Journal of Economic Integration
23(3), September 2008; 463-488

Global Economic Integration and Land Use Change

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Abstract

The goal of this work is to investigate the role of global integration in determining long-run patterns of land-use change. We utilize a dynamic general equilibrium model that has been modified to incorporate the most important economic features driving global land demand and supply, and simulate a baseline period from 1997-2025 over which land rents world-wide rise sharply and the global allocation of land between agriculture and forestry changes rather significantly in some regions. Through a series of restricted simulations of the model, we are able to isolate the impact on land markets of the following elements of growth and globalization: (i) population growth, (ii) real income growth, (iii) access of new forest lands, and (iv) international trade. We found that international trade plays a very substantial role in mediating between the land-abundant, slower growing economies of the Americas and Australia/New Zealand, and the land-scarce, rapidly growing economies of Asia. In summary, when combined, the forces of globalization are expected to play a large role in determining the pattern of land use change.

- **JEL classification:** C68, R14, Q24
- **Key words:** land use, climate change policy, baseline, general equilibrium, agro-ecological zones

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I. Introduction and Motivation

Changes in land use practices are regarded as an important component of long term strategies to mitigate climate change. According to results from the EMF-21 (Energy Modeling Forum) study models, the land based mitigation strategies are a significant part of the mitigation portfolio required for a climate stabilization policy, accounting for anywhere from 18 to 72 per cent of total abatement by 2050 and 15 to 44 per cent of total abatement by 2100 (Rose *et al*. (2007)). The efficiency of one or another strategy, however, depends critically on the baseline land use changes. The latter depends on many factors, the most important of which are population and per capita income growth as well as the degree of integration in the global economy.

In this work, the GTAP-Dyn (Ianchovichina and McDougall, 2001) dynamic general equilibrium (GE) model of the global economy is modified and extended to investigate the role of population and per capita income growth and global economic integration in determining long-run patterns of land-use change, where the latter is decomposed by Agro-Ecological Zone (AEZ). We are able to isolate the impact of each of these three factors on the development of land use in the long run through a series of carefully designed experiments. While the impact of population and income growth on the derived demand for land is relatively predictable, once supply-side constraints are brought to bear - including the potential to access currently non-commercial lands, the picture becomes more complex. International trade serves to moderate the changes in land rents across regions of the world, transmitting demand growth from the fast-growing, land-constrained countries (e.g., China) to the slower growing, land abundant countries such as Australia and New Zealand. Trade is also shown to have a significant impact on the composition of land-using activities, inducing significant shifts between crops, livestock and forestry uses. In our analysis we consider the 28 year period from 1997 to 2025. While this period is shorter than those usually considered in studies of climate change mitigation strategies, this period is long run in an economic sense; it assumes no fixed factors of production, including land employed in commercial production that can be expanded by conversion of virgin forests into commercially managed land. Though 28 years may not be a long enough time period to observe dramatic changes in climate, it is long enough for climate change policy to have a significant impact on the economy - and for changes in land use to have a significant impact on emissions. So this analysis is highly relevant for those seeking insight into the drivers of land use change over this intermediate time horizon.

Examples of previous studies that have investigated the tradeoffs between different land use decisions are Adams *et al.* (1996) using the Forest and Agriculture Sectors Model (FASOM), Darwin *et al.* (1995) using the Future Agricultural Resource Model (FARM), Ianchovichina *et al.* (2001) using dynamic extension of FARM, and Ahammad and Mi (2005) using the modified global trade and environment model (GTEM). The work presented in this paper is quite similar to that of Ianchovichina *et al.* (2001) and Ahammad and Mi (2005), in that we incorporate land use based on AEZs into recursive dynamic, general equilibrium model. Ianchovichina *et al.* (2001) explore the implications of technological change in agriculture for the pattern of land use in their baseline simulation. Ahammad and Mi (2005) explore the implications of climate policy for land use. However, neither of these studies isolate the impacts of fundamental drivers of supply and demand behind their baseline projections of land use. Therein lies a key contribution of this paper. In addition, we introduce an econometrically estimated consumer demand system, aimed at capturing the changing patterns of consumer purchases as incomes rise. This is coupled with the potential for investment in access to new lands in regions where such non-commercial areas are still available. Taken together, these extensions of traditional global general equilibrium analysis allow us to go much further in understanding the impact of global economic growth and integration on land use change.

II. Methodology

A. Modeling Approach

For this paper, we build on the earlier paper by Golub, Hertel and Sohngen (2007), henceforth referred to as GHS. They used a modified version of the dynamic GTAP model called GTAP-Dyn (Ianchovichina and McDougall, 2001). The GTAP-Dyn model is a multi-sector, multi-region, recursive dynamic applied general equilibrium model that extends the standard GTAP model to include international capital mobility, endogenous capital accumulation, and an adaptive expectations theory of investment. The authors undertook several modifications to the model to capture the most important determinants of supply and demand for land and to facilitate long run projections of the sort desired for climate change policy analysis. Here we briefly describe those that are most important for the issue of global economic integration and land use change.

The most important driver of the demand for land is consumer demand because it influences the scale and location of each production activity. In GHS, consumer demand is modeled with An Implicit Directly Additive Demand System (AIDADS) developed by Rimmer and Powell (1996). The AIDADS demand system is rank 3, meaning that it is very flexible in its ability to represent the non-homothetic demand for consumer goods, which is especially important for fast-growing, developing countries that account for an increasing share of global economic growth. Furthermore, it has been shown to outperform competing demand systems in the prediction of observed demands - particularly demand for food - across a wide range of income levels (Cranfield *et al.* (2003)).

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

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

where s_{kn} is the average budget share spent on good k in country n, p_{kn} is the price of good k in country n, I_n is total per capita expenditures in country n, U_n is per capita utility in country n, γ_k is estimated parameter reflecting the subsistence level of good k, and $p'\gamma$ is minimally sustainable per-capita income in country n. Parameters α_k and β_k represent bounds on marginal budget shares at very low (i.e., close to subsistence) and very high income levels, respectively.

The AIDADS parameters estimated by Reimer and Hertel (2004) using the GTAP 5.0 data base, representing the world economy in 1997, are reported in Table 1.

Table 1. Parameter Estimates for AIDADS Demand System

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

Source: Reimer and Hertel (2004), based on cross-section estimation using the GTAP version 5 data base.

The estimation results are consistent with one's intuition regarding how the composition of consumption is likely to differ across income levels. The estimated subsistence levels γ_k for "Meat, dairy, fish", "Utilities, other housing services" and "Transport, communication" are zeros, implying that these three categories are not necessary for survival. In contrast, subsistence level for "Grains, other crops" is 0.298, highlighting importance of grains and crops at the lowest income levels.

The estimated lower (α_k) and upper (β_k) bounds on marginal budget shares reported in Table 1 also make sense. At the low income levels, 8.4 and 12.2 cents of each additional dollar are spent on "Grains, other crops" and "Meat, dairy, fish", respectively. The upper bound on marginal budget share, β_k, for "Grains, other crops" is zero implying that expenditures on this consumption category are not increasing at high income levels. As per capita income grows, marginal budget shares decline for food categories, as well as for "Textiles, apparel and footwear", "Manufactures, electronics" and "Transport, communication", while they grow for "Utilities, other housing services", "Wholesale/retail trade", "Financial and business services", and "Housing, education, health, public services" categories that are generally viewed as luxuries at low income levels.

In order to implement AIDADS in our model, we regionalize the parameters in Table 1 to allow this demand system to reproduce the observed, base period budget shares, while retaining the overall pattern of the estimated Engel effects.[1] These base budget shares for the crops, meat and dairy products, other foods and all other goods (aggregated for purposes of this table only) are reported in Table 2 - at producer prices (i.e. wholesale/retail margins are in the "other" category). Our choice of regional aggregation scheme is driven by our focus on the derived demand for land due to income growth. The 78 regions of the GTAP 5.4 data base (Dimaranan and McDougall, 2002) are aggregated to 11 regions according to the mapping reported in Appendix. This aggregation, while parsimonious, represents a broad spectrum of income levels and development across regions.

In the poorest countries it is clear that food expenditures still command a large share of per capita income (45 per cent in South Asia), and much of this comes in the form of purchases of land-intensive goods (crops and meats/dairy). On the other hand, food's share in the total budget is quite small in the richest countries (less than 10 per cent of income, when expenditures are measured at producer

[1]This involves re-scaling the α_k and β_k parameters for each good, while preserving their ratio. Details are available in Golub (2006).

Table 2. Budget Shares for Consumed Goods Grouped in Four Categories

Consumed good	Scenario/year	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAm	WEU	EIT	MENA	ROW
Crops	1997 benchmark	0.0095	0.2029	0.0263	0.0879	0.2473	0.0058	0.0492	0.0136	0.0529	0.0876	0.1008
	2025 PE projections	0.0059	0.0924	0.0137	0.0626	0.1907	0.0038	0.0422	0.0081	0.0325	0.0706	0.0802
	2025 baseline projections	0.0060	0.1025	0.0141	0.0720	0.2132	0.0038	0.0433	0.0080	0.0315	0.0715	0.0841
Meat and Dairy	1997 benchmark	0.0318	0.1570	0.0220	0.0744	0.1166	0.0195	0.0821	0.0508	0.1318	0.0838	0.0852
	2025 PE projections	0.0253	0.1764	0.0166	0.0696	0.1370	0.0163	0.0766	0.0400	0.1105	0.0747	0.0874
	2025 baseline projections	0.0255	0.1756	0.0168	0.0694	0.1346	0.0164	0.0770	0.0403	0.1115	0.0751	0.0874
Processed food, beverages, tobacco (OthFoodBev)	1997 benchmark	0.0887	0.1228	0.0850	0.1237	0.0832	0.0455	0.1269	0.0629	0.1266	0.1235	0.1394
	2025 PE projections	0.0710	0.0805	0.0649	0.1071	0.0429	0.0382	0.1175	0.0498	0.1015	0.1082	0.1309
	2025 baseline projections	0.0715	0.0799	0.0655	0.1074	0.0427	0.0384	0.1182	0.0501	0.1015	0.1081	0.1297
Other	1997 benchmark	0.8700	0.5173	0.8667	0.7141	0.5529	0.9291	0.7418	0.8727	0.6887	0.7051	0.6746
	2025 PE projections	0.8978	0.6507	0.9048	0.7607	0.6293	0.9417	0.7637	0.9020	0.7555	0.7465	0.7014
	2025 baseline projections	0.8971	0.6420	0.9036	0.7512	0.6095	0.9415	0.7615	0.9016	0.7556	0.7453	0.6988

Source: Base data, GTAP version 5.4 and authors' simulations prices), and most of this represents expenditure on highly processed goods. Thus the geographic pattern of global income growth is very important in determining the global demand for land in agriculture. Rapid income growth in South Asia and China will have a much more significant impact on the derived demand for land than will equivalent growth in North America or Europe.

To reflect the fact that land is a heterogeneous endowment, GHS bring in climatic and agronomic information by introducing AEZs (Lee *et al*. (2005)). This data base enhances the standard GTAP global economic data base by disaggregating land endowments into AEZs.[2] The AEZs represent six different lengths of growing period (6×60 day intervals). The concept "length of growing period refers to the number of days within the year of temperatures above 5^oC when moisture conditions are considered adequate for crop production. This approach evaluates the suitability of each AEZ for production of crops, livestock and forestry based on currently observed practices, so that the competition for land within a given AEZ across uses is constrained to include activities that have been historically observed to take place in that AEZ.[3] 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. The different AEZs then enter as inputs into national production function for each land-using sector (e.g., wheat). With a sufficiently high elasticity of substitution in use,[4] the returns to land across AEZs, but within a given use, will move closely together.[5]

Even after disaggregating land use by AEZ, there remains substantial heterogeneity within AEZs. In addition, there are numerous barriers to land conversion between agriculture and forestry, as well as within agriculture - say between crops and livestock uses. Therefore, limit the potential for movement of land from one use to another within an AEZ. In the model, the allocation of land is determined through a nested constant elasticity of transformation (CET), multi-stage optimization structure (Ahammad and Mi, 2005). Owners of the particular type of land (AEZ)

[2]Lee *et al*. (2005) adopt the FAO/IIASA convention of agro-ecological zoning. Agro-ecological zoning refers to segmentation of a parcel of land into smaller units according to agro-ecological characteristics, e.g., moisture and temperature regimes, soil type, landform, etc. In other words, each zone has a similar combination of constraints and potentials for land use.

[3]In this work AEZs are static. However, they may shift due to climate change.

[4]The elasticity of substitution among AEZs in production is set to 20.

[5]Information on relative importance of each AEZ in each of 11 regions considered in this study, and how important is each sector within AEZ can be found in Golub *et al*. (2007).

first decide on the allocation of land between agriculture and forestry to maximize the total returns from land. Then, based on the return to land in crop production, relative to the return on land used in ruminant livestock production, the land owner decides on the allocation of land between these two broad types of agricultural activities. GHS set the elasticities of transformation amongst uses based on econometric evidence on the responsiveness of land use to changes in land rental differentials.

A final modification to the dynamic GTAP framework is required to accurately capture future developments in the global market for land. We must account for the possibility that currently inaccessible forestland will be brought into commercial production - either of forestry or agriculture products. This is potentially quite important. In North America, 75 per cent of forest lands are estimated to be currently inaccessible, and therefore not employed in commercial production. In Australia/New Zealand, this figure is above 90 per cent (Global Timber Market and Forestry Data Project, 2004). This represents a substantial source of commercial land, some of which could reasonably be expected to come into use if land rents were to rise sufficiently to bring them into production. In order to allow for this possibility, GHS introduce a new investment activity into the model which converts inaccessible forest land to accessible, and hence commercially viable land within an AEZ. Below we highlight the main features of the investment activity, while for the detailed description of the implementation a reader is referred to GHS.

A land owner's decision to add new land to production is modeled as an investment decision. Specifically, the investment in conversion of unmanaged land today yields a stream of future benefits from production undertaken on this land, reflected in the present value of land which is measured as a discounted stream of future land rents.[6] Conversion of unmanaged land is costly because it requires building roads and other infrastructure. It consumes resources and becomes more costly as more land is accessed and less land is left unmanaged. These considerations determine the choice of a functional form for marginal cost of access, which is convex in the share of accessed forests in total forests. New land is accessed only when value of land in a region is high enough to cover the costs of access. In equilibrium, the marginal cost of access is equal to the discounted stream of land rents expected to be obtained from commercial activities. The access cost functions

[6]Myopic expectations for both the land rents and the rate of return are the only option available in our recursive dynamic model. For this reason, investors value land based on current land rents and expected rate of return to capital.

are specified at the regional level, thereby augmenting regional AEZs proportionally, where the proportionate additions are based on the AEZ's current share of accessible forests in the total regional accessible forests.

B. Baseline Assumptions

We adopt the baseline assumptions developed by Hertel *et al.* (2006) . The starting point of our simulation is the world economy in 1997, as depicted in the GTAP v.5.4 (Dimaranan and McDougall, 2002) data base. In our simulations from 1997 to 2025, labor force, population and productivity growth are all exogenous to the model. Projections of labor force (skilled and unskilled labor) growth rates for 1998 - 2025 are taken from Walmsley *et al.* (2000). The historical real GDP and population growth rates for 1998-2004 period are constructed using World Development Indicators database. The real GDP path for 2005-2025 is driven by our assumptions about productivity growth in various sectors of the economy. Productivity growth rates in non-land using sectors are based on our assumptions about economy-wide labor productivity growth in each region, adjusted for productivity differences across sectors using estimates reported in Kets and Lejour (2003). For detailed description of the productivity growth in non-land using sectors the reader is referred to Hertel *et al.* (2006). Productivity growth rates in agriculture are based on Ludena *et al.* (2007). These play a key role in determining the location of future agricultural production. Those authors project rapid catching up in non-ruminants productivity, whereas divergence (more rapid growth in productivity in the rich countries) is more common for ruminant livestock. In the case of crops productivity growth, the industrialized economies show continued strong growth, as is the case for China and South Asia. East and Southeast Asia are projected to continue a recent trend of negligible productivity growth in agriculture. In the absence of better information, productivity growth rates in forestry are assumed to be equal to the average of productivity growth rates in crops and ruminants, weighted by the share of their output in total output of crops and ruminants. This is a "neutral" assumption that does not have an affect on the allocation of land between agriculture and forestry. Productivity growth in forestry processing is predicted based on results from the Global Timber Model (Sohngen and Mendelsohn, 2006).

C. Experimental Design

The channels through which global economic growth and integration affect global patterns of land use are varied and complex. In order to isolate these on an individual basis, we conduct a sequence of simulations which may, in turn be contrasted with the baseline simulation in order to gain insight into these mechanisms. The first two experiments focus on the demand side of global economic growth. In so doing, they abstract from supply-side considerations. This is accomplished by fixing primary factor prices in each region, allowing supplies to adjust freely to meet any level of demand required. These demand-side forces are separated into two component parts: population growth at constant per capita income, and per capita income growth at constant population. The first experiment, that involving the population shock, permits us to explore the impact of differential population growth across the globe on the demand for land-using commodities, and hence the demand for land.

In the second, demand-side experiment, we shock per capita utility, reflecting the growth in real income anticipated by the baseline scenario. With real income rising, the budget share equation (1) dictates how the pattern of household expenditure will change, thereby shifting the demand for commodities, and hence the derived demand for land, in each region. In the relatively wealthy regions, where the income elasticities of demand for food products are quite low, we expect stronger increases in the derived demand for land in the forest products sector. On the other hand, in the poorest countries, where the income elasticity of demand for food is still high, strong income growth may generate substantial increases in food demand, and hence the demand for land used in agriculture.

The third experiment represents our baseline scenario. As such, it shares the same population and per capita income growth with scenarios one and two, but it now brings to bear the supply-side constraints in the economy. Specifically, we restrict the supply of accumulable endowments according to the theory of the model (capital and land), which, coupled with exogenous projections of the skilled and unskilled labor forces in each region, permits us to endogenize endowment prices. By bringing the supply-side into the picture, we reflect the fundamental scarcity of global land endowments, thereby requiring land rents to adjust to achieve a global, general equilibrium. This has a strong impact on the pattern of land use by region and AEZ.

One important dimension of the supply-side of our baseline is the potential for accessing new commercial lands. In order to isolate the impact of forest access on land markets, we also consider an alternative simulation in which this feature of the model is turned off, so that total land area available for commercial activity is fixed over the entire projections period.

Up to this point the experiments all focus on the impact of economic growth on the derived demand for land. However, we also believe that global integration, in the form of increased trade can be an important determinant of the pattern of global land use. In the baseline imports and exports adjust in order to equilibrate the global demand and supply of land. Thus, as we will see, rapidly growing, land scarce regions, such as China, tend to increase imports of land-intensive crops thereby effectively “importing land use”. On the other hand, land-abundant, slower growing economies, such as Australia and New Zealand, will tend to “export” land use. But how important is this inter-regional arbitrage in the services of land? Would land use look very different in a global economy in which agricultural and forestry products were largely non-traded? We explore this issue in our final simulation experiment. Since it is not possible to solve our global general equilibrium model in the complete absence of trade, we adopt a more modest restriction on trade flows. In particular, we eliminate the possibility of firms and households substituting imported for domestic goods in response to domestic scarcity. Thus, if 95 per cent of the wheat consumed by Chinese households is currently domestic in origin, that ratio must be preserved over the course of the baseline simulation under the model specification adopted in our final experiment. Specifically, this final, stylized experiment corresponds to a baseline simulation with zero trade elasticities. The population and productivity growth assumptions are identical across the two simulations. By comparing baseline and alternative experiments, we are able to assess the role of globalization in land use change by the year 2025.

III. Results

Changes in demand for land projected based on the first two stylized scenarios, as well as the baseline, are reported in Table 3. Begin with the top panel of Table 3. The first row reports the cumulative population changes by region from 1997 to 2025. These population growth rates are the highest in the Rest of the World (largely Sub-Saharan Africa) and Middle East and North Africa, followed by South Asia. With perfectly elastic supplies of endowments, the changes in population are translated into changes in demand for land. Within a region, the changes in demand for land across AEZs are very similar and follow closely the population growth rates. They deviate from the population growth rates because of the presence of intermediate inputs and international trade - both of which break the direct link

Table 3. Cumulative Growth in the Demand for Land from 1997 to 2025

(unit: %)

Variable	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAm	WEU	EIT	MENA	ROW
Impact of Population Growth on the Demand for Land											
Population growth	22.99	19.65	2.8	40	46.33	22.74	40.8	-0.74	-3.27	58.63	78.56
Total change in demand for land, by AEZ											
AAEZ1	21.9	15.1	-	-	43.4	21.6	35.2	1.7	1.9	49.0	64.8
AAEZ2	22.2	17.2	-	-	43.4	21.5	34.7	3.5	-0.7	51.3	65.7
AAEZ3	22.5	17.5	3.8	-	43.1	20.2	34.7	3.1	-0.6	46.6	66.7
AAEZ4	22.2	17.6	3.5	33.9	42.8	21.1	34.8	2.7	-0.5	49.4	63.9
AAEZ5	19.6	17.7	3.4	33.7	41.8	20.8	34.6	2.6	-0.7	50.4	65.9
AAEZ6	17.7	16.8	3.6	31.1	42.1	19.9	34.5	2.5	0.5	-	62.5
Impact of Income Growth on the Demand for Land											
Utility	82.72	784.22	126.51	125.74	237.93	64.94	43.16	93.23	177.3	74.88	51.99
Total change in demand for land, by AEZ											
AAEZ1	60.7	288.4	-	-	141.0	44.3	35.8	49.4	111.1	53.7	50.1
AAEZ2	60.6	290.5	-	-	139.8	44.0	36.6	66.8	103.3	48.2	46.0
AAEZ3	60.5	290.5	46.0	-	130.5	49.1	36.6	56.2	102.0	56.2	35.6
AAEZ4	61.5	290.1	39.4	67.9	134.1	45.1	35.6	49.0	102.6	50.4	39.4
AAEZ5	68.0	289.1	35.8	68.6	139.1	46.3	36.5	48.4	103.3	48.3	36.5
AAEZ6	72.1	282.4	40.5	71.1	134.6	50.3	36.0	46.2	106.0	-	45.8
Impact of the Demand Growth and Supply Constraints on Land Use											
AEZ1	0.00	0.01		-		0.54	0.65		0.06	0.00	0.00
AEZ2	0.00	0.23		-		6.86	3.62		1.79	0.02	0.01
AEZ3	0.01	1.02		-		9.81	4.49		1.83	0.07	0.04
AEZ4	0.18	1.03		0.74		2.77	4.89		0.36	0.07	0.37
AEZ5	2.07	1.22		0.93		2.99	8.77		0.76	0.32	0.70
AEZ6	2.62	1.11		1.43		3.94	17.75		1.06	-	1.05

Source: Authors' simulations

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

from consumer demand for food and forestry products to the derived demand for land. The largest increases in land demand are observed in the fast growing population regions: Africa and the Middle East, as well as South Asia.

Now turn to the second panel of Table 3 which shows changes in demand for land when we hold population constant and simply perturb per capita utility by the cumulative growth rate observed over the baseline simulation. As with the first experiment, we render the endowments perfectly elastic such that prices of these endowments - and hence prices of the produced goods and services - do not change. The fastest growth in per capita utility is achieved in rapidly growing China, followed by South Asia. Recall from equation (1) that increased utility causes households to move their discretionary spending away from the lower bound (α_k), towards the upper (β_k). This results in a decline in the share of spending on food and a rise in the share of spending on non-food (including forest products). The 2025 budget shares resulting from this partial equilibrium simulation are reported in the second row of Table 2 and may be compared with the base period shares immediately above them. For example, the crops budget share in China is more than cut in half, whereas livestock/dairy budget share rises slightly. Returning to the second panel of Table 3, we see that, with perfectly elastic supply, land employed in production would expand the most in the low income - fast growing regions - nearly 300 per cent cumulative growth in land requirements in the case of China. Note, however, that this growth is now far less rapid than the overall growth in demand (change in utility in second panel of Table 3), simply because food's overall share in consumers' budgets is falling (Table 2).

Finally, turn to the bottom panel of the Table 3 which displays changes in demand for land under the baseline scenario - when we bring in supply constraints. If we had simply used the land market specification from the standard GTAP model, all of these numbers would have been zero, since the land endowments are fixed in that framework. However, recall that this analysis incorporates the possibility of accessing new lands in regions where inaccessible land is available and land prices are high enough to cover the cost of access. Therefore, the total land use changes by AEZ, reported at the bottom of Table 3, are the direct consequence of accessing unmanaged forests.

Thus, the bottom panel of Table 3 shows that total commercial land area expands in Australia/New Zealand region, but only in AEZ3-AEZ6. In AEZ1 and AEZ2, there is no forestry, so production land cannot expand. Total land in production expands the most in Latin America, followed by North America, where there are sizable tracts of inaccessible forests remaining. To the extent that these previously inaccessible forests are converted to crop land, there will be adverse consequences for greenhouse gas emissions, as the carbon content of the natural forests is released into the atmosphere - either immediately through burning, or more gradually through the harvest and subsequent use of the timber products. This rate of deforestation is a key determinant of CO2 concentrations in the atmosphere, and hence rates of global warming (Sohngen and Mendelsohn (2003), Sohngen *et al.* (forthcoming)).

Now let us look more closely at the drivers of land use change in our baseline simulation. Table 4 reports changes in consumer demand for crops, livestock and forestry. As population and incomes rise, consumer demands for crops, livestock and forestry products also rise in all regions, with the strongest increases in China, followed by South Asia (Table 4). Amongst these three sectors, the strongest growth in demand is predicted for forestry products, which reflects rising demands for furniture, construction and paper products. The production patterns in the baseline scenario are also reported in Table 4. The differential growth rates in consumption and production serve to highlight the importance of intermediate inputs and international trade for these land using sectors. For example, demand for crops in China grows rapidly, while production expands much more slowly in the baseline scenario, with the difference being accommodated through international trade. At the same time, the opposite is observed in the Americas.

These changes in regional trade balances, by commodity, for the baseline scenario are reported in the top panel of Table 5. Here, we see that China is expected to increase its annual net imports of crops by about $279 billion by the end of the baseline projections period. ASEAN, South Asia, High Income Asia and Middle East and North Africa also increase net imports of crops. When combined, this results in a very substantial increase in net crop export requirements from the rest of the world. The largest share of this increase in crops is supplied by North America, followed by Latin America and Europe. North America and Europe are two regions with high rates of technological progress in crops, low population growth rates, relatively low per capita income growth rates and low income elasticities of demand for food. All these factors support expansion of crops exports from these two regions.

The direction of change in the sectoral trade balances for ruminants and forestry is similar to that for crops, but of much smaller magnitude due to their lesser importance in global trade. High Income Asia, ASEAN, South Asia, Middle East and North Africa, as well as Europe, expand net imports of ruminants. This

Table 4. Cumulative Growth Rates in Consumption and Production of Crops, Ruminants and Forestry, from 1997 to 2025

Sector	Scenario	ANZ	China	HYAsia	ASEAN	SAsia	NAM	LAM	WEU	EIT	MENA	ROW
							Consumption					
Crops	Baseline	30	184	10	62	126	30	61	29	79	108	99
	Restricted trade	56	131	-13	18	104	49	75	35	82	89	105
Ruminants	Baseline	61	883	78	105	200	92	113	55	169	144	120
	Restricted trade	71	708	76	89	153	98	119	55	164	105	115
Forestry	Baseline	120	1244	136	207	472	106	91	90	188	169	177
	Restricted trade	111	1216	124	197	462	105	86	90	191	168	174
							Production					
Crops	Baseline	388	88	-28	4	110	253	161	125	94	32	138
	Restricted trade	143	185	14	42	138	126	114	61	94	91	112
Ruminants	Baseline	82	637	38	46	201	106	153	39	142	50	128
	Restricted trade	88	438	64	68	168	109	157	37	134	97	128
Forestry	Baseline	-13	73	20	72	339	-5	80	32	94	44	139
	Restricted trade	20	156	5	26	337	10	57	-1	19	64	85

Source: Authors' simulations

Table 5. Change in Trade Balance, by Sector ($US billions), from 1997 to 2025

	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAm	WEU	EIT	MENA	SSA	Total
						Baseline						
Crops	47	-279	-53	-66	-113	263	91	72	-7	-43	29	-59
Ruminants	3	0	-1	-5	-1	9	3	-3	2	-8	0	-1
NonRuminants	-1	-4	-7	-1	-5	-24	102	-33	-24	-10	-12	-18
PrFood	13	-140	-148	-13	-13	164	157	-13	-10	-80	20	-64
Forestry	0	-32	3	3	-7	-2	5	10	8	-1	9	-4
NatResources	22	-352	-12	-80	-178	-31	4	0	213	322	26	-66
Mnfcing	-36	903	-732	-178	223	414	-202	-562	-79	-159	-42	-449
Trans/Comm	6	131	-48	-20	109	176	-4	119	193	25	-9	678
OthSvces	27	-350	-333	407	71	245	250	-50	-313	-45	74	-17
Total	80	-124	-1331	47	88	1214	405	-460	-17	1	97	0
						Restricted trade						
Crops	7	-13	-8	-13	-9	42	7	3	-10	-15	-4	-12
Ruminants	0	0	0	-1	0	3	1	-3	0	-1	0	0
NonRuminants	-1	-2	1	-1	0	-3	9	-3	-1	0	0	-2
PrFood	10	-21	-36	-30	-7	57	98	-72	-23	-18	16	-25
Forestry	0	-1	3	-1	-2	0	1	2	0	0	-1	0
NatResources	12	-108	-84	-70	-109	-69	-3	-19	129	264	21	-35
Mnfcing	4	69	-557	-33	143	698	15	-476	-120	-196	38	-414
Trans/Comm	14	59	-28	2	88	166	12	92	95	2	-5	498
OthSvces	13	-108	-122	235	46	100	179	-173	-120	-70	10	-10
Total	60	-127	-831	90	151	994	321	-648	-51	-34	75	0

Source: Authors' simulations

Table 6. Impact of Global Economic Integration on Annual Growth Rates in Land Rents from 1997 to 2025, per cent

Land using sector	Scenario	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAm	WEU	EIT	MENA	ROW
All sectors	Baseline	6.91	5.26	-0.87	2.53	6.92	5.75	4.66	2.64	2.71	2.43	5.25
	No access	7.08	5.41	-0.74	2.64	6.96	6.02	5.11	2.79	2.81	2.53	5.35
	Restricted trade	2.87	9.05	3.72	6.10	7.87	2.48	2.92	0.73	2.04	5.12	3.71

Source: Authors' simulations

expansion is satisfied by exports from Americas and Australia/New Zealand. Rapidly growing demand for forestry in China and South Asia results in increasing imports of forestry by these regions. This imbalance in forestry trade is met by increasing exports from Western Europe, the natural resource rich Economies in Transition, and Latin America.

Now let us turn to our alternative simulations in which we restrict the degree of global economic integration. Results from the restricted trade scenario are reported in the lower panel of Table 5. In this simulation imported and domestic use of each commodity grow in fixed proportion. That is, China and South Asia cannot increase absorption of imported crops without increasing absorption of domestically produced crops - in effect the extent of global economic integration of goods and services is frozen at base period levels. Before considering these entries in detail, return to Table 4 which reports consumption and production increases under the restricted trade scenario. Now crop consumption in China grows much less rapidly (131 per cent vs. 184 per cent cumulative growth), whereas production must grow much more rapidly (185 per cent vs. 88 per cent cumulative growth) than under the baseline scenario in order to satisfy domestic demand in the absence of increased economic integration. The mirror image of this result is shown in the column for Australia/New Zealand, where consumption is now higher, and production growth far lower, than under the baseline scenario. Freezing the extent of global economic integration has significant consequences for the patterns of consumption and production of land-using commodities.

The changes in trade balance by commodity reported at the bottom of Table 5 underscore these effects. In the restricted trade scenario, the increases in net imports of crops by China, South Asia, ASEAN and High Income Asia are much smaller. Indeed, their combined trade balance for crops is now $468 billion higher compared to the baseline scenario. This, in turn, reduces the net export requirements on the part of the Americas, Western Europe and Australia and New Zealand. Similarly, ruminant, forestry and food imports into Asia are much lower. When importers cannot substitute away from more expensive domestic production towards imports, domestic production in Asia must expand, and consumption must be reduced (through higher prices).

What is the effect of the global economic integration on the land market? The most direct measure to consider is the change in aggregate land rents. These figures are reported in Table 6 as average annual growth rates in average land rents across the agriculture and forestry sectors. These vary by region, and they only reflect conditions in agriculture and forestry. In the baseline scenario, pressure on land rents is very high in the agriculture and forestry exporting countries, as they seek to fill the gap between consumption and production of land-intensive goods in the rapidly growing, densely populated markets - particularly in Asia. In Australia and New Zealand average across sectors annual growth rate in land rents is 6.9 per cent over the projections period.

The growth rates in land rents in the Americas are somewhat slower, but still very high. And these growth rates rival those in the rapidly growing economies of China and South Asia themselves. In the slower growing, more mature economies of High Income Asia, where the income-responsiveness of consumer demand for food is weak and agricultural productivity growth rates are very low, land rents are flat.

The second row in Table 6 reports the annualized rate of change in land rents when investment in the access of virgin forests is not permitted. With the aggregate supply of land fixed, land rents rise more rapidly worldwide - but the increment to the baseline is highest in those regions where there is a substantial role for forest access in the baseline: Australia/New Zealand, North America and Latin America.

The final row of results in Table 6 explores the impact of freezing the degree of economic integration in the commodity markets at base period levels. Now there is a much greater divergence in land rents between the net exporting and net importing regions. Aggregate land rental rates in Australia/New Zealand rise by less than 3 per year and growth is even slower in North America. On the other hand, China’s land rents grow at the brisk pace of more than 9 per year, as local production is called upon to satisfy most of the growth in domestic demand. Land rents also rise more strongly in High Income Asia, as imports can no longer be used to offset potential declines in inefficient domestic production. Clearly, trade is very important force influencing land markets.

A Detailed Look at Land Use: Having ascertained that global economic integration through trade has very large impact on the aggregate demand for land, it is interesting to take a closer look at the pattern of land use induced by this form of globalization. We do so by examining land use by AEZ, as reported in Table 7. Entries in this table are the percentage change in land use in each category, weighted by the economic importance of that category (i.e. land rents) in a given AEZ. Thus, the changes across uses (agriculture vs. forestry) within a given AEZ are directly comparable. If the positive increment in use exceeds the negative one, then there is an expansion in total area in use within the AEZ as a consequence of forest access (recall Table 3, bottom panel). We focus here on the trade-off between land in agriculture vs. land in forestry, as that is the most important distinction from the point of view of net greenhouse gas emissions.[7]

Consider the first column in the top panel of Table 7. This reports the rental share-weighted percentage change in land use in agriculture and forestry in Australia and New Zealand, by AEZ, in the baseline simulation. Clearly there is a strong movement of land from commercial forestry into agriculture, as well as conversion of inaccessible forests onto agricultural use - particularly in the high productivity AEZs (5 and 6) (Table 3). In China, there is a small amount of forest access that enables both agriculture and commercial forestry activities to expand marginally in most AEZs. In High Income Asia, low productivity growth in agriculture (Ludena *et al*. (2007)) results in a shift in land into forestry production. In the Americas there is fairly substantial access of new forest lands, as well as a shift of commercial activity from forestry to agriculture - particularly in North America. Western Europe does not have the same reserve of currently inaccessible forests to draw on for new lands. However, like North America, relatively high agricultural productivity projections (Ludena *et al*. (2007)) result in a shift of land from commercial forestry into agriculture. The opposite is the case in the EIT, MENA and ROW regions.

The lower panel of Table 7 shows the impact on land use under the restricted trade scenario, whereby the extent of global economic integration in goods and services markets is frozen at base period levels. The first thing to note is that these numbers are quite different - varying both in magnitude and in sign. This is hardly a surprise, given the significant difference in aggregate land rents, as reported in Table 6. There are several distinct patterns evidenced in a comparison of the two sets of results in Table 7. First of all, by limiting trade opportunities, the high-productivity agriculture, Asia-exporting regions of Australia/New Zealand and North America experience much smaller expansion in agricultural area. This is accompanied by smaller reductions in commercial forestry activity. On the other hand, the fast-growing Asian economies are forced to devote more land to agriculture. This leads to numerous sign reversals, with country/AEZs now expanding agricultural activity rather than contracting. The same is true for the Middle East and Africa (MENA and ROW). In Western Europe, the no trade scenario marginally

[7]The movement of land from forestry into agriculture accounts for a large share of the accumulated CO2 concentrations in the atmosphere. Meanwhile, increasing land cover in forestry offers potential carbon sequestration benefits (Sohngen *et al*. (forthcoming)).

Table 7. Revenue Share-weighted Cumulative Growth Rates in Demand for Land by AEZ from 1997 to 2025

Agro-Ecological Zones	ANZ	China	HYAsia	ASEAN	SAsia	NAm	LAm	WEU	EIT	MENA	ROW
Baseline											
Agriculture											
AEZ1	0	0.01			-0.16	1.94	2.1	0	-4.48	-1.77	-1.56
AEZ2	0	0.23			-0.1	8.36	6.71	5.1	-2.58	-1.11	-1.14
AEZ3	0.21	0.85	-8.97		-0.31	18.1	7.46	5.29	-2.64	-2.55	-0.26
AEZ4	2.84	0.8	-6.54	0.39	-0.6	6.32	6.3	2.77	-4.41	-2	-0.28
AEZ5	22.26	0.66	-3.62	0.39	-1.43	8.54	11.52	2.47	-2.95	-1.43	0.21
AEZ6	29.01	-0.18	-6.76	-0.84	-1.29	15.03	19.38	1.22	-6.51		-0.29
Forestry											
AEZ1	0	0			0.16	-1.37	-1.42	0	4.76	1.8	1.58
AEZ2	0	-0.002			0.1	-1.38	-2.89	-4.86	4.48	1.14	1.16
AEZ3	-0.2	0.16	9.86		0.31	-7.03	-2.77	-5.02	4.6	2.69	0.3
AEZ4	-2.58	0.23	7	0.35	0.6	-3.34	-1.33	-2.7	4.99	2.1	0.65
AEZ5	-16.51	0.56	3.75	0.54	1.45	-5.12	-2.46	-2.41	3.82	1.78	0.49
AEZ6	-20.45	1.29	7.24	2.28	1.3	-9.64	-1.36	-1.21	8.1		1.35
Restricted Trade Scenario											
Agriculture											
AEZ1	0	0.01			0.18	1.56	1.98	0	5.54	1.02	2.37
AEZ2	0	0.3			0.11	7.32	6.32	8.18	3.87	0.54	2
AEZ3	0.14	1.16	1.42		0.27	13.63	7.06	6.26	3.71	1.28	0.83
AEZ4	1.84	1.18	0.91	1.61	0.55	4.94	6.03	3.11	3.02	0.92	2.08
AEZ5	11.85	1.4	0.46	2.31	1.31	6.41	10.96	2.76	2.82	1.06	1.69
AEZ6	13.65	1.33	0.95	7.56	1.12	10.29	18.65	1.37	6.01		3.12
Forestry											
AEZ1	0	0			-0.18	-1.05	-1.31	0	-5.2	-1.01	-2.31
AEZ2	0	-0.04			-0.11	-0.92	-2.62	-7.56	-2.21	-0.51	-1.95
AEZ3	-0.13	-0.02	-1.4		-0.27	-4.03	-2.49	-5.89	-2.03	-1.16	-0.78
AEZ4	-1.64	-0.03	-0.9	-0.8	-0.55	-2.27	-1.18	-3.01	-2.63	-0.81	-1.69
AEZ5	-8.79	-0.04	-0.45	-1.27	-1.29	-3.43	-2.15	-2.69	-2.1	-0.58	-0.99
AEZ6	-9.76	-0.09	-0.94	-5.59	-1.11	-6.03	-1.09	-1.35	-4.79		-2.03

Source: Authors' simulations

accentuates the movement of land from forestry to agriculture, as Europe is forced to satisfy more of its own demands for food. On the other hand, there is a strong reversal in the direction of land movement between forestry and agriculture in Eastern Europe and the Commonwealth of Independent States region (EIT).

Figures 1 and 2 offer a visual summary of the differences between the top and bottom panels of Table 7 for forestry and agriculture, respectively. In particular, these figures map the deviation from baseline in cumulative land use change, by region/AEZ, due to trade. For example, in the case of land use for commercial forestry production in AEZ6 of the Australia/New Zealand region, the baseline rental share-weighted percentage change is -20.45 per cent (Table 7, top panel). Deducting the restricted trade outcome (-9.76 per cent) from the baseline value, we obtain -10.69 per cent, which is the minimum entry in Figure 1, appropriately shading the Southeastern corner of Australia and much of New Zealand. From this figure it is clear that global economic integration through international trade leads to a substantial shift in forestry activity from Australia/New Zealand and the Americas into Northern Europe, Central Asia, and even parts of Africa. On the other hand, Figure 2 shows that increased international economic integration through trade leads to strong increases in agricultural activity in Australia/New Zealand and the Americas, with the largest reductions coming in Asia. In short, global economic integration has a very important impact on the pattern of land use around the world.

IV. Summary

Land use change - in particular deforestation - has contributed substantially to current greenhouse gas concentrations in the atmosphere. In addition, agriculture and forestry have a potentially very significant role to play in stabilizing greenhouse gas concentrations. Yet the role of global economic integration in driving land use change is poorly understood. This paper aims to shed light on this complex topic. We do so by utilizing a dynamic general equilibrium model that has been modified to incorporate the most important economic features driving global land demand and supply. These include: an econometrically estimated, international demand system for commodities, a new data base and modeling framework that characterizes land use by Agro-Ecological Zone, and an explicit model of investment which drives the access of non-commercial forests in each region of the world.

We use this model to simulate a baseline period from 1997 to 2025 over which land rents world wide rise sharply and the global allocation of land between agriculture and forestry changes rather significantly in some regions. Through a series of restricted simulations of the model, we are able to isolate the impact on land markets of the following elements of growth and globalization: (i) population growth, (ii) real income growth, (iii) access of forest lands, and (iv) international trade. Of the two demand-side factors, real income growth is shown to be the most important. The potential for accessing new forest lands plays a small role in dampening the growth in global land rents.

International trade plays a very substantial role in mediating between the land-abundant, slower growing economies of the Americas and Australia/New Zealand, and the land-scarce, rapidly growing economies of Asia. If the degree of integration in the global economy is frozen at base period levels, a significant divergence in agriculture/forestry land rents arises across regions. And trade also plays an important role in determining where deforestation is likely to occur. In summary, when combined, the forces of globalization are expected to play a large role in determining the pattern of land use change.

We close this paper with a discussion of some of the most salient limitations of our approach. First, we found that income growth in poor countries will generate substantial increases in food demand and the demand for agricultural land. It should be noted, however, that we do not take into account potential changes in income distribution. We have implicitly assumed that incomes of all households in each region rise in equal proportions. Second, it is assumed in the model that only crops, ruminant livestock and forestry compete for land, while all other sectors do not use land. Thus, residential, commercial and recreational demands for land are omitted from the baseline. Another important component of the contemporaneous land use baseline, absent from current work, is demand for biofuels. Finally, we do not believe that present implementation of the land use component of this model is sufficiently detailed. While the 11 region/6 AEZ/crop-livestock-forestry breakdown does yield some interesting heterogeneity across AEZs, in future work, we would like to use a larger number of AEZs as well as more crops in order to capture the heterogeneity of land use across AEZs. For example, reducing the Length of Growing Period in each AEZ from 60 to 10 days, and distinguishing Boreal, Temperate and Tropical climates would yield a total of 108 AEZs. We believe this would be manageable in future analyses. This would considerably enrich the physical detail of the ecological constraints on production in the model at relatively low cost.

Received 30 September 2007, Revised 7 March 2008, Accepted 8 April 2008

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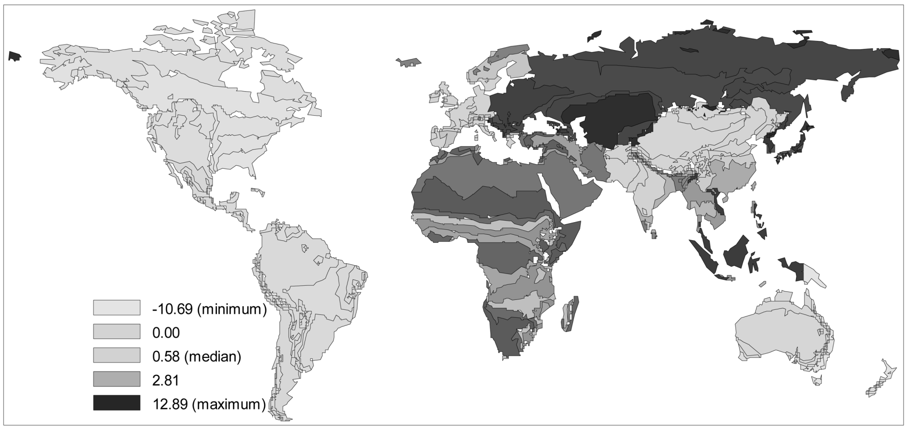
Appendix

Aggregation of GTAP Regions

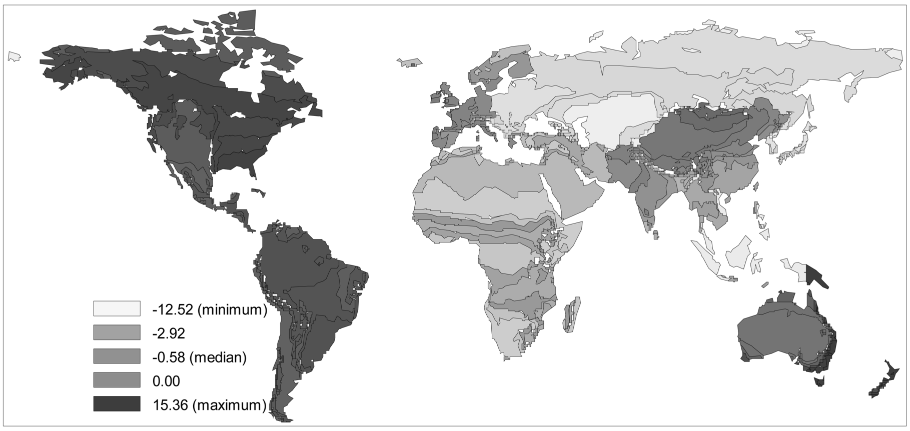
Region	GTAP regions
Australia and New Zealand (ANZ)	Australia, New Zealand
China (CHN)	China
High Income Asia (HYAsia)	Hong Kong, Japan, Korea, Taiwan
Association of Southeast Asian Nations (ASEAN)	Indonesia, Malaysia, Philippines, Singapore, Thailand, Viet Nam
South Asia (SAsia)	Bangladesh, India, Sri 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

Figure 1. Impact of Global Economic Integration through Trade on Land Use Change: Revenue Share Weighted Changes in Land Used in Forestry, per cent (Difference between baseline and restricted trade scenarios)



Source: Authors' simulations

Figure 2. Impact of Global Economic Integration through Trade on Land Use Change: Revenue Share Weighted Changes in Land Used in Agriculture, per cent (Difference between baseline and restricted trade scenarios)



Source: Authors' simulations