts to meet the derived demands for land.

The paper devotes considerable attention to alternative approaches to modeling the supply of AEZ 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 which also accounts for the heterogeneity of land within AEZs. Here, landowners solve a sequential revenue maximization exercise in which land is first allocated between forestry and agriculture, then between grazing and crops, and finally, amongst competing crops. The supply elasticities are consistent with econometric estimates of these parameters. We find that the most realistic representation of land supply results in baseline land rental changes in forestry and grazing that appear excessive. This likely stems from limitations of the current model, such as absence of unmanaged land and the lack of forestry input-augmenting productivity growth in forestry processing sector. Having identified these limitations, we plan to address them in future versions of this paper.

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1. Introduction and motivation

Emissions of non-carbon dioxide (non-CO2) greenhouse gases (GHG), such as methane (CH4) and nitrous oxide (N2O), contribute significantly to global greenhouse GHG emissions and radiative forcing because these gases are more effective at trapping heat than CO2 (Scheehle and Kruger, forthcoming).[2] Global anthropogenic emissions of CH4, N2O and other non-CO2 GHG account for approximately 30 percent of the enhanced greenhouse effect since pre-industrial times (U.S. Environmental Protection Agency (US EPA), forthcoming). Because of its relatively short 12 years chemical lifetime in the atmosphere, CH4 is a candidate for mitigating global warming over the near term (USEPA, forthcoming).[3]

Changes in land use and land cover represent an important driver of net GHG emissions. Currently, agricultural activities generate the largest share, 58 percent, of the world's anthropogenic non-CO2 emissions: (84% of N2O and 47% of CH4) and make up roughly 14% of all anthropogenic greenhouse gas emissions (US EPA, forthcoming). In 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 greenhouse gas emissions as a result of mitigation efforts. A large part of the problem has been the difficulty in appropriately modeling the demand and supply for land in the very long run. This is the focus of our paper.

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[2] The radiative forcing is defined as the extent to which injecting a unit of a greenhouse gas into the atmosphere raises global average temperature (USEPA).
[3] For comparison, CO2 lifetime is 100 years.

In this work a multi-sector, multi-region, recursive dynamic applied general equilibrium model called GTAP-Dyn (Ianchovichina and McDougall, 2001) is used to explore the impact of changing patterns of consumer demand on the developments of regional demand for land in agriculture and forestry 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. After all, it is the demand for food and forestry products that drive much of the long run demand for land, and, 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 green house gases from agriculture and forestry.

For purposes of this paper, we have modified the standard demand and production structures of GTAP –Dyn. Specifically, 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. We also modify the production structure and allocation of land in the model to better capture the role of heterogeneous land endowments. Indeed, the modeling of land supplies is a focal point of this paper, and this issue is addressed via a sequence of successively more sophisticated models of land supply. We begin with the naïve assumption that land is like labor and capital inputs – homogeneous and perfectly mobile in the medium run. This version of the model overstates 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 in CGE models. In our second version of the model we bring climatic and agronomic information to bear on the problem – introducing Agro-Ecological Zones (AEZs). By separating land into different types, with different observed uses, we restrict the degree of land mobility across diverse uses of land. Indeed, if two uses (e.g., citrus groves and wheat) do not presently appear in the same AEZ, then they will not compete in the land market.

Of course, there are many other factors, beyond agronomic factors, that limit land mobility. These include: costs of conversion, managerial inertia, un-measured benefits from crop rotation, etc. For this reason, land mobility in the AEZ-constrained model is still too high. In our third model the land supply within an AEZ is constrained via the Constant Elasticity of Transformation (CET) frontier. This is the approach taken in the standard GTAP model, and it is effective at restricting land mobility. A further advantage of this approach is that it permits us to take into account the degree of heterogeneity *within AEZs*, permitting this to be reflected in the elasticity of transformation across uses. Thus, in calibrating the CET parameters for each region/AEZ for our fourth model, we adjust the elasticity of transformation to account for a measure of AEZ heterogeneity such that land mobility is lower, the more heterogeneous the endowment.

Our final model variant introduces a nested structure to better reflect the transformation possibilities across uses. Here, land owners first decide on whether the land will be in forestry or agriculture, and then they evaluate relative returns in crops and grazing. Though not modeled in this work, the nested structure can be expanded to allow the allocation of land to various crops.[4] At each stage in the decision making process, the CET parameter increases, reflecting the greater sensitivity to relative returns amongst crops, for example – where allocations may be freely varied from year to year, as opposed to between forestry and agriculture – where the allocation decision can be irreversible in the near term.

The paper is organized in five sections. The choice and specification of the demand system suitable for the long run projections of the global economy are discussed in section two. We discuss various issues in modeling land supply and use in section three. In section four we briefly

[4] Currently we have only one crop commodity in the model.

introduce the GTAP-Dyn model and present key baseline assumptions. The projected derived demand for land from the five consequent models is analyzed in section five. Section six concludes.

2. Consumer demand

Choice of framework for modeling consumer demands

There is a long tradition of forecasting future demands for commodities based on per capita income and population. At constant per capita income, and unchanging prices, uniform population growth worldwide simply translates into uniform growth in the demand for all goods and services. However, population growth tends to be higher in countries with lower per capita income (prior to the so-called demographic transition), and, since poorer households tend to spend a higher portion of their income on food, population growth tends to boost the relative importance of food consumption worldwide. On the other hand, growth in per capita income has the opposite effect; as households become richer, their expenditure share on food tends to fall. Also the composition of food expenditures shifts from staple products, aimed a fulfilling caloric requirements, to animal protein, edible oils, fruits and vegetables as consumer incomes rise above the poverty line.

These points are illustrated in Figure 1, which shows the calculated expenditure shares at different per capita expenditure levels on an exhaustive 10-way split of commodities and services for the Association of Southeast Asian Nations (ASEAN) region as a whole. The horizontal axis shows per capita consumption evaluated at market exchange rate in 1997 $US. These should be multiplied by about a factor of four to get to PPP international dollars. The first vertical line in this figure shows the $2 per day (PPP basis) poverty line. At this per capita income level, the largest expenditure item is staple grains, followed by processed food, beverages and tobacco and housing.

Expenditure on meat, dairy and fish is much lower. The total food expenditure share at this level of income is estimated to be about 45%. Clearly, population growth in this income class translates into a strong increase in food demand, relative to other goods and services.

The second vertical line in the figure shows the expenditure shares at the 1997 average income level in the ASEAN region. At this point, staple grains expenditures have fallen below many other items in the budget, and the total expenditure share on food is now well under one-third of the total household budget, and this is continuing to fall at the margin. Now housing, health and education services, and manufactured items dominate the budget. So, overall income growth in ASEAN (i.e. rising per capita income) fuels a *relative* decline in the demand for food.

The predicted budget shares in Figure 1 are based on a *demand system* econometrically estimated on the global, GTAP 5.0 data base (Dimaranan and McDougall, 2002). The system-approach is far preferable to the estimation of individual demand equations – particularly in an economy-wide projections approach such as that used in this paper. In the single equation approach, there is no guarantee that households will remain on their budget constraint – expenditures for all goods could increase without a corresponding rise in income. This is not possible in the system-wide approach. In addition, the system approach also takes account of the full range of substitution possibilities amongst goods and services.

In the choice of demand system for our analysis we follow Yu *et al*. (2002) where the properties of demand system desirable for long run projections are identified. First, the demand system should be international 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 rising. 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 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.

This paper builds on the econometrically estimated, an implicit directly additive demand system (AIDADS) developed by Rimmer and Powell (1996) and estimated on GTAP 5.0 data base in Reimer and Hertel (2004). 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 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.

In the AIDADS system, the predicted budget share is a sum of subsistence and discretionary budget shares:

$$s_{kn} = \frac{p_{kn}\gamma_k}{I_n} + \left(\frac{\alpha_k + \beta_k \exp(U_n)}{1+\exp(U_n)}\right)\left(\frac{I_n - p_n{'}\gamma}{I_n}\right)$$

where s_{kn} is the average budget share spend on good k in country n, p_{kn} is the price of good k in country n, I_n is total expenditures in country n, U_n is utility in country n, γ_k is estimated parameter reflecting the subsistence level of good *k*, and $p\gamma$ is minimally sustainable per-capital income in any country. Parameters α_k and β_k are estimated lower and upper bounds on marginal budget shares at very low (i.e., close to subsistence), and very high income levels. Figure 2 illustrates the behavior of the marginal budget shares in an estimated version of this model.

Estimation and Calibration of the Demand System

Our starting point for the analysis is the AIDADS parameters estimated in Reimer and Hertel (2004) using the GTAP 5.0 data base, representing world economy in 1997. These parameters, reported in Table 1, represent global preferences and are country invariant. (They also correspond to the parameters underlying Figure 2.) To implement AIDADS in the general equilibrium model, the estimated parameters must be calibrated for each post-aggregation region to ensure equality of fitted AIDADS budget shares and ones observed in the initial data base. Our calibration procedure is implemented in GAMS and consists of four steps which we describe below.

The choice of aggregation scheme is driven by our focus on the derived demand for land due to income growth. We aggregate 78 regions of GTAP 5.4 data base to 11 regions according to the mapping reported in Table 2a.[5] This aggregation, while parsimonious, represents broad spectrum of income levels and development across regions. The 57 sectors of the GTAP 5.4 data base are aggregated to 10 consumed goods using the proposed mapping in Reimer and Hertel (2004). Since the GTAP data base reports consumption in value terms only, we must find a way to separate these value flows into prices and quantities. Here, we follow Reimer and Hertel (2004)

[5] Both data bases, 5.0 and 5.4, represent world economy in 1997. In data base 5.4 some of the GTAP v.5.0 data base composite regions are disaggregated. Since both data bases represent the same year, AIDADS estimates obtained on v.5.0 can be applied to highly aggregated version (78 regions to 11 regions) of v.5.4 data base.

and define prices as the ratio of imports valued at domestic prices to imports valued at c.i.f. prices. Consumed quantities are then obtained by dividing GTAP expenditure by price.

Calibration proceeds as follows. The first step involves finding region specific utilities U^n that corresponds to the global preferences parameters reported in Table 1. For each region, AIDADS can be represented as (see Rimmer and Powell, 1996):

$$\sum_k U_k(q_k, U) = 1, \tag{1}$$

where U is the utility level, and U_k is a twice-differentiable monotonic and strictly quasi-concave in q_k and has the following form:

$$U_k = \frac{(\alpha_k + \beta_k \exp(U))}{1+\exp(U)} \ln\left(\frac{\alpha_k + \beta_k \exp(U)}{A\exp(U)} \left(\frac{I - p'\gamma}{p_k}\right) \right) \tag{2}$$

For each region, we minimize the sum of squared errors Q_n to find region specific utilities U_n:

$$Q_n = \left(\sum_k \frac{(\alpha_n + \beta_n \exp(U_n))}{1+\exp(U_n)} \ln\left(\frac{\alpha_n + \beta_n \exp(U_n)}{1+\exp(U_n)} \left(\frac{I - p_n\gamma}{p_{kn}}\right) \right) - U_n - \kappa\right)^2 \tag{3}$$

where parameter $\kappa = 1+\ln A$ is also estimated in Reimer and Hertel (2004). These estimates of region specific utility $\hat{U}_n$ are used to calculate the fitted AIDADS budget shares $\hat{s}_{kn}$.

Step two of the calibration procedures follows Cranfield *et al*. (2005). Specifically, we assume that estimated subsistence parameters γ_k are precisely measured and constant across regions. The differences between observed budget shares s_{kn} and fitted budget shares $\hat{s}_{kn}$ must then be due to errors in measurement of the discretionary shares δ_{kn}. Accordingly, we calculate fitted discretionary shares $\hat{\delta}_{kn}$:

$$\hat{\delta}_{kn} = \left(\frac{\hat{\alpha}_k + \hat{\beta}_k \exp(\hat{U}_n)}{1+\exp(\hat{U}_n)} \right) \left(\frac{I_n - p_n{}' \hat{\gamma}}{I_n} \right) \tag{4}$$

and then rescale estimates of $\hat{\alpha}_k$ and $\hat{\beta}_k$ such that fitted and actual discretionary budget shares are equal:

$$\overline{\alpha}_{kn} = \hat{\alpha}_k \, \delta_{kn} \big/ \hat{\delta}_{kn} \tag{5}$$

$$\overline{\beta}_{kn} = \hat{\beta}_k \, \delta_{kn} \big/ \hat{\delta}_{kn} \, .$$

We normalize the values of $\overline{\alpha}_{kn}$ and $\overline{\beta}_{kn}$ to ensure they sum to unity as it is required by AIDADS: $\tilde{\alpha}_{kn} = \overline{\alpha}_{kn} \big/ \sum_k \overline{\alpha}_{kn}$ and $\tilde{\beta}_{kn} = \overline{\beta}_{kn} \big/ \sum_k \overline{\beta}_{kn}$ (Cranfield *et al.*, 2005). The third step in the calibration exercise involves using γ_k fixed at levels in Table 1 and calibrated region specific $\tilde{\alpha}_{kn}$, $\tilde{\beta}_{kn}$, thereupon solving the demand system for new values of utility $\overline{U}_n$ and the parameter $\overline{\kappa}_n$, with demands fixed at observed levels. To achieve this, we minimize global sum of squared errors subject to observed demands q_{kn} and AIDADS constraints:

$$\min \sum_n \sum_k e_{kn}{}^2 \tag{6}$$

$$\text{s.t.} \quad q_{kn} = \hat{\gamma}_k + \frac{\tilde{\alpha}_{kn} + \tilde{\beta}_{kn} \exp(\overline{U}_n)}{1 + \exp(\overline{U}_n)} \left(\frac{I_n - \hat{\gamma}' p}{p_{kn}} \right) + e_{kn} \quad \text{for n=1..11, k=1..10}$$

$$\sum_k \frac{\tilde{\alpha}_{kn} + \tilde{\beta}_{kn} \exp(\overline{U}_n)}{1 + \exp(\overline{U}_n)} \ln(q_{kn} - \gamma_k) - \overline{U}_n = \overline{\kappa}_n \quad \text{for n=1..11.}$$

The errors e_{kn} obtained at this step are very small with the largest of the order 0.0001 percent of observed demands in China and South Asia (SAsia). However, to implement the demand system in general equilibrium model very high precision is desirable. To eliminate the errors e_{kn}, we move to a fourth step. Here, we recalibrate region-specific utilities and allow for small cross-country differences in the subsistence levels. We find new utilities and subsistence levels by solving the following system of equations (7):

$$q_{kn} = \tilde{\gamma}_{kn} + \frac{\tilde{\alpha}_{kn} + \tilde{\beta}_{kn} \exp(\tilde{U}_n)}{1 + \exp(\tilde{U}_n)} \left(\frac{I_n - \tilde{\gamma}'_n p}{p_{kn}} \right) \qquad \text{for n = 1..11, k=1..10} \tag{7}$$

$$\sum_k \frac{\tilde{\alpha}_{kn} + \tilde{\beta}_{kn} \exp(\tilde{U}_n)}{1 + \exp(\tilde{U}_n)} \ln(q_{kn} - \tilde{\gamma}_{kn}) - \tilde{U}_n = \tilde{\kappa}_n \qquad \text{for n=1..11,}$$

with the imposed restriction that subsistence is less than observed consumption. For each region in this system there are 11 equations with 11 unknowns: $\tilde{\gamma}_{kn}$ for each of ten consumed goods and one additional parameter, $\tilde{\kappa}_n$. Final calibrated AIDADS parameters for 11 regions are given in Table 3. As can be seen from this table, subsistence levels are different in the seventh decimal point only for two regions: China and South Asia, where the errors from the third step of our calibration procedure were measurable, but still tiny.

Implications for Consumer Demands in 2025

With a complete demand system in hand, we are in a position to project the pattern of per capita, national consumer demands in our 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 the cumulative 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 GTAP baseline (Walmsley *et al*., 2000). Figure 3 shows the results for China – the region with the highest expected per capita growth rate over this period. In the initial year (1997) total spending on food, beverages and tobacco is about 48% of the per capita household's expenditures. This falls over the projections period – most sharply for staple grains, followed by processed food, and finally also by meat, dairy and fish (from about 2005 onward). By the end of the projections period, the per capita expenditure share on food in China is under one-quarter. Of course this doesn't mean that total spending on food products falls, since income and population growth are growing strongly over this period. However, it does mean that this growth is much more modest than for products with a high income elasticity of demand (e.g., housing services).

Table 4 reports the 1997 and projected in 2025 expenditure shares for the 10 aggregate commodities at constant prices in each of the 11 regions. Note that these shares vary relatively little for ANZ, HYAsia, NAM and 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 correspondingly decreases in budget shares for other commodities. In contrast, budget shares in low income and rapidly growing regions, represented by China and 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 only moderate (ASEAN, EIT) or low (LAM, MENA, 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.

3. Issues in modeling land supply and use

Production functions

The supply side of this model begins with the standard GTAP 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. These 17 produced goods are then combined into 10 consumed goods according to mapping in Table 2b using proportions fixed at levels in the initial data base.

In keeping with our interest in the derived demand for land, we modify the production structure in the livestock sectors to permit producers to vary the intensive margin of ruminant livestock production. In particular, we permit substitution amongst feedstuffs, and between feedstuffs and land.[6] Thus, 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 will make greater use of feedlots and intensify their livestock production practices.

Model 1: Perfect mobility of land

This paper focuses on the structure of the land market, beginning with a very simple representation, and successively introducing additional complexity – evaluating at each stage the marginal impact of the added features. We begin with the naïve assumption that land is like labor and capital inputs – homogeneous and perfectly mobile across crops, livestock and forestry in the medium run. In this case, there is a single land rental rate that is equated across all uses.[7] Therefore, when the derived demand for land in one sector (e.g., forestry) increases, a substantial

[6] We set the elasticity of substitution between feed and land to 0.2 and elasticity of substitution between feedstuffs to 0.5. We set the later to higher value to reflect the fact that substitution between feedstuffs is much easier than between feed and land.

[7] In standard GTAP model, land is assumed to be imperfectly mobile across various agricultural activities, such that uniform rental rates across the economy are not enforced. Also, in the standard model, land is assumed not to move from agriculture and forestry.

shift in land is required in order to re-equilibrate the system. This version of the model should overstate the potential for heterogeneous land to move across uses.

Model 2: Perfect mobility of land within AEZs

A natural way to overcome this heterogeneity problem is to disaggregate the land endowment – much as is done with labor in CGE models. We do this by bringing climatic and agronomic information to bear on the problem – introducing Agro-Ecological Zones (AEZs) (Lee *et al*., 2005). 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 FAO and IIASA, the length of growing period depends on temperature, precipitation, soil characteristics and topography. This approach evaluates the suitability of each AEZ for production of alternative crops and livestock 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.

Lee *et al*. (2005) first allocate global land area by AEZ and country. They then associate different production activity levels (physical outputs and yields) with each national/AEZ pair. When combined with price data from the FAO, these different production activities are translated into value terms, and these value shares are ultimately used to allocate land rents from each land-using activity across AEZs within the GTAP data base. If we aggregate the land rents on each AEZ, in each region of our aggregation, then we can compute the relative economic importance (land rental share) of each activity within a given AEZ in the model.

Table 5 summarizes land rental shares for cropping, livestock and forestry activities, within six AEZs, in the 11 model regions (we aggregate over the climate dimension for purposes of this paper). AEZ1 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 only in EIT. Cropping activity tends to be economically dominant in AEZ2 for China, South Asia, LAM, EIT and MENA, forestry is relatively important in WEU, whereas grazing activities dominate in ANZ, WEU and ROW. On the other hand, cropping activity dominates in all regions in the more productive AEZs 3 – 6. However, forestry becomes economically important in AEZ6 in ANZ, NAM, EIT and ROW. Forestry importance in all regions is gradually rising from AEZ3 to AEZ6.

It is also important to look at the pattern of land rents across AEZs, within a given country and compare this to the row totals. Crops dominates ruminants and forestry in all regions, however ruminants sector is economically important in ANZ, LAM and MENA. Row totals in Table 5 give 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. And similarly, a rise in the price of beef will have very little impact on the land market in AEZ6 of China, given the small land rental share of that activity. For the same reason, however, rising beef prices will have large positive impact on growth of grazing land in AEZ6. Overall, forestry activity in China plays a small role in the land market, although the greatest relative impact of a rise in forestry products prices will be felt in AEZ6 of that country.

By contrast, activities which already dominate land rents in a given AEZ, such as crops in China's AEZs 5 and 6, 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 AEZs 1 and 2, there is very little scope for expansion at the extensive margin of the higher AEZs. Of course, the activity/AEZ variation would be much greater if we disaggregated crops into paddy rice, cotton, wheat, etc., making the AEZ disaggregation even more important. We plan to do so in the future.

We compare patterns of land use in different countries by calculating correlations between land rental shares, pooling together all AEZs and sectors. In this calculation we drop forestry share since it completes crops and ruminants. Table 6 shows that land rental shares across AEZs and sectors are similar in all regions except for ANZ, ASEAN and MENA. These regions are different because of relatively large share of ruminant sector in ANZ in all AEZs, absence of AEZ6 in MENA, and absence of AEZs 1-3 in ASEAN.

Model 3: Imperfect mobility of land within AEZs

Of course, given 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 supply 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.[8] In this specification, the

[8] Difference between this variant of the model and the standard GTAP model is that land is assumed to move from agriculture to forestry.

absolute value of the CET parameter represents the upper bound (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 rental share). In this variant of the supply structure we set elasticity of transformation to -1.

Model 4: Imperfect mobility of land adjusted for land heterogeneity

To account for a measure of AEZ heterogeneity, we adjust the elasticity of transformation such that land mobility is lower, the more heterogeneous the endowment. We constructed heterogeneity index using five variables: growing degree day, moisture index, soil carbon density, soil pH and topography. For each country/AEZ the normalized standard deviation of each variable is calculated, and the heterogeneity index is defined as average of these five standard deviations for each country/AEZ. To adjust the elasticities of transformation, we assume that 1) relationship between the elasticity of transformation and AEZ heterogeneity is linear; 2) the world average heterogeneity index corresponds to elasticity of transformation -1; 3) and the world largest observed heterogeneity index correspond to zero elasticity of transformation, situation when the heterogeneity is so high that land is immobile across uses.

The country/AEZ heterogeneity adjusted elasticity of transformation amongst crops is reported in Table 7. Note that it varies considerably across AEZs and countries around its base value -1 in the range from -0.592 to -1.631. The lowest absolute values of this parameter arise in North America and China – two regions, with very large land areas and very heterogeneous agroecological endowments. The most homogeneous regions – with the highest land supply response within a given AEZ – are Western Europe, High Income Asia and ASEAN – indeed, this index reaches its maximum absolute value of -1.631, as the area of the AEZ goes to zero, which is the case for AEZs 1, 2 and 3 in ASEAN, and AEZs 1 and 2 in High Income Asia.

Note, simply by definition, large AEZs are more heterogeneous than smaller ones. In the same time, large AEZ have large revenue share in total land rents. This means that introduction of the heterogeneity coefficient would make a difference mostly in the regions where majority of land (AEZs) is characterized by high or low heterogeneity. For example, in China and NAM, where land is very heterogeneous in all AEZs, introduction of heterogeneity adjusted elasticity of transformation will reduce elasticity of land supply. In ASEAN, where only AEZs 4-6 are present, introduction of the heterogeneity coefficient will increase mobility of land across uses. On the other hand, in South Asia where AEZs have different degree of heterogeneity, it is hard to predict the effect of the introduction of the heterogeneity coefficient.

Model 5: Nested supply of land within AEZs

Our next model variant introduces a nested, multi-stage, optimization structure to better reflect the transformation possibilities across uses. This follows the approach first proposed in Darwin *et al*. (1995) and then further developed in Ahammad and Mi (2005). In Model 5, 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 composite return to land in crop production, relative to the return in ruminant livestock production, the land owner decides on the allocation of land between these two broad types of agricultural activities. These allocations are governed by CET functions.

We set the base value (before adjustment for AEZ heterogeneity) of the elasticity of transformation parameters in the nested structure between -1 and -0.25. The elasticity of transformation of land across crops, which base value is -1, is our upper bound on the absolute magnitude of the elasticity of transformation of land across uses. We set the elasticity of transformation of land between agriculture and forestry to -0.25, which is our lower bound on the absolute magnitude of the elasticity of transformation. This lower bound is consistent with econometric evidence in Choi *et al*. (2006). Using data for the Midwestern US counties, Choi *et al*. (2006) have estimated the responsiveness of land supply to commercial forestry as a function of land rents. They found that supply elasticity of land to forestry with respect to rental rates in forestry is in the range from 0.033 to 0.549, depending on region considered and model specification. In their regional model, which is based on all countries of the study and also includes weather, soil and topography variables, the supply elasticity of forestland is 0.198.

The estimates in Table 7 are used to represent the transformation possibilities amongst crops, for example – where allocations may be freely varied from year to year. These are cut in half at the next level of the supply "tree", reflecting the greater costs associated with converting crop land to grazing or vice versa. Finally, the CET parameter governing the allocation of land between forestry and agriculture is one-quarter of the estimates reported in Table 7. Here, the allocation decision can be irreversible in the near term and small swings in relative returns are less likely to have an impact of the allocation of land. Currently, we have last two levels of the decision making process in the model, but plan to introduce the transformation possibilities amongst crops in the future. Also, what the model does not do at present is capture the potential supply of unmanaged land. This will limit land supply response to increasing demand for forestry products in our simulations.

Competition in Product vs. Factor Markets

It remains to describe 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. Presuming like products produced in different AEZ 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. From the point of view of land markets – the focus of this paper – this is the key result – the returns to land on different AEZs employed in the production of the same product must move together. Now this result can be obtained 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. An alternative is to retain a single, national 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 (we use 20), we are assured that the return to land across AEZs, but within a given use, will move closely together. This is the approach taken here.

4. Projections Framework and Baseline

The projections in this model are undertaken using 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 standard GTAP model (Hertel, 1997) to include international capital mobility, endogenous capital accumulation, and an adaptive expectations theory of investment.

The main objective of GTAP-Dyn is to provide a time path of the global economy and a better treatment of foreign ownership of capital, all within the basic GTAP framework. GTAP-Dyn model is a real asset model. That is, there is no financial market and no distinction between debt and equity investment. In GTAP-Dyn, capital can move between regions, and hence asset location and asset ownership are separately identified. Regions therefore accumulate not only physical capital stocks, but also wealth assets which represent indirect claims to physical capital. The wealth assets in GTAP-Dyn are not intended to provide an adequate representation of financial assets in the real world, but rather they serve to simplify the representation of international capital mobility without creating leakages in the foreign accounts (Ianchovichina and McDougall, 2001).

The distinguishing feature of the model is its disequilibrium mechanism determining the regional supply of investments. This mechanism consists of adjustment of the expected rate of return toward actual rate of return and adjustment of the expected rate of return toward the global rate of return to capital. In the model, investors respond to expected rates of return when making decisions about how much to invest. The model allows for errors in investors' expectations to take account of real world data where observed rates of return often appear to fly in the fact of international investment flows. For example, when investment is high despite low observed rates of return, errors in expectations are incorporated allowing expected rates of return to exceed actual rates. Over time investors adjust their expectations to eliminate errors in expectations and expected rates of return move towards actual rates.

Investment in each region in each period is determined by the investors' expectations about the rates of return and world wide constraint on investment.[9] The global trust, a financial intermediary for all foreign investment, distributes funds among regions according to investors' expectations and the constraint. The funds are distributed between regions such that capital moves gradually from regions with lower expected rates of return to regions with higher expected rates of returns, driving the expected rates of return down. At the same time, the expected rates of return

[9] This constraint is that global savings equal global investments.

converge to the actual rates of return over time. These two mechanisms lead to the equalization of rates of return, expected to actual and across regions, in the long run. In this work we parameterize the lagged adjustment mechanisms, as well as the mechanism determining the composition of capital and allocation of wealth according to econometric estimation documented in Golub (2006).

The GTAP-Dyn model inherits from the standard GTAP its specification of the regional household demand system, and, in particular, the treatment of saving. As in the standard GTAP model, there is a fixed average propensity to save; in other words, saving is a fixed proportion of income in each region. There are two unwelcome implications of this. First, net foreign positions grow without bound in GTAP-Dyn simulations. In the real world, saving and investment are highly correlated across countries (Feldstein and Horioka, 1980), and net international capital flows and, as a result, net foreign positions are much smaller. The second problem is 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 falling without bound. This doesn’t make economic sense, and it also prevents us from running meaningful simulations with the Dynamic GTAP model over longer time horizons.

In this work we adopt a new approach to the evolution of savings over time documented in Golub and McDougall (2006). While this approach is not derived from explicit, intertemporal optimizing behavior, it is a practical solution to this difficult problem and it is well-supported by empirical evidence that wealth to income ratios are very stable for the majority of countries. The theoretical structure of GTAP-Dyn is modified such that wealth to income ratio in each region are stabilized at region specific level and savings rate in each region is endogenous and 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.

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) for 1997 – 2025 are taken from Walmsley *et al*. (2000). We use historical real GDP and population growth rates for 1997-2004 period constructed using World Development Indicators data base. The real GDP path for 2005-2025 is driven by several assumptions. First, we express productivity growth in non-land using sectors in terms of labor productivity growth only, which is customary in economic growth models. Second, we make assumptions about *base* average labor productivity growth rates in non-land using sectors. These assumptions are listed in the first column of Table 8. Third, we adjust these rates to reflect differences across sectors. These differential coefficients are derived from Kets and Lejour (2003). Kets and Lejour (2003) compute historical total economy-wide and sectoral factor productivity (TFP) growth rates in OECD countries. It should be noted that while Kets and Lejour (2003) define growth in TFP as the increase in output per unit of value-added, we use their results to differentiate across sectors growth in labor productivity only. The simple average annual growth rates in non-land using sectors reported in Kets and Lejour (2003) are in the range from 0.42% in services to 1.95% in manufacturing with economy-wide growth rate at 0.87% per year. We define sectoral differentials as a ratio of TFP growth rate in services, manufacturing and natural resource based sectors to economy-wide average and then apply them to our *base* growth rates. These differentials together with final non-land using sectoral labor productivity growth rates are reported in Table 8.

So far we have defined productivity growth rates in non-land using sectors. Land using sectors have two subsets: agricultural sectors and forestry. Agriculture, in turn, combines crops, ruminants and non-ruminants. While non-ruminants are included in the land using sectors for purposes of discussion here, in the model the value of land in this sector is zero to reflect real world fact that production of non-ruminants more and more takes form of factories. For three agricultural sectors, the projected productivity growth rates are taken from Ludena (2005). These productivity growth rates are different from ones in Kets and Lejour (2003) because they take into account the productivity of all inputs, not just value-added. We assume that productivity growth rates in forestry are average of productivity growth rates in crops and ruminants, weighted by share of their output in total output of crops and ruminants.

The baseline is summarized in Figures 4 – 7. China is a leader in GDP growth (Figure 6), which is driven by assumed high labor productivity growth (Table 8). SAsia and ASEAN are characterized by high growth in their skilled labor force (Figure 4) that serves as a strong attraction for new investments (Figure 5). These factors result in rapidly growing GDP in these countries as well (Figure 6). However, population (Figure 7) is also fast growing in these regions, so that China, with an aging population in the next decade, continues to surpass ASEAN and SAsia in terms of per capita consumption expenditure growth rates.

5. Results

We start from the consumer demand side of the model, as this is the theme of our paper. For each of 11 regions, the path of consumer demand is not significantly affected by our choice of land modeling approach. Prices and quantities per capita of 10 consumed goods (and as a result budget shares) in 2025 are very similar across five land supply specifications. This allows us to focus on the results using the baseline Model 5. Consider specifically the case of China – which is the fastest growing region in the model. The average budget shares in China, projected with the dynamic model are shown in Figure 8. As can be seen from comparison of Figures 3 and 8, the pattern is similar; however changes in budget shares projected with general equilibrium model are less than changes projected in partial equilibrium framework. This is because general equilibrium model allows for changes in relative prices.

Some of the 10 consumed goods are composites of several produced goods (Table 2b). For example, 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, and this rate is similar across five models, prices of the composites diverge. Moreover, prices of ruminants (composite of MeatDairy) and forestry (composite of Manufacturing) depend on land supply specification.

In our baseline, demand for crops, ruminants and forestry is growing in all regions, except for ASEAN, were cumulative growth in the demand for ruminants is negative, but small by absolute magnitude. This is driven by very small initial budget share spent on ruminants (0.03%), negative productivity growth in this sector and resulting high prices. Strength of the demand and growth in sectoral productivity, as well as availability of land, determines prices of output in land using sectors. Since growth in demand for forestry is increasing in all regions as incomes rising over time, prices for forestry rise. Prices of crops and ruminants rise in some regions, where effect of increasing demand is very strong relative to improved land productivity, like in China, and fall in regions where effect of improved productivity is stronger, like in WEU. Consumer demand for crops, ruminants and forestry translates into demand for land. Derived demand for land in crops increases in WEU, ANZ, LAM and NAM – traditional exporters of crops – in all AEZs, except for AEZ 3 – 6 in NAM, and declines in all AEZs in all other regions. Land in ruminants sector declines in all AEZs in most of the regions with exception of China, EIT and ASEAN. In China the increase is driven by strong demand, in EIT by increase in demand and small growth in productivity, in ASEAN by negative growth in consumption but even stronger decline in productivity. The land in forestry sector grows in all regions and AEZs suitable for forestry. This is important since it suggests a strong move towards afforestation in response to increased demand for forest products worldwide, including ASEAN, South Asia and the Rest of the World – three regions which have experienced extensive deforestation in the past few decades.

Having main features of the baseline, we compare results of five models, focusing on land use and land prices. When presenting the results, we concentrate our attention on China, South Asia and Western European Union. These regions are characterized by very different economic growth and land endowments. The economic growth is rapid in China and South Asia, but slow in Western European Union (Figure 6). Within AEZs, land in China is very heterogeneous, while it is more homogenous in Western European Union and relatively homogenous in South Asia (Table 7).

We start from comparison of changes in total consumption, consumption of domestically produced goods only, and production of crops, ruminants and forestry. The cumulative growth (in percentages) of these variables from 1997 to 2025 projected with the baseline Model 5 is reported in column 3 of Table 9. Results of Models 1-4 are reported relative to Model 5 in columns 4-7 of the same table.

In China, growth in income together with moderate population growth translates into increase in consumption of crops, ruminants and a substantial increase in consumption of forestry products (column 3 in Table 9). Growth rate in consumption of these three goods are uniform across five models. However, changes in elasticity of land supply affect split of consumption of crops and forestry between domestic and imported goods. When land supply is more elastic, as it is in Models 1-3, Chinese consume more domestically produced crops and forestry. Note, much of the produced products are not directly sold to consumption because of exports and intermediate demands, and so the production side story is different from consumption. Cumulative growth in production of crops is uniform across 5 models, but production of ruminants is sensitive to land supply specification, as well as forestry. More restrictive elasticity of land supply leads to relatively smaller growth in ruminant production, but larger growth in forestry.

In South Asia cumulative growth in consumption projected with baseline Model 5 is much more moderate than in China. This is explained by slower growth in per capita expenditure and also differences in region specific AIDADS parameter $\hat{\beta}_k$ determining marginal budget shares at very higher per capita expenditure levels. $\hat{\beta}_k$ for manufacturing, demand for which drives demand for forestry, and meat and dairy products are lower in SAsia than in China (Table 3). The comparison of the consumption and production growth in South Asia across five models is similar to China's one with exception of forestry. More elastic land supply (Models 1-4) leads to larger growth in private demand for forestry, increasing part of which is demand for domestically produced forestry with corresponding large, relative to Model 5, growth in production.

In Western European Union, where population declines (Figure 7) and income does not grow much (Figure 6), the baseline cumulative growth in consumption is very small. Since the absolute growth rates are relatively small, the differences across models are noticeable.[10] Growth in consumption of ruminants is sensitive to the specification of the land supply: total growth is less when supply of land is more elastic. Consumption of domestically produced ruminants even declines (negative growth) relative to baseline when supply of land is more elastic, which suggest shift in favor of imported products. The growth in production of ruminants and forestry in Western European Union is less in the case of more transformable land across uses. Given that growth in

[10] For example, growth in consumption of ruminants in our baseline model is 7% (table 9). Growth in consumption in Model 1 is 5.6%. Though growth rates are similar (small), the ratio 5.6/7 = 0.8 is noticeably different from 1.

productivity is the same across models, any differences in production translate into differences in land use across models, which we consider next.

Changes in the derived demand for land by AEZ and sector, projected with five models, are shown in Table 10. In Table 11 we calculated weighted average land use change in each sector by weighting growth in the demand for land in each AEZ/sector by corresponding AEZ share in total land revenue in a region. This is to compare Model 1, where there are no AEZs, with Models 2-5. As projected by all five models, in China land moves from crops to ruminants and forestry. Since initially most of the land is used by crop sector in all six AEZs (Table 5), small decline in crop land translates into relatively large growth rates in land used in ruminants and forestry sectors. For example, in AEZ 6, where 95% of land rents are generated by crop land (Table 5), 6.18% revenue share weighted of crop land is transformed into 79.83% increase in grazing land and 42.47% increase in forestry (Table 10).

In China, the degree of land transformability across uses affects the changes in distribution of land across uses and the magnitude of changes. When land supply is very elastic (Model 1), land used by crops sector declines less than in base case. This cropland is transformed mostly to pasture and some to forestry. As we restrict land supply elasticities by introducing AEZs (Model 2), more land is transformed from cropland to pasture and forestry with stronger growth in forestry. Though one would expected that Model 2, where land is assumed to be less transformable across uses, should project smaller decline in cropland, decline in Model 2 is larger than in Model 1 because the distribution of land across three sectors is different across AEZs (Table 5). Different magnitudes of adjustments in land use across AEZs (Table 10) results in large decline in cropland in Model 2. In Model 3 we introduce non-nested CET structure with elasticity of transformation -1. Land in crop sector is further reduced and moved to ruminants and even more to forestry. In Model

4 we differentiate AEZs by introducing land heterogeneity adjusted elasticity of transformation across uses (Table 7). This adjustment is the same across uses, but different across AEZs. In China, the heterogeneity adjusted elasticity of transformation is less than 1 by absolute magnitude in all AEZs which should reduce land supply response. In fact, growth rates in demand for land in three sectors are smaller than in Model 4. In Model 5 we add nested CET structure which further reduces elasticity of supply of land and allows different degrees of land transformation across uses at different levels of the nest. The elasticity of transformation of land between agriculture and forestry is one quarter of the elasticities listed in Table 7. The elasticity of transformation of land in agriculture between crop production and ruminants grazing is one half of the elasticities listed in Table 7. This nested structure results in smaller decline in crop land and smaller increase in land in ruminants and forestry sectors.

In South Asia, demand for land projected with all five models declines not only in crop sector, but also in ruminants, while land in forestry increases. These developments are driven by the strong growth in demand for forestry products and smaller growth in demand for ruminants. Introduction of AEZs in Model 2 have very small reducing effect on land movements from ruminants to forestry and no effect on land in crops compare to Model 1. Introduction of non-nested CET in Model 3 increases decline of cropland in favor of forestry, while movement of land from ruminants to forestry is reduced. In South Asia, land is more homogenous than in China (Table 7): in AEZs 1, 2, 3 (AEZ 3 is the largest) and 6 land heterogeneity adjusted elasticity of transformation is greater than 1 by absolute magnitude, while in AEZs 4 and 5 the absolute magnitude of the elasticity is less than 1. These differences are reflected in growth rates reported in Table 10. In Model 4 projections, changes in AEZs 1-3 and 6 are larger and in AEZs 4 and 5 are smaller in all sectors, than in Model 3 projections. Introduction of such elasticity of transformation of land across uses together with other developments in the model (pressure from the consumer demand and availability of imports) results in smaller decline of land in crops, some larger decline of land in ruminants sector and increase of land in forestry. Introduction of nested CET in Model 5 further restrict transformation of land across uses.

In Western European Union – crops exporter with weak growth in consumer demand – high mobility of land across uses (Models 1 and 2) results in deforestation and transformation of grazing land into crop land. Introduction of AEZs in Model 2 reduces the magnitude of this development to some extend. Introduction of non-nested CET function with elasticity of transformation -1 change the story and greatly reduce mobility of land. Crop land is expanding, but to less extend, and most important forestry land is expanding in expense of ruminants sector. This result highlights importance of modeling of land supply for climate change policy: different assumption about mobility of land across uses leads to different projected land use changes and will results in different projections of green house gas emissions. In WEU land is very homogenous (Table 7) and introduction of the heterogeneity adjusted elasticity of transformation reduce effect achieved in Mode 3 to some extend. Cropland is expanding and grazing land is declining more than is projected with Model 3. Land in forestry is rising, however growth in this sector is smaller than one projected with Model 3. Further reduction of land mobility in Model 5 results in small increase in cropland and forestry in expense of grazing land.

Finally, we look at the effect of the assumption about mobility of land across uses on land prices. Table 12 reports the cumulative growth from 1997 to 2025 in prices of land projected with the baseline Model 5 and growth rates projected with Models 1-4 relative to Model 5. Since the returns to land on different AEZs employed in the production of the same product move together, the differences in changes in prices of land, used in the same activity, across AEZ are almost identical. Because of this, for each activity we report weighted by revenue shares average across AEZs growth rates.

The growth in land prices over 28 years in all regions and sectors, projected with five models, is implausibly high, and especially in China under the pressure of increasing demand, high productivity and very restricted mobility of land. The divergence of land rents across uses is also unrealistic.

In all land using sectors in China, gradual restriction of the mobility of land across uses is reflected in land rents increase from less to more restrictive models. In contrast to South Asia and WEU, prices for grazing land in China increase similar to forestry which is explained by large increase in per capita expenditures and, as a result, increase in derived demand for ruminants used in ruminant products (PrRum) and textile and apparel (TextAppar) sectors.

In South Asia, where the growth in consumption of ruminants is much smaller than in China (see Table 9), change in price of land used in ruminants sector is also smaller. The gradual restriction of the mobility of land across uses is reflected mostly in price of land used in forestry sector, where growth in consumption is the strongest among three land using sectors (Table 9). In crops and ruminants we observe opposite: very restrictive supply of land in Model 5 leads to smaller increase in land prices than in Models 1-4. This picture in three sectors is driven by stronger demand for forestry products: land moves from crops and ruminants to forestry. As in China, the introduction of nested CET (Model 5) has much stronger effect on land prices in forestry than introduction of heterogeneity (Model 4). The same is true for forestry sector in Western European Union. The price of land in crops in WEU behaves like one in China – growth rates in land rents increase from less to more restrictive models. In WEU ruminants sector, land prices behave similar to prices of grazing land in South Asia – the growth rates decline as land supply elasticity decline. In Model 3 and 4, under the pressure of demand, land moves from ruminants not only to crops, but also to forestry. Larger degree of land transformability across uses in Models 3 and 4 results in greater increase in land prices in ruminants and smaller increase in land prices in forestry than in the baseline Model 5. Growth in prices of total land increases as land supply become less elastic from Model 1 to 5 (Table 12, bold).

6. Conclusion

The goal of this paper is to improve modeling of the supply and demand of land in the long run in a global, general equilibrium framework, thereby enhancing the suitability of this type of model for purposes of analyzing climate change policy – particularly the abatement of greenhouse gas emissions driven by land use and land use change. In this work, we have used the dynamic GTAP model (Ianchovichina and McDougall, 2001) to project world economy from 1997 to 2025. The dynamic framework, as opposed to a static one, allows endogenous capital accumulation – and unlike the comparative static projections – it enforces the long run equalization of rates of return to capital. This can be very important in some of the rapidly growing regions of the world (e.g., China and India) where current rates of capital accumulation are very high – but future growth rates are likely to diminish as returns to capital decline.

Since the focus of the paper is on land use, we modified the standard consumer demand and production structures, as well as the model for land allocation across the land using sectors in GTAP-Dyn. To explore patterns of consumer demand in the future, we introduced the AIDADS demand system which is very flexible in its ability to represent the non-homothetic demand for consumer goods. The non-homotheticity property, which allows changes in budget shares as income rising, is very important in our analysis since we project rapid economic growth and large cumulative changes in per capita incomes from 1997 to 2025 in many developing countries. These changes in consumer demands determine changes in the derived demand for land.

In the standard GTAP model, only one broad type of land is specified which is imperfectly mobile across various agricultural activities. This approach ignores the fact that land represents a heterogeneous endowment which is often not suitable for many types of activities. We address the issue of land mobility across different uses via sequence of successively more sophisticated models of land supply. In our first model we assume that land is absolutely mobile across uses. In second version of the model, various types of land (AEZs), distinguished by length of growing season, are introduced. By separating land into different types, we restrict the degree of land mobility across diverse uses of land. This approach evaluates the suitability of each type of land for production of alternative crops and livestock 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. In our third model we further constrain mobility of land within an AEZ via a CET function with elasticity of transformation set uniformly across different land uses and AEZs. In the fourth model, we account for a measure of AEZ heterogeneity by adjusting the elasticity of transformation based on the inherent heterogeneity of land within the model's AEZs. In our final model we introduce a nested, multi-stage, optimization structure to better reflect the transformation possibilities across uses. 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 composite return to land in crop production, relative to the return in ruminant livestock production, the allocation of land between these two broad types of agricultural activities is made. At each level the land allocation is governed by a CET function, with different degree of land mobility at each level.

With the introduction of AEZs, we change the production structure in the land using sectors. We retain a single, national production function for each commodity, but introduce the different AEZs as inputs to this national production function. With a sufficiently high elasticity of substitution in use, we are assured that the returns to land across AEZs, but within a given use, will move closely together. Finally, we modify the production structure in the livestock sectors to permit substitution amongst feedstuffs, and between feedstuffs and land. Thus, as land rents rise much faster than crop prices over the baseline projections period, producers will make greater use of feedlots.

In our baseline, from 1997 to 2025, consumer demand for crops, ruminants and forestry is growing in all regions, except for demand for ruminants in ASEAN. Prices of forestry products rise in all regions, while prices of crops and ruminants rise in some regions, where effect of increasing demand is very strong relative to improved land productivity, and fall in regions where the effect of improved productivity is stronger. Consumer demand for crops, ruminants and forestry translates into a derived demand for land. The derived demand for land in crops increases in WEU, ANZ, LAM and declines in all other regions. The demand for grazing land declines in all AEZs in most of the regions with exception of China, EIT and ASEAN. However, the derived demand for land in the forestry sector grows in all regions and all AEZs where forestry is present. The projected afforestation is driven entirely by the increased demand for forest products. The fact that deforestation is presently occurring in many of these regions suggests that there are serious problems with property rights and management incentives, as the underlying economic incentives appear to be favorable for forestry expansion.

The sequential restriction of land mobility does not significantly affect consumer demand, but it does affect composition of consumed imported and domestic goods. In general, the composition of consumption shifts toward more domestic goods when supply of land is more elastic. The degree of land mobility (i.e. the CET parameter) across uses affects the changes in the distribution of land across uses and the magnitude of changes. One would expect that a lower mobility of land across uses should result in smaller redistribution of land across uses. However, it is not always the case. Though projections with the most restrictive Model 5 give the smallest changes in land use in most of the AEZ/sectors/region cases (Table 11), the movement from Model 1 to 5 is not monotonic in terms of the magnitude of land use changes (Tables 10 and 11). Introduction of heterogeneity-adjusted elasticity of transformation have noticeable effect mostly in regions where the majority of AEZs are characterized by either very high or very low heterogeneity. Introduction of nested CET structure have very strong restrictive effect on the land use changes, consistent across most of AEZs, sectors and regions.

While we believe that the most restrictive land mobility model (Model 5) offers the most realistic representation of land supply, the resulting baseline land rental changes in forestry and grazing seem unrealistic. This likely stems from other limitations of the current model – as well as our baseline projections. And it is to these issues that we now turn.

Land is indeed a scarce resource and under the pressure of income per capita and population growth and, as a result, as the total demand for land using products rises, so too should the price of land. However, the growth in land prices over the 28 years projected in simulations with all five models is implausibly large, and land rents diverge substantially across uses. The divergence of growth rates and magnitude of growth in land prices could be simply decreased by setting the elasticities of transformation to some larger values. However, such adjustments do not appear to be supported by recent evidence on the responsiveness of land supply to land rental rates in the United States (Choi (2006)) – and it is hard to imagine significantly larger supply elasticities in other regions of the world – many of which have much stricter land use regulations. So we turn our attention to other explanations for the unrealistic outcomes.[11]

Since the change in rental rate on land is also a function of the cost share of land in the land-using activities, these, too, deserve some scrutiny. If they are too small, the percentage change in land rental rates associated with a given commodity price change could be too large. These cost shares are reported in Table 13. The cost shares for crops and ruminants are based on econometric estimates of the composition of value-added in all of agriculture (see Hertel and Tsigas, 2002), together with the share of value-added in total costs obtained from original national input-output tables, as reflected in the GTAP data base. To the extent that the original econometric studies have accurately characterized land rents, these should be reasonably accurate. However, the same cannot be said of the estimated land rents in forestry. Here, the share of land in forestry has 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 estimates of accessible forest land documented in Sohngen, Mendelsohn and Sedjo (1999) and Sohngen and Mendelsohn (2006).

Another important factor that could have a bearing on the excessive rise in land rents in forestry is the presence of large amounts of unmanaged forest land in many parts of the world. In some cases, this can be readily added to production when the derived demand for land is high. The

[11] As a direction for future research, it would be worthwhile to look thoroughly at the previous studies (if available) and, conditional upon findings of the literature review, econometrically estimate the elasticities of transformation for different levels of our nested CET function. Currently we set the elasticity of transformation of land between crops and grazing to one half of the elasticity between crops, which is arbitrary and require further investigation. Analysis of correlations between prices of land in forestry and agriculture as a whole, and separately in crops and grazing would permit us to address the issue of divergence in growth rates in land prices. The analysis described above would require data on land quantities and relative prices, and of course, the implementation of such work is conditional on data availability. Though such analysis would be useful, we do not think that it would change the story dramatically, since low CET parameter between forestry and agriculture in the model seems to be consistent with econometric evidence.

introduction of such unmanaged land in the model should act as a buffer on prices. To address this, we will augment the data base with total available unmanaged land by AEZ in each region and build into the model unmanaged land supply functions. The unmanaged land supply function will represent the relationship between the degree of deforestation and prices of land. Higher land prices under the pressure of demand for crops, ruminants and forestry will attract more unmanaged land into the production process.[12] Since the conversion of the unmanaged land into agriculture or commercial forestry is not free – roads should be built to access inaccessible forest – the basic land supply schedule can be augmented via expenditure of resources needed to access currently inaccessible land.

There are other issues that may have an important bearing on the rate at which land rents rise over time in the future. We have assumed that productivity growth rates in forestry are the simple average of productivity growth rates in crops and ruminants, weighted by the share of their output in total output of crops and ruminants. The total factor productivity measures in crops and ruminants, in turn, take into account the productivity of all inputs. However, recent technical change in forestry seems to be strongly land-augmenting, as opposite to neutral across inputs. For example, Sedjo (2006) suggests that traditional forestry breeding programs can achieve yield increases of 1% per year, and when combined with cloning technologies, yield increases could be 2% per year. Introduction of land-augmenting technical change in the model will depress the growth in land rents.

Technical change in the forest products using sectors can also play an important role in determining the derived demand for forest land. Here, we model technical change in forestry processing sector as labor augmenting — as with all the non-land using sectors. However, there is

[12] This supply function should take into account observed rates of deforestation and increased speed of deforestation as land rents rise. The later would require some projected land rents and associated deforestation at some point in the future. With these pieces of information we could introduce the unmanaged land supply schedule into the model.

evidence that timber harvesting globally have remained fairly constant over the past 20 years, while wood products output risen strongly. According to experts' assessments, real output in the forest products industry in the U.S. increased 3.8% per year since 1977, whereas the quantity of industrial round wood harvested in the U.S. increased only by 1.2 % per year over the similar period (Haynes, 2003).[13] According to Haynes (2003), United States production of wood, paper, and paperboard products per unit of round wood input (industrial round wood) increased 35 percent in the past 50 years, but the rate of increase is projected to slow down over next 50 years. This suggests that there has been strong technical change in the forest products manufacturing sector. Introduction of forestry input-augmenting technical change in the forestry processing sector will reduce harvesting in forestry, as well as land rents in forestry, at given level of consumer demand for forestry products in the model.

There are other interesting issues that need to be addressed. First, we model production process in land using sectors with one function for each commodity, but introduce the different AEZs as inputs to this national production function. We think with high elasticity of substitution between AEZs the result of such specification should be equivalent to alternative one, where there is one production function for each AEZ in each activity. A formal sensitivity analysis with respect to specification of the production function would be useful. Note, we assume that products produced in different AEZ are perfect substitutes, production functions are similar, and the firms face the same prices for nonland factors. If so, then land rents in comparable activities must also move together. The later could be tested on real data. Disaggregated by AEZ land rents data in Choi *et al*. (2006) could be used to test the hypothesis that land rents in similar uses move together across AEZs.

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[13] This information is obtained from personal communications with Dr. Brent Sohngen, Professor of Environmental and Natural Resource Economics at the Ohio State University.

There are other aspects of the model that also deserve additional attention – and possibly justify some further econometric investigation. The first of these is the "intensification elasticity" in livestock production, which governs the rate at which cattle production shifts from grazing to feedlots in response to changing relative prices. We would also like to revisit the land supply equations and test the hypothesis that these supply elasticities are a function of land heterogeneity – as hypothesized in our model.

Finally, and most importantly, we need to undertake some backcasting exercises in which we seek to explain historical patterns of land use change using this model (or various component parts). It is only through such work that we can be confident of the validity of this land use model for climate policy analysis.

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Table 1. GTAP-Based AIDADS estimates: Household Consumption Expenditures. Source: Reimer and Hertel (2004)

Consumed Good	γ_k	α_k	β_k
Grains, other crops (Crops)	0.298	0.084	0.000
Meat, dairy, fish (MeatDairy)	0.000	0.122	0.026
Processed food, beverages, tobacco (OthFoodBev)	0.142	0.138	0.032
Textiles, apparel, footwear (TextAppar)	0.030	0.068	0.030
Utilities, other housing services (HousUtils)	0.000	0.035	0.047
Wholesale/retail trade (WRTrade)	0.078	0.132	0.238
Manufactures, electronics (Mnfcs)	0.002	0.169	0.099
Transport, communication (TransComm)	0.000	0.115	0.097
Financial and business services (FinService)	0.014	0.030	0.118
Housing, education, health, public services (HousOthServ)	0.086	0.108	0.313

Table 2a. 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 2b. 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		

Table 3. Calibrated region-specific AIDADS parameters

Parameter	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAm	WEU	EIT	MENA	ROW
$\tilde{\alpha}_{kn}$											
Crops	0.025	0.095	0.084	0.060	0.177	0.023	0.052	0.037	0.039	0.102	0.039
MeatDairy	0.076	0.216	0.052	0.090	0.162	0.062	0.106	0.115	0.162	0.109	0.106
OthFoodBev	0.204	0.088	0.192	0.127	0.022	0.138	0.155	0.136	0.141	0.149	0.128
TextAppar	0.057	0.108	0.064	0.060	0.097	0.064	0.098	0.072	0.050	0.064	0.051
HousUtils	0.033	0.021	0.038	0.039	0.021	0.050	0.043	0.041	0.076	0.038	0.040
WRTrade	0.171	0.094	0.158	0.111	0.104	0.156	0.126	0.146	0.087	0.129	0.198
Mnfcs	0.139	0.184	0.151	0.192	0.110	0.186	0.183	0.204	0.153	0.142	0.136
TransComm	0.115	0.081	0.117	0.092	0.160	0.097	0.129	0.112	0.113	0.120	0.119
FinService	0.013	0.043	0.011	0.047	0.033	0.039	0.019	0.042	0.039	0.016	0.060
HousOthServ	0.168	0.070	0.134	0.183	0.115	0.186	0.089	0.094	0.140	0.132	0.123
$\tilde{\beta}_{kn}$											
Crops	0	0	0	0	0	0	0	0	0	0	0
MeatDairy	0.014	0.054	0.011	0.016	0.036	0.010	0.024	0.023	0.032	0.023	0.018
OthFoodBev	0.041	0.024	0.043	0.024	0.005	0.024	0.039	0.030	0.030	0.035	0.024
TextAppar	0.022	0.056	0.027	0.022	0.044	0.022	0.046	0.030	0.020	0.028	0.018
HousUtils	0.038	0.033	0.049	0.042	0.029	0.051	0.061	0.052	0.093	0.051	0.043
WRTrade	0.267	0.198	0.275	0.162	0.195	0.215	0.243	0.249	0.143	0.233	0.284
Mnfcs	0.071	0.126	0.085	0.091	0.067	0.084	0.115	0.113	0.082	0.083	0.063
TransComm	0.084	0.080	0.095	0.063	0.140	0.063	0.117	0.090	0.087	0.101	0.080
FinService	0.043	0.195	0.042	0.149	0.134	0.117	0.079	0.155	0.141	0.063	0.187
HousOthServ	0.420	0.235	0.374	0.431	0.348	0.414	0.276	0.259	0.372	0.383	0.283
$\tilde{\gamma}_{kn}$											
Crops	0.298	0.2980000	0.298	0.298	0.2980002	0.298	0.298	0.298	0.298	0.298	0.298
MeatDairy	0	0	0	0	0	0	0	0	0	0	0
OthFoodBev	0.142	0.1420000	0.142	0.142	0.1420000	0.142	0.142	0.142	0.142	0.142	0.142
TextAppar	0.030	0.0300001	0.030	0.030	0.0300001	0.030	0.030	0.030	0.030	0.030	0.030
HousUtils	0	0	0	0	0	0	0	0	0	0	0
WRTrade	0.078	0.0780004	0.078	0.078	0.0779999	0.078	0.078	0.078	0.078	0.078	0.078
Mnfcs	0.002	0.0020002	0.002	0.002	0.0020001	0.002	0.002	0.002	0.002	0.002	0.002
TransComm	0	0	0	0	0	0	0	0	0	0	0
FinService	0.014	0.0140004	0.014	0.014	0.0139999	0.014	0.014	0.014	0.014	0.014	0.014
HousOthServ	0.086	0.0860005	0.086	0.086	0.0859998	0.086	0.086	0.086	0.086	0.086	0.086
$\tilde{\kappa}_{n}$	2.064	2.165	2.083	1.821	2.102	1.915	2.056	1.931	1.900	2.009	1.791

Table 4. 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

Table 5. Land earnings by sector and AEZ for 11 regions of the model

Regions	Sectors	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	All land
ANZ	Crops	0.225	0.440	0.655	0.687	0.771	0.414	0.589
	Ruminants	0.775	0.560	0.345	0.303	0.125	0.373	0.351
	Forestry	0.000	0.000	0.001	0.010	0.104	0.213	0.060
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
China	Crops	0.398	0.827	0.907	0.921	0.973	0.952	0.934
	Ruminants	0.602	0.168	0.086	0.070	0.014	0.011	0.043
	Forestry	0.000	0.005	0.007	0.008	0.013	0.037	0.023
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
HYAsia	Crops	0.000	0.000	0.877	0.925	0.926	0.902	0.922
	Ruminants	0.000	0.000	0.062	0.045	0.061	0.066	0.056
	Forestry	0.000	0.000	0.061	0.030	0.013	0.032	0.022
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
ASEAN	Crops	0.000	0.000	0.000	0.954	0.936	0.902	0.918
	Ruminants	0.000	0.000	0.000	0.042	0.057	0.060	0.056
	Forestry	0.000	0.000	0.000	0.004	0.007	0.038	0.026
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
SAsia	Crops	0.686	0.697	0.838	0.813	0.826	0.869	0.809
	Ruminants	0.309	0.300	0.154	0.170	0.120	0.089	0.176
	Forestry	0.005	0.003	0.008	0.017	0.054	0.042	0.015
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
NAM	Crops	0.489	0.762	0.816	0.907	0.905	0.896	0.865
	Ruminants	0.504	0.230	0.121	0.075	0.064	0.023	0.100
	Forestry	0.007	0.008	0.063	0.018	0.031	0.081	0.035
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
LAM	Crops	0.651	0.702	0.704	0.772	0.746	0.806	0.765
	Ruminants	0.339	0.275	0.273	0.218	0.231	0.179	0.219
	Forestry	0.010	0.023	0.023	0.010	0.023	0.015	0.016
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
WEU	Crops	0.295	0.257	0.696	0.828	0.836	0.834	0.808
	Ruminants	0.705	0.553	0.227	0.143	0.140	0.155	0.158
	Forestry	0.000	0.190	0.077	0.028	0.024	0.011	0.034
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
EIT	Crops	0.482	0.788	0.857	0.841	0.779	0.759	0.834
	Ruminants	0.194	0.186	0.118	0.127	0.199	0.140	0.138
	Forestry	0.324	0.026	0.025	0.032	0.023	0.101	0.029
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
MENA	Crops	0.609	0.783	0.775	0.891	0.933	0.000	0.751
	Ruminants	0.333	0.194	0.125	0.062	0.034	0.000	0.203
	Forestry	0.058	0.023	0.099	0.047	0.033	0.000	0.045
		1.000	1.000	1.000	1.000	1.000	1.000	1.000
ROW	Crops	0.288	0.444	0.816	0.877	0.831	0.707	0.803
	Ruminants	0.629	0.498	0.168	0.074	0.145	0.203	0.150
	Forestry	0.084	0.059	0.017	0.049	0.024	0.089	0.047

Table 6. Correlations of land earnings between countries pooling together sectors and AEZs (forestry is omitted since it is residual after crops and ruminants are included)

	ANZ	ASEAN	China	EIT	HYAsia	LAM	MENA	NAM	ROW	SAsia	WEU
ANZ	1	0.41	0.66**	0.44	0.52*	0.4	0.58**	0.62**	0.84	0.46	0.81***
ASEAN		1	0.64**	0.61**	0.82***	0.64**	0.32	0.66**	0.65**	0.62**	0.71***
China			1	0.93***	0.77***	0.93***	0.73***	0.99***	0.90***	0.93***	0.81***
EIT				1	0.79***	0.96***	0.77***	0.94***	0.78***	0.96***	0.64**
HYAsia					1	0.74***	0.47	0.78***	0.81***	0.76***	0.79***
LAM						1	0.73***	0.96***	0.76***	0.99***	0.67**
MENA							1	0.75***	0.66**	0.74**	0.48
NAM								1	0.89***	0.96***	0.81***
ROW									1	0.81**	0.95**
SAsia										1	0.72***
WEU											1

Table 7. Adjusted for land heterogeneity elasticity of transformation across uses, within AEZs

Region	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6
ANZ	-0.885	-1.013	-1.040	-0.943	-0.832	-0.942
China	-0.642	-0.776	-0.676	-0.774	-0.712	-0.991
HYAsia	-1.631	-1.631	-1.442	-1.267	-1.343	-1.389
ASEAN	-1.631	-1.631	-1.631	-1.180	-1.068	-0.981
SAsia	-1.082	-1.060	-1.163	-0.968	-0.978	-1.162
NAm	-0.609	-0.657	-0.592	-0.745	-0.908	-0.951
LAm	-0.844	-0.813	-0.888	-0.888	-0.985	-1.016
WEU	-1.631	-1.316	-1.080	-1.041	-1.070	-1.082
EIT	-0.993	-1.019	-1.094	-1.172	-1.232	-1.361
MENA	-1.124	-0.908	-1.008	-1.079	-0.890	-1.631
ROW	-1.102	-1.091	-1.135	-1.162	-1.192	-1.244

Table 8. Non-land using sectoral labor productivity growth rates*

Region	Base rates	Services	Manufacturing	Natural resources extraction
Sectoral differentials		0.48	2.24	0.78
NAM	1	0.48	2.24	0.78
LAM	1	0.48	2.24	0.78
WEU	1	0.48	2.24	0.78
EIT	3	1.45	6.72	2.34
MENA	1	0.48	2.24	0.78
ROW	1	0.48	2.24	0.78
ANZ	1	0.48	2.24	0.78
China	5	2.41	11.21	3.91
HYAsia	1.5	0.72	3.36	1.17
ASEAN	2	0.97	4.48	1.56
SAsia	4	1.93	8.97	3.13

Services includes WRtrade, FinServices, Utilities, Construction, HousOtheServ.
Manufacturing includes PrRuminants, PrNRuminants, PrFood, TextAppar, Mnfcs, TransComm.
Natural Resource Extraction includes Fisheries, Petroleum.

Table 9. Cumulative growth rates from 1997 to 2025 in total consumption, consumption for domestic products only, and production of crops, ruminants and forestry products*

Region	Variable	Model 5 (AEZ, nested CET, heterogeneity)	Model 1 (perfect mobility, no AEZs)	Model 2 (AEZ, perfect mobility)	Model 3 (AEZ, non-nested CET)	Model 4 (AEZ, non-nested CET, heterogeneity)
1	2	3	4	5	6	7
China	Growth in consumption					
	crops	195	1.01	1.01	1.00	1.00
	ruminants	417	1.00	1.00	1.00	1.00
	forestry	1368	1.02	1.02	1.02	1.02
	Growth in consumption of domestic products					
	crops	142	1.39	1.39	1.37	0.99
	ruminants	416	1.00	1.00	1.00	1.00
	forestry	1026	1.36	1.36	1.35	1.01
	Growth in production					
	crops	91	1.00	1.00	0.99	0.99
	ruminants	515	1.19	1.19	1.12	1.10
	forestry	383	0.86	0.86	1.06	1.02
SAsia	Growth in consumption					
	crops	114	0.99	0.99	0.99	0.99
	ruminants	95	0.98	0.98	0.99	0.99
	forestry	372	1.43	1.43	1.29	1.29
	Growth in consumption of domestic products					
	crops	88	0.97	0.97	0.97	0.97
	ruminants	95	0.98	0.98	0.99	0.99
	forestry	315	1.72	1.72	1.50	1.51
	Growth in production					
	crops	89	0.99	0.99	0.98	0.98
	ruminants	110	1.00	1.00	1.00	1.00
	forestry	341	1.69	1.69	1.42	1.43
WEU	Growth in consumption					
	crops	29	1.06	1.06	1.02	1.02
	ruminants	7	0.80	0.80	0.92	0.91
	forestry	92	1.00	1.00	1.00	1.00
	Growth in consumption of domestic products					
	crops	46	1.06	1.06	1.02	1.02
	ruminants	0	-27.05	-26.96	-6.69	-7.89
	forestry	106	0.74	0.75	0.94	0.94
	Growth in production					
	crops	141	1.06	1.06	1.03	1.03
	ruminants	25	0.67	0.67	0.89	0.87
	forestry	170	0.44	0.44	0.66	0.65

*Cumulative growth rates, obtained from simulations with baseline Model 5, are expressed in percentages. Cumulative growth rates obtained from simulations with Models 1-4 are expressed as ratios of growth in the model of interest to corresponding growth in Model 5.

Table 10. Cumulative growth rates (%) from 1997 to 2025 in demand for land in crops, ruminants and forestry sectors by AEZ

Region	AEZ	Land using sector	Model 5 (AEZ, nested CET, heterogeneity)	Model 2 (AEZ, perfect mobility)	Model 3 (AEZ, non-nested CET)	Model 4 (AEZ, non-nested CET, heterogeneity)
China	AEZ1	Crops	-28.00	1.54	1.42	1.18
		Ruminants	10.19	2.75	1.89	1.46
		Forestry				
	AEZ2	Crops	-16.45	1.09	1.12	1.11
		Ruminants	39.47	2.16	1.56	1.44
		Forestry	25.58	1.47	1.84	1.21
	AEZ3	Crops	-8.86	1.16	1.25	1.06
		Ruminants	42.59	2.40	1.78	1.41
		Forestry	25.89	1.94	2.32	1.42
	AEZ4	Crops	-8.99	0.97	1.07	1.06
		Ruminants	51.69	2.05	1.53	1.41
		Forestry	30.77	1.72	2.04	1.45
	AEZ5	Crops	-2.81	0.93	1.18	0.97
		Ruminants	55.68	2.15	1.64	1.38
		Forestry	31.53	2.00	2.35	1.59
	AEZ6	Crops	-6.18	0.61	0.85	0.96
		Ruminants	79.83	1.47	1.10	1.43
		Forestry	42.47	1.44	1.66	1.66
SAsia	AEZ1	Crops	-0.23	1.01	1.95	2.16
		Ruminants	-2.66	1.03	0.98	1.01
		Forestry	62.04	3.04	2.09	2.23
	AEZ2	Crops	0.15	1.10	-0.01	-0.11
		Ruminants	-2.25	1.05	0.97	0.98
		Forestry	61.11	3.10	2.14	2.22
	AEZ3	Crops	-1.18	0.95	1.12	1.33
		Ruminants	-3.77	0.96	0.92	1.04
		Forestry	66.65	2.79	1.91	2.26
	AEZ4	Crops	-2.26	1.25	1.40	1.26
		Ruminants	-4.41	1.20	1.20	1.09
		Forestry	51.14	3.54	2.41	2.21
	AEZ5	Crops	-6.96	1.34	1.41	1.30
		Ruminants	-9.02	1.28	1.30	1.20
		Forestry	44.57	3.64	2.42	2.27
	AEZ6	Crops	-6.90	1.06	1.13	1.30
		Ruminants	-9.34	1.03	1.05	1.20
		Forestry	57.04	2.94	1.97	2.31

Continued

Table 10. Cumulative growth rates (%) from 1997 to 2025 in demand for land in crops, ruminants and forestry sectors by AEZ (Contd.)*

Region	AEZ	Land using sector	Model 5 (AEZ, nested CET, heterogeneity)	Model 2 (AEZ, perfect mobility)	Model 3 (AEZ, non-nested CET)	Model 4 (AEZ, non-nested CET, heterogeneity)
WEU	AEZ1	Crops	29.93	37.46	25.65	40.04
		Ruminants	-16.52	-15.86	-12.94	-19.96
		Forestry				
	AEZ2	Crops	10.24	33.56	18.71	23.79
		Ruminants	-23.05	-18.25	-17.75	-21.70
		Forestry	25.78	7.02	17.78	21.10
	AEZ3	Crops	2.56	11.41	6.54	6.88
		Ruminants	-23.78	-31.80	-26.18	-26.91
		Forestry	21.11	-10.73	5.71	4.95
	AEZ4	Crops	2.08	6.46	3.98	4.03
		Ruminants	-23.34	-34.84	-27.96	-27.93
		Forestry	21.10	-14.70	3.16	2.21
	AEZ5	Crops	2.17	6.23	3.87	4.01
		Ruminants	-23.86	-34.98	-28.03	-28.64
		Forestry	21.81	-14.88	3.06	2.15
	AEZ6	Crops	2.94	6.57	4.29	4.47
		Ruminants	-23.54	-34.77	-27.74	-28.61
		Forestry	22.82	-14.61	3.47	2.58

Table 11. Revenue share weighted cumulative growth rates from 1997 to 2025 in demand for land in crops, ruminants and forestry sectors

Region and Sector	Share of total land rents	Model 5 (AEZ, nested CET, heterogeneity)	Model 1 (perfect mobility, no AEZs)	Model 2 (AEZ, perfect mobility)	Model 3 (AEZ, non-nested CET)	Model 4 (AEZ, non-nested CET, heterogeneity)
China						
Crops	0.934	-6.403	-5.158	-5.527	-6.566	-6.508
			(0.806)	(0.863)	(1.025)	(1.016)
Ruminants	0.043	1.965	4.067	4.054	2.996	2.790
			(2.070)	(2.063)	(1.525)	(1.420)
Forestry	0.023	0.901	1.355	1.363	1.582	1.475
			(1.505)	(1.513)	(1.756)	(1.637)
SAsia						
Crops	0.809	-1.695	-1.997	-1.997	-2.222	-2.218
			(1.178)	(1.178)	(1.311)	(1.309)
Ruminants	0.176	-0.704	-0.772	-0.770	-0.757	-0.758
			(1.096)	(1.094)	(1.076)	(1.077)
Forestry	0.015	0.818	2.685	2.682	1.816	1.842
			(3.284)	(3.280)	(2.221)	(2.253)
WEU						
Crops	0.808	1.808	5.693	5.684	3.472	3.584
			(3.149)	(3.143)	(1.920)	(1.982)
Ruminants	0.158	-3.729	-5.332	-5.329	-4.311	-4.389
			(1.430)	(1.429)	(1.156)	(1.177)
Forestry	0.034	0.736	-0.423	-0.418	0.163	0.141
			(-0.575)	(-0.569)	(0.221)	(0.192)

In parentheses, the cumulative growth rates obtained from simulations with Models 1-4 are expressed as ratios of growth in the model of interest to corresponding growth in Model 5.

Table 12. Cumulative growth rates from 1997 to 2025 in land prices in crops, ruminants and forestry sectors*

Region	Sector	Growth rate	Model 5 (AEZ, nested CET, heterogeneity)	Model 1 (perfect mobility, no AEZs)	Model 2 (AEZ, perfect mobility)	Model 3 (AEZ, non-nested CET)	Model 4 (AEZ, non-nested CET, heterogeneity)
China	crops	cumulative, %	582.95	556.16	556.33	578.54	578.69
		relative to base	1.00	0.95	0.95	0.99	0.99
		average, %	7.10	6.95	6.95	7.08	7.08
	ruminants	cumulative, %	2467.61	580.26	587.11	1249.69	1475.05
		relative to base	1.00	0.24	0.24	0.51	0.60
		average, %	12.29	7.09	7.13	9.74	10.35
	forestry	cumulative, %	3433.74	573.79	572.87	1121.22	1138.82
		relative to base	1.00	0.17	0.17	0.33	0.33
		average, %	13.58	7.05	7.05	9.35	9.40
	Total	**cumulative, %**	**729.38**	**557.61**	**558.05**	**619.99**	**630.33**
		relative to base	**1.00**	**0.76**	**0.77**	**0.85**	**0.86**
		average, %	**7.85**	**6.96**	**6.96**	**7.30**	**7.36**
SAsia	crops	cumulative, %	659.05	664.88	664.95	670.03	671.40
		relative to base	1.00	1.01	1.01	1.02	1.02
		average, %	7.51	7.54	7.54	7.56	7.57
	ruminants	cumulative, %	624.93	664.12	663.76	652.99	655.27
		relative to base	1.00	1.06	1.06	1.04	1.05
		average, %	7.33	7.53	7.53	7.48	7.49
	forestry	cumulative, %	4529.65	705.57	707.68	1677.65	1635.05
		relative to base	1.00	0.16	0.16	0.37	0.36
		average, %	14.68	7.74	7.75	10.82	10.73
	Total	**cumulative, %**	**712.44**	**665.37**	**665.40**	**682.50**	**683.35**
		relative to base	**1.00**	**0.93**	**0.93**	**0.96**	**0.96**
		average, %	**7.77**	**7.54**	**7.54**	**7.62**	**7.63**

Continued

Table 12. Cumulative growth rates from 1997 to 2025 in land prices in crops, ruminants and forestry sectors (Contd.)*

Region	Sector	Growth rate	Model 5 (AEZ, nested CET, heterogeneity)	Model 1 (perfect mobility, no AEZs)	Model 2 (AEZ, perfect mobility)	Model 3 (AEZ, non-nested CET)	Model 4 (AEZ, non-nested CET, heterogeneity)
WEU	crops	cumulative, %	464.92	426.58	426.71	455.32	455.32
		relative to base	1.00	0.92	0.92	0.98	0.98
		average, %	6.38	6.11	6.11	6.31	6.31
	ruminants	cumulative, %	225.94	414.12	413.65	284.63	284.63
		relative to base	1.00	1.83	1.83	1.26	1.26
		average, %	4.31	6.02	6.02	4.93	4.93
	forestry	cumulative, %	1052.98	421.33	420.36	450.63	450.63
		relative to base	1.00	0.40	0.40	0.43	0.43
		average, %	9.12	6.07	6.07	6.28	6.28
	Total	**cumulative, %**	**447.17**	**424.43**	**424.43**	**428.16**	**428.16**
		relative to base	**1.00**	**0.95**	**0.95**	**0.96**	**0.96**
		average, %	**6.26**	**6.10**	**6.10**	**6.12**	**6.12**

***** Cumulative growth rates over 1997-2025, as well as annual average growth rate, are obtained from simulations with Models 1- 5. In addition, the cumulative growth rates obtained from simulations with Models 1-4 are expressed as ratios of growth in the model of interest to corresponding growth in Model 5. The growth rates across AEZs are very similar in each sector. Because of this, we report weighted by revenue shares average across AEZs growth rates.

Table 13. Cost share of land in total production costs of three sectors in the initial database

Region	Crops	Ruminants	Forestry
ANZ	0.23	0.22	0.13
China	0.35	0.39	0.11
HYAsia	0.29	0.26	0.12
ASEAN	0.53	0.57	0.09
SAsia	0.46	0.47	0.09
NAM	0.41	0.28	0.16
LAM	0.26	0.27	0.10
WEU	0.32	0.13	0.10
EIT	0.36	0.37	0.15
MENA	0.12	0.12	0.11
ROW	0.26	0.33	0.12

Figure 1. Expenditure shares at different per capita expenditure levels on 10 commodities and services for the ASEAN region. Calculation is based on AIDADS parameters reported in Reimer and Hertel (2004) and calibrated to match AIDADS budget shares with budget shares in 1997 recorded in GTAP v.5.4 data base.

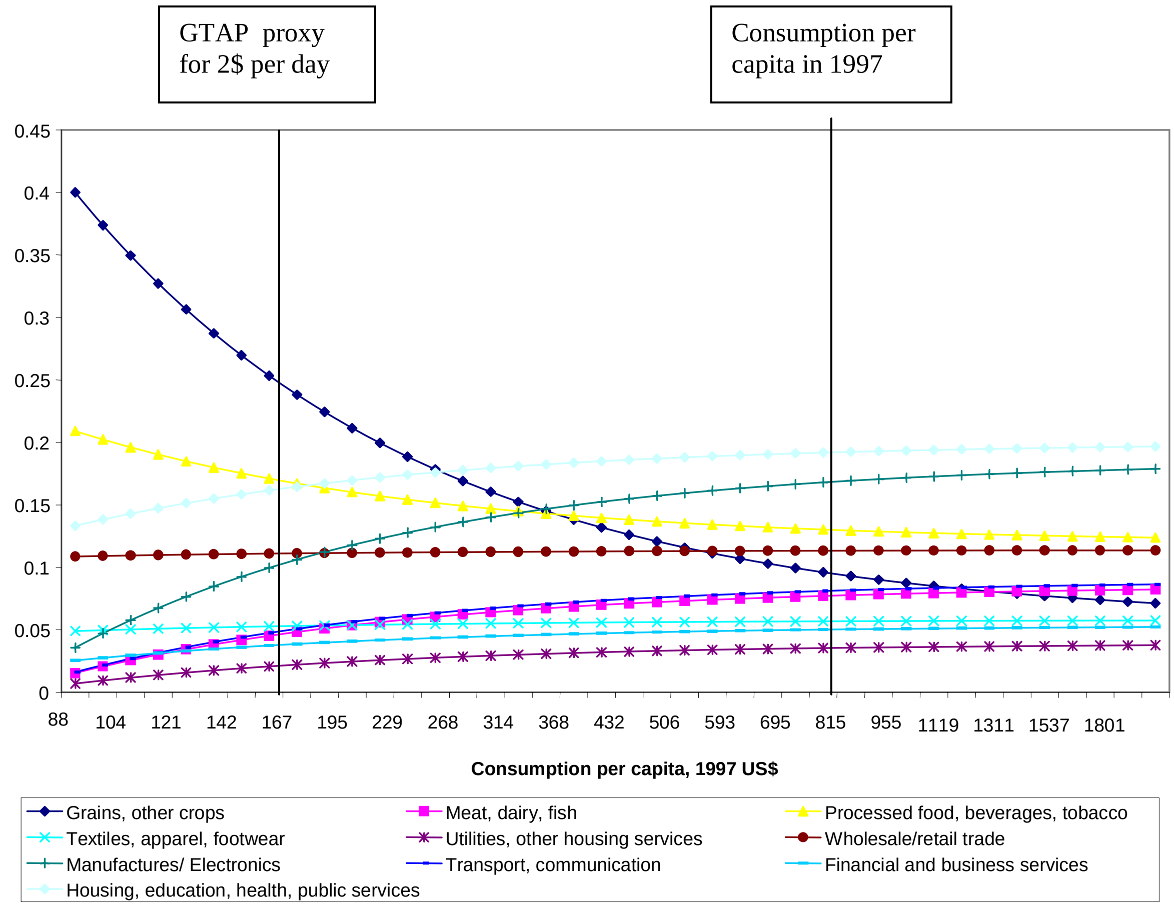


Figure 2. Marginal budget shares for agricultural products across income spectrum. Calculations are based on estimates reported in Reimer and Hertel (2004).

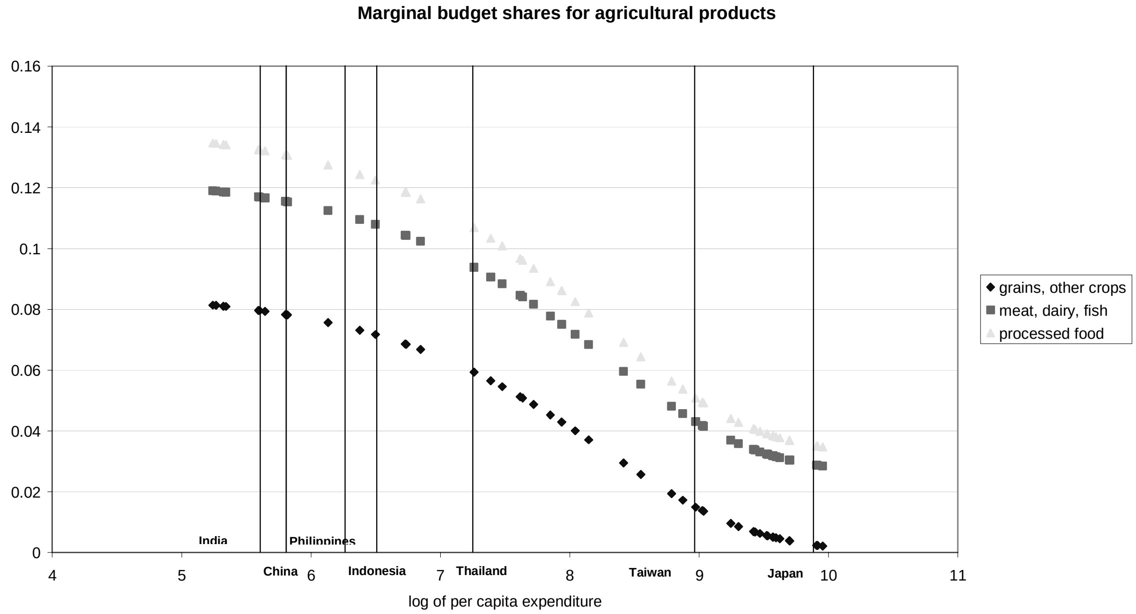


Figure 3. Projected average budget shares in China. Projections are obtained based on projected income per capital growth calculated using GTAP baseline (Walmsley *et al*., 2000) and assuming constant prices, i.e. in partial equilibrium framework. The initial AIDADS estimates reported in Reimer and Hertel (2004) are calibrated to fit initial structure of consumption in China.

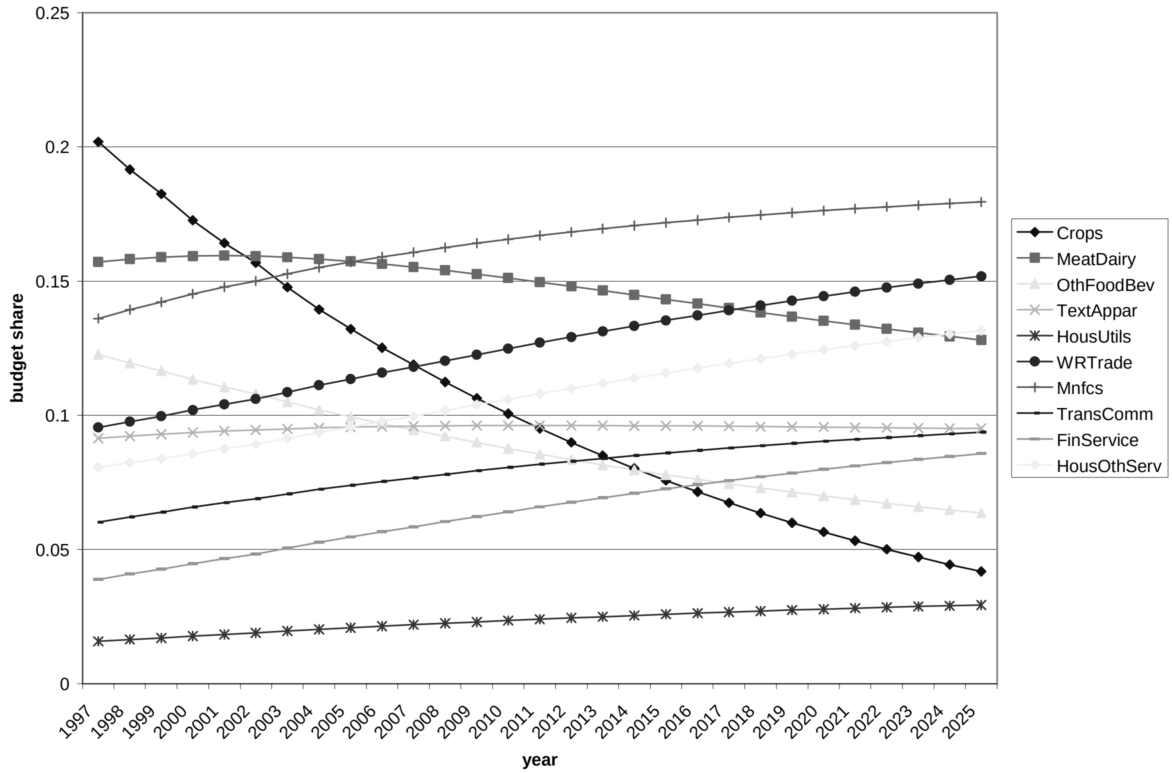
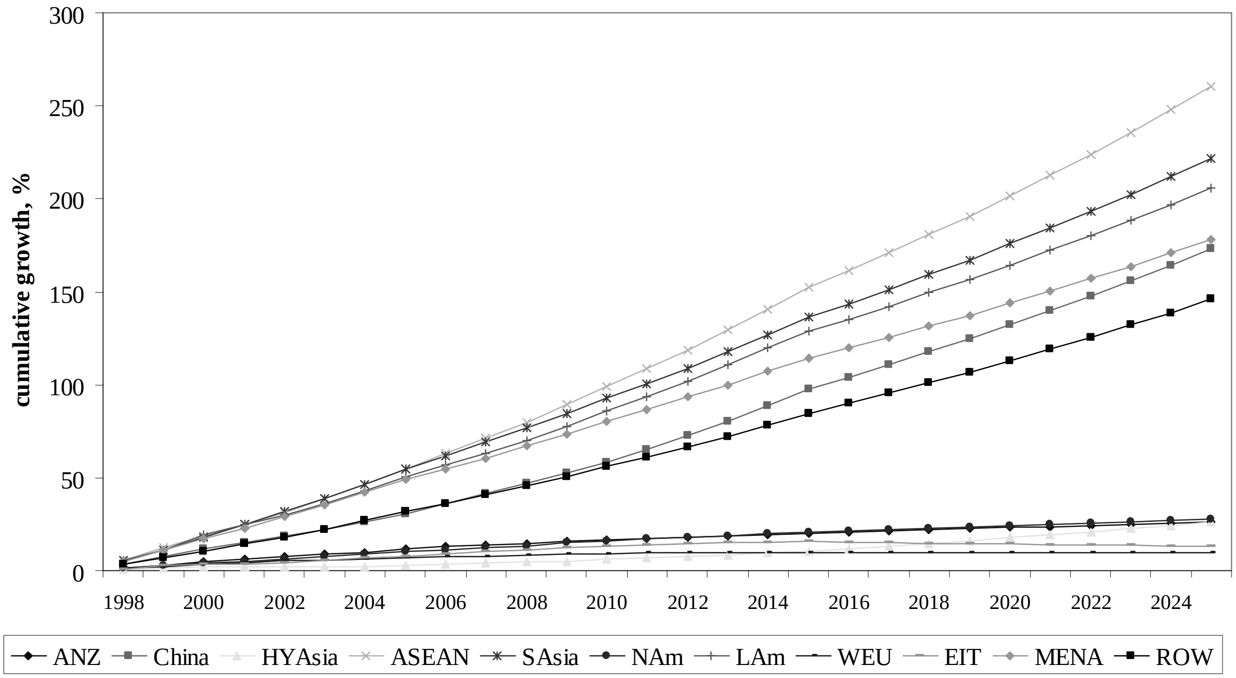
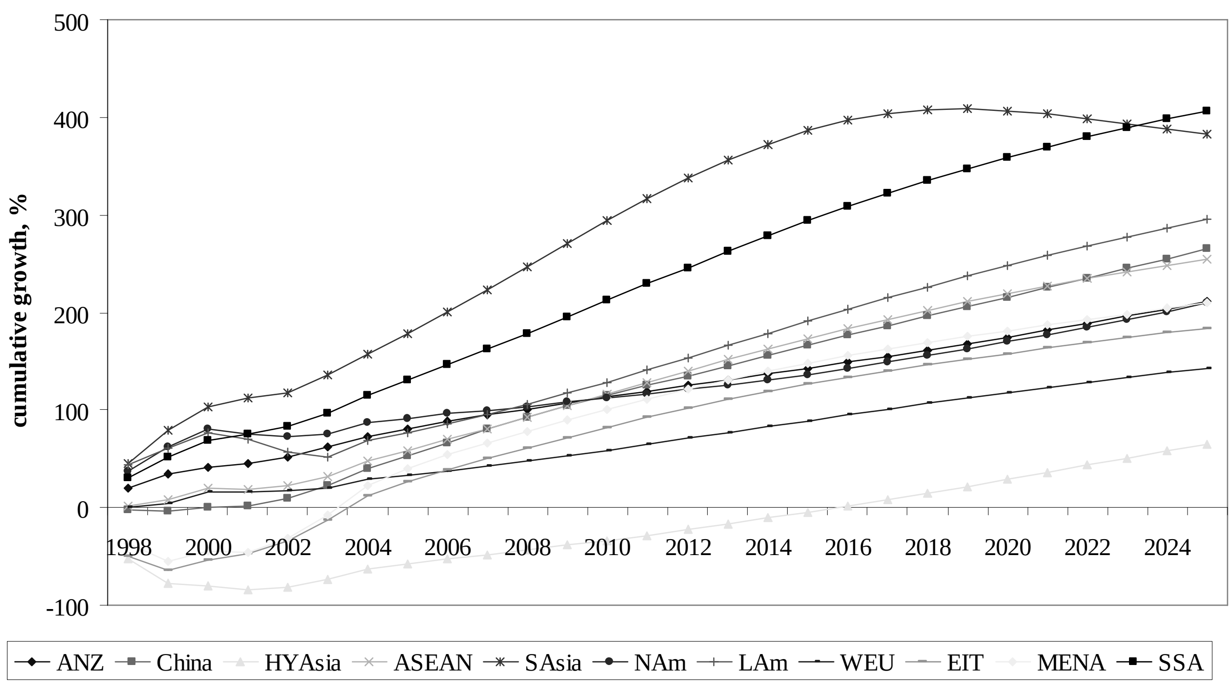


Figure 4. 1997-2025 cumulative skilled labor force growth



Source: Walmsley (2000).

Figure 5. 1997-2025 cumulative growth in investments



Source: simulation with GTAP-Dyn.

Figure 6. Actual (1997-2004) and projected (2005-2025) in simulation with GTAP-Dyn real GDP growth rates

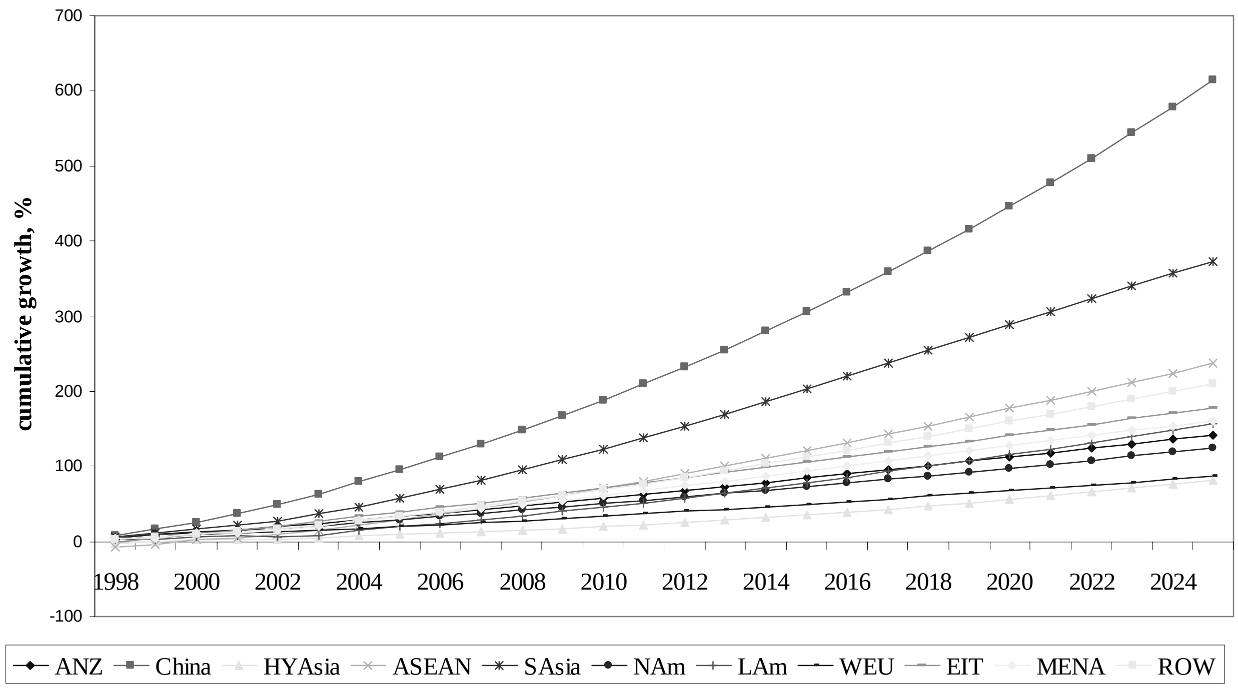
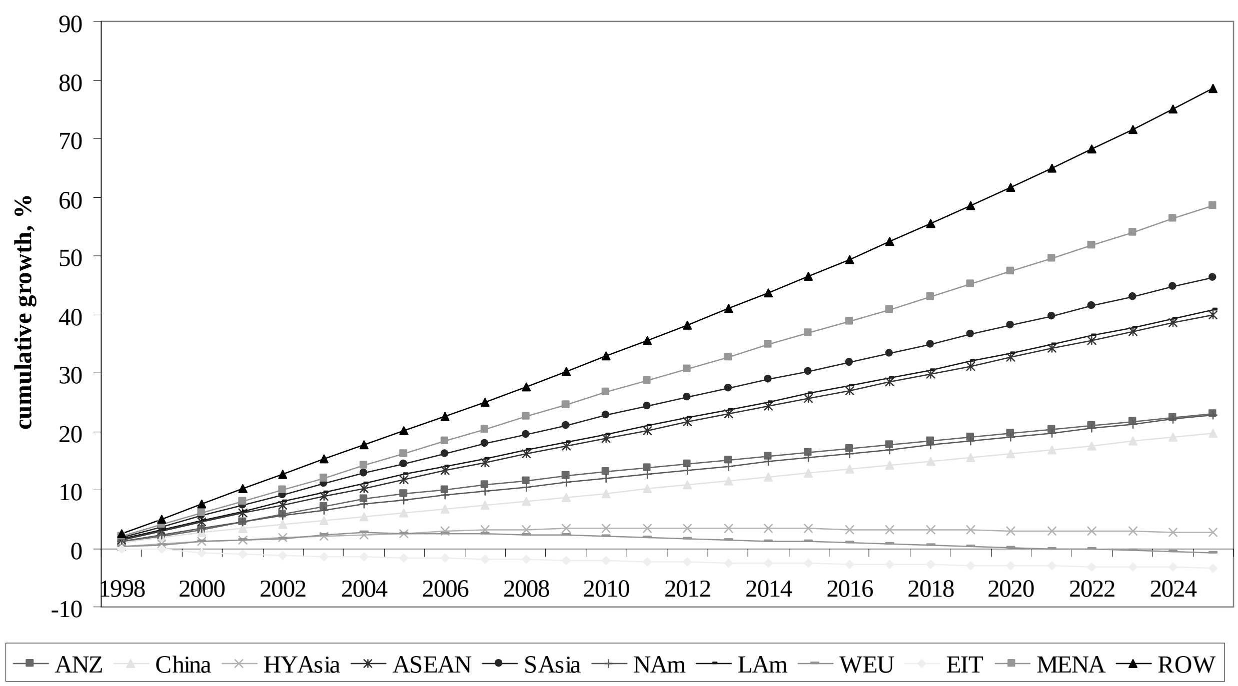


Figure 7. 1997-2025 cumulative population growth rates



Source: Walmsley (2000).

Figure 8. Projected average AIDADS budget shares in China. Source: simulation with GTAP-Dyn