An Integrated Global Land Use Data Base for CGE Analysis of Climate Policy Options*

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1. Introduction

The preceding two chapters[1] of this volume have discussed physical and economic data bases for global agriculture and forestry, respectively. These form the foundation for the integrated, global land use data base discussed in this chapter. However, in order to utilize these data for global CGE analysis, it is first necessary to integrate them into a global, general equilibrium data base. This integration is the subject of the present chapter.

The most widely used, global economic data base for CGE modeling is GTAP: the Global Trade Analysis Project data base. This is released every 2 – 3 years, and, at the time this book was being written, GTAP 6 was the most current version, benchmarked to the year 2001 (Dimaranan, 2007). This fits nicely with the global agricultural data bases of Ramankutty et al. (2006) and Monfreda et al. (2006), as they refer to data from several years centered around 2000. The same is true of the forestry data base of Sohngen et al. outlined in Chapter 3[2].

The GTAP data base reports estimated economic flows in the year 2001. When it comes to the global land use data base, the relevant flows will be the land rents associated with a given economic activity, taking place in a given Agro-Ecological Zone (AEZ). Ideally, where an active land rental market is present, we could observe land rents, by use and AEZ. It would then be a simple matter of multiplication (land rents/ha. * total ha.) to obtain land rents in each activity/AEZ. However, such data are not readily available in most countries, and where it is

[1] GTAP Working Papers No. 40 and No. 41
[2] GTAP Working Paper No. 41

available, it is not grouped by detailed use or AEZ. In addition, since it supports global, economy-wide analysis, the GTAP data base must satisfy a number of key equilibrium conditions, including: costs = revenues, and national supplies = domestic uses plus export demands for each good or service produced in all 57 sectors of each of the 87 regions in the version 6 data base, national income is exhausted on national expenditures, and global savings = global investment. Because of these requirements, we cannot simply go into the data base and alter a given set of flows (e.g., returns to land in crop production) without destroying one or more of these equilibrium conditions. For all of these reasons, our approach will instead be one of "sharing out" existing land rents in the GTAP data base, according to the information provided in the previous two chapters[3].

In the following sections, we describe how we allocate the GTAP land rents across AEZs. As our data sources and procedures differ for crops and livestock, we discuss the associated procedures first for crops and then for livestock. We then describe how we adjust sectoral value-added to preserve the estimates of primary factor shares from literature, given that we assumed in section the indirect use of land by non-ruminant sectors. Forest land rent allocation is described next, followed by an overview of the final data base, validation, evaluation, and implications for future research.

2. GTAP Cropland Rent Data By 18 AEZs

Harvested area vs. physically cultivated area: While it might seem, at first glance, that physically cultivated area is preferred to harvested area in building this global data base, this is not the case. In the GTAP economic accounts for each country, land rents are generated from the activity (or use) on a given parcel of land during the calendar year. Therefore, we are interested in the value of the land in production over the course of the entire year, not just one season.

[3] GTAP Working Papers No. 40 and No. 41

Consider the case of a farmer in Southern China who grows early double-crop rice from March to July, and then grows "catch crops" (fast growing crops, e.g., vegetables) over the rest of the calendar year. The GTAP Input-Output data identify sectors in terms of crops (e.g., the paddy rice sector, the cereal grain sector, the oil seeds sector, etc.), not hectares of land, per se. So the land rents of the crop sectors should accrue to the harvested area, by crop. In this particular example, we allocate the land rent generated, due to the growing of paddy rice, to the GTAP paddy rice sector, while we allocate the land rents generated due to the growing of vegetables to the GTAP vegetables sector, both within the same AEZ. Thus, while the harvest-based land rents can be allocated to GTAP sectors within a given AEZ, the physically cultivated-based land rents cannot.

An additional argument in favor of working with harvested area is due to the fact that land based emissions (e.g., CH_4 emissions from paddy rice cultivation) are often tied to the harvested area (IPCC 1996 Guidelines). For example, for given soil conditions, prices and crop types, fertilizer use is normally proportional to harvested area. So, we conclude that harvested area is a useful, as well as a practical basis for developing the GTAP land use data, rather than the crop-specific physically cultivated area. In those cases where cultivated area is preferred (e.g., soil N_2O and soil CO_2 emissions), we can make side calculations based on available data on cropland cultivated area.

Procedures for Splitting out Land Rents: We split the GTAP sectoral land rents into 18 AEZs according to the AEZ-specific production shares as derived from the data provided by MRF and BTHM (chapters 2[4] and 3[5]). Recall Table 1 from Chapter 2 which reports the mapping from FAO's 175 crops (Set *FAO*) to GTAP's 8 crops sectors (Set *crops*). This mapping is used in conjunction with the following formula to split the GTAP sectoral land rents into 18 AEZs (L_{ca}). For region r,

[4] GTAP Working Paper No. 40
[5] GTAP Working Paper No. 41

$$L_{ca} = L_c \{ \sum_{i \in FAO=c} P_i Y_{ia} H_{ia} / \sum_{a \in AEZ} \sum_{i \in FAO=c} P_i Y_{ia} H_{ia} ,$$
$$\forall c \in crops, i \in FAO$$

where:

L_{ca} is the land rent accrued to GTAP crop sector c in AEZ a;

L_c is the total land rent of GTAP crop sector c, (no AEZ distinction: header VFM in GTAP);

P_i is the per-ton price of FAO crop i (invariant to AEZs, sourced from FAOSTAT)

Y_{ia} is the yield (ton/1000ha) of FAO crop i in AEZ a, (sourced from MRF); and

H_{ia} is the harvested area of FAO crop i in AEZ a, (sourced from MRF).

An illustration of the GTAP crop sector land rents by 18 AEZs: Table 1 shows world total value-added, including land rents (header "VFM", from the GTAP v6.0 database) for the GTAP crop sectors (sectors 1 to 8) split into 18 AEZs. The data show that most of the world's crops (value-basis) are grown in the tropical and temperate AEZs (1 - 12). The largest total crop land rents, an estimated $50,416million, are generated in AEZ 10 – temperate climate with LGP of 180 – 240 days. This is followed by the longer LGP temperate AEZs: 11 and 12, then AEZs 9, 8 and finally tropical AEZ 6. The values of land rents generated in the boreal zones are an order of magnitude smaller, and essentially negligible for the shortest growing periods.

Figure 1 offers a visualization of the cropland rent allocation among AEZs, by GTAP crop sector. This reveals some interesting points about specific crops. For example, we see that paddy rice ("pdr") is mostly grown in AEZs with longer LGPs (e.g., AEZs 3 – 6, and 11 - 12). Vegetables, fruits and nuts ("v_f") are a high value crop sector and therefore dominate the total land rents picture in most of the AEZs. This can be explained by their shorter cultivation period, which allows for multiple cropping, the widespread irrigation of fruit and vegetable production, as well as the potential for greenhouse production.

The dominance of the "v_f" sector in the total cropland rent distribution within each AEZ is further emphasized in Figure 2, which shows a share-based breakout of total land rents in each of the Agro-Ecological Zones, world wide. In this figure, the totals all sum to 100% and we simply see the relative economic importance of each crop within a given AEZ. From this figure we also see the relatively greatly importance of wheat and coarse grains in the boreal AEZs, followed by the temperate zones, with relatively little contribution from these crops sectors in the tropical Agro-ecological Zones.

3. GTAP Livestock Sector Land Rent Data By 18 AEZs

Methodology: There are four primary livestock production sectors in the GTAP data base: ruminants (ctl = cattle, sheep and goats), dairy production (rmk), wool (wol) and non-ruminants (oap = pigs and poultry). In the case of non-ruminants, we assume that the sector does not use substantial amounts of land directly in production.[6] By their very nature, what they consume has already been produced using land somewhere else in the system (e.g., feedgrains). As production intensifies, these animals are confined to a facility which is more nearly akin to a manufacturing sector than a land-using sector. Therefore, we abstract from the direct competition for land between non-ruminant production, ruminant production, crops and forestry. Of course there is indirect competition, insofar as increased production of poultry, for example, will boost the feed requirements and hence increase the demand for land in feed grains. However, we capture this competition via the intermediate demand for feed in non-ruminant production in the CGE model.

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[6] Since we assume the "oap" sector does not use land directly we must take away GTAP land rents in this sector and augment payments to labor and capital by the amount of these land rents to keep the total costs of the two sectors correspond to their total revenue. To preserve the country-specific shares of agriculture value-added, as well as the agriculture-wide labor/capital ratio, we scale up land rents of the other agriculture sectors (i.e., crop sectors, “ctl”, “rmk” and “wol” sectors) by amounts summing up to the total land rents of the non-ruminants sector, while scaling down payments to labor and capital in these other agriculture sectors accordingly.

In order to estimate land rents by AEZ for the crops sectors, we capitalized on the MRF data base on crop harvested area and yields, by crop and AEZ. However, in the case of the livestock sectors, we do not have a similar allocation of production by AEZ. Therefore, we are forced to resort to a different approach. From the REMF land cover data base, we know how much total grazing land there is in each AEZ. To this, we seek to add an estimate of the relative productivity of these different land in all types of ruminant production across AEZs. The most natural thing is to use an index of crop yields as a predictor of land productivity in forage. Since there is no single "forage crop" sector in our data base, we use the average yield of GTAP coarse grains sector (i.e., "gro") in each the AEZ/country, multiplied by the SAGE pasture land cover hectares of the 18 AEZs, to split the GTAP livestock sectors' land rents into 18 AEZs. Since we do not have independent estimates of land used for dairy production vs. land used for cattle, sheep and goats, the aggregate land rents within each of these sectors are shared out across AEZs in the same proportions for each of the sectors. (I.e., if AEZ 8 has 20% of the beef land rents in Australia, it will also have 20% of the dairy land rents in that country.)

A summary of the GTAP livestock sector land rents by 18 AEZs: Table 2 shows world total land rents (header "VFM", from v6.0 database) of the three GTAP land-using livestock sectors: ruminants, dairy and wool, split into 18 AEZs. Note that the distribution of land rents across AEZs is now much more even than was the case with crops. Indeed, AEZ7 has slightly higher land rents than AEZ10, which clearly dominated in the case of crops. Note also that the tropical AEZs 3 – 6, and the boreal AEZs 13 - 15 show relatively high levels of livestock land rents, worldwide. This reflects the fact that livestock production is more amenable to the shorter growing seasons, and sometimes more adverse circumstances, characterized by these AEZs.

4. GTAP Forest Land Rent Data By 18 AEZs

We now turn to the estimation of GTAP-consistent land rents in the forestry sector, based on the work of Sohngen et al. reported in Chapter 3[7]. In the standard GTAP data base, the land share in forestry is unrealistically small – about 7% of value added. This share of land in forestry was 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 measurement of land rents. Therefore, a new estimate is needed. We focus our attention on the *share* of land rents in total costs (sales) so that the estimate is portable across data sets as well as over time.

In order to estimate the share of land rents in total costs, we begin with the total hectares in forestry (see Chapter 3). From this, we must deduct the inaccessible hectares, to obtain the currently accessed land in forestry production. (Inaccessible land will not generate land rents, by definition.) Accessible forest land, by management class, is then multiplied by estimated forest land rents, which vary by management class (see above).

In order to estimate total costs, we assume that sales are fully exhausted on costs (zero profits – in keeping with the standard CGE model assumptions). Sales are estimated as timber production multiplied by quality adjusted timber price, as obtained from the Global Timber Supply Model (Sohngen and Mendelsohn). On this basis, Gouel and Hertel (2006) find that, on a global basis, the estimated forest land rental share amounts for 38% of product sales.

In equilibrium, land rents should always be less than total sales in all AEZs/regions. However, this is not always the case in the estimates of Gouel and Hertel (2006). Furthermore, for incorporation into the GTAP data base, the land rental share in total costs must be less than the value-added share. Not surprisingly, this is violated even more frequently than the land rents < costs condition. There are many reasons why this might arise, include disequilibrium, as well as mis-estimation of land rents, accessible forest area, product sales or price. Rather than making somewhat arbitrary allocations on a region-by-region basis, we choose the following approach. First, compute the share of land rents in value-added at a global level. In the version 6 data base,

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the share of value-added in global forestry costs is 62%, so the share of land in global forestry value-added is 0.38/0.62 = 61%. We then assume this relationship holds in each and every country, so that, given value-added in each region, we can now compute forest land rents at the national level as simply being equal to 61% of this value.

We derive the AEZ-specific forestry land rent shares from the Sohngen et al data on timberland land rent (by tree type and by country), multiplied by timberland area by tree type, by age, by AEZ, and by country. Then we split the forestry land rent into 18 AEZs according to these forestry land rental shares by AEZ. Table 3 shows world total value-added (header "VFM", from v6.0 database) of the GTAP forest sector ("frs") split into 18 AEZs. Note that the longer length of growing period AEZs tend to have higher aggregate land rents in the tropical and temperate zones, but total land area under commercial forestry comes into play as well, and, as with crops, AEZ10 is shown to be a very large source of forestry land rents in the world.

5. *Validation of the GTAP AEZ Land Rent Data*

The construction of the GTAP AEZ land rent data base has involved a host of different assumptions. So it is natural to ask: how does this compare with observed land rents, when the rents themselves are divided by the hectares of observed crop and pasture land cover? Ideally we would like to undertake such a comparison for all regions in the GTAP data base. However, we only have the data of observed land rents for the U.S. so far. Therefore, we present here the comparison of per hectare land rents between the GTAP land rent data and the observed cash land rent only for the US, using data published by the U.S. Department of Agriculture (USDA).

Figure 3 shows the data available from the USDA for crop and pasture land rents by state, as well as the national average, in the year 2001. Note that there is tremendous variation in cropland rents – with the highest figures in the states where irrigated cropland is predominant. Indeed, the cropland data for Arizona (AZ), Washington (WA) and California (CA) cover only irrigated land.

The overall average U.S. cropland cash rent is $175/hectare, while the average pasture land cash rent is $23/hectare—about 13% of per hectare cropland rents[8].

To compare these estimates to those implied by the GTAP-AEZ data base, we must first perform some intermediate calculations. This is done in Table 4. The first pair of columns in this table report total land rents, by AEZ, in the modified GTAP data base, for both crops and livestock. In order to compute land rents per hectare, we must divide these figures by the REMF land cover data in the second pair of columns in Table 4. This yields the estimated land rents per hectare, by AEZ, reported in columns E and F. Ignoring the boreal AEZs, which show very little area, and are likely influenced by greenhouse production, we see crop land rents varying between $177/ha. and $244/ha., with livestock land rents in the range of $21 - $30/ha. For all crop land in the US, the estimate is $205/ha. – somewhat higher than the $175/ha. estimated by USDA. In the case of grazing land, the aggregate estimate from our data is virtually the same as that of USDA -- $23/ha.

It is also of interest to consider the relative land rents for crop and livestock activities within a given AEZ. This ratio is reported in the next column of Table 4. Not surprisingly, the overall ratio of pasture land rents to crop land rents in our data base is slightly lower than from USDA, 0.11 vs. the USDA ratio of 0.13, since our cropland rental estimate is higher. However, this varies widely across the temperate AEZ's in the GTAP-AEZ data base, ranging from 0.09 in AEZ9 to 0.16 in AEZ 11.

In light of the fact that we do not have cash rents for the US, disaggregated by AEZ, it is useful to compare our estimates of land rents to those from another source. Towards this end, the latter columns of Table 4 report per hectare land rents from Mendelsohn *et al.* (2005) for the United States. Those authors' aggregate land rents for the entire US are quite a bit lower than the

[8] This USDA cash land rent finding was provided by Alla Golub.

GTAP-AEZ and USDA estimates: $118/ha. for crops and $12/ha. for grazing. However, the ratio of relative land rents in grazing vs. crops estimated by Mendelsohn *et al.* (2005) – 0.11 -- is the same as for GTAP-AEZ).

However, unlike the USDA estimates, Mendelsohn's estimates can be mapped to AEZs and this has been done. This mapping gives us a basis of comparison for the distribution of land rents across Agro-Ecological Zones. Here we see greater differences between the two data bases, with the Mendelsohn et al. cropland estimates ranging from $68/ha. in AEZ7 to $196/ha. in AEZ10. Their pastureland rental estimates range from $8/ha. in AEZ7 to $47/ha. in AEZ 11.

Figures 4 and 5 report the distribution of total land rents in each AEZ of the US for the two data bases, for crops and livestock, respectively. This is a comparison of the relative importance of the agricultural land endowment, by AEZ for the US. Begin with crop land rents, by AEZ (Figure 4). The first thing to note is that, with the exception of AEZ 11, the GTAP-AEZ land rents are higher for all AEZs. Also, the same broad pattern of relative land rents, by AEZ applies in the two data bases. The largest discrepancy between the two is for AEZ7, the short growing period, temperate AEZ. In the case of livestock land rents, the bulk of the divergence occurs in AEZ7, where Mendelsohn et al. estimate a relatively low land rental rate for pastureland, but the GTAP-AEZ productivity estimate, based on coarse grains yield, is much higher. This would appear to highlight a significant weakness in the GTAP-AEZ methodology for imputing relative productivity of land in grazing, across AEZs. A more direct measure of productivity would be desirable. (This will be discussed further below.) The broad pattern of livestock land rents across the other AEZs is similar between the two data bases.

Before proceeding, we need to say something about the extremely high per hectare land rents in the boreal AEZs – particularly AEZs 15 and 16. Firsly, note that the total area involved is very small (column A in Table 4), so this is not a serious problem in the aggregate. Nonetheless, it is worthwhile considering why this problem arises. To do so, return to the methodology for constructing the GTAP-AEZ data base. We start with information on land use, by AEZ. This is combined with estimates of total land rents, based on the average share of land rents in crop production for the entire United States, and value of output from MRF, in order to infer total land rents by hectare. Not surprisingly, there is a fair amount of high value vegetable production undertaken in the boreal zone (primarily Alaska) – largely under greenhouses. This leads to a relatively high apparent land rent. Yet the total number of hectares is small. So the implied per hectare land rent is very high. However, this is not really a proper estimate of land rents, as the greenhouse-based production requires considerable infrastructure in order for the land to be productive. Indeed, without these improvements, land productivity would be very low. So these gross errors for the boreal zone are largely a function of our inability to separate returns to capital and land in greenhouse production. In order to overcome this problem, we need a more direct approach to the estimation of land rents in agriculture. A natural approach would be to build on the work of Mendelsohn *et al.* (2005), applying their estimated land rents by AEZ to the total hectares in the land use data base. However, to date, we have only been able to obtain these data for the US. Once such a data base becomes available for the world as a whole – or even for the majority if the countries in the world, it will clearly be preferable.

While we do not have independent data with which to validate the GTAP-AEZ land rental estimates for countries other than the US, it is still instructive to examine the pattern of land rents across these countries. The total farm land rent, agricultural land area and implied average land rental rates for each of the 87 GTAP-AEZ regions in GTAP v.6 are reported in Table 5, in descending order (highest to lowest per hectare land rents). The results are broadly as expected. The highest land rents arise in the densely populated, high income countries of East Asia: Hong Kong, Korea and Japan, as well as some of the smaller, high income countries of Europe, including Switzerland, Netherlands and Denmark. The lowest land rents per hectare arise in Sub-Saharan Africa – amounting to scarcely more than $1/ha. in Botswana, which is sparsely populated and dominated by the Kalahari Desert – an arid area, much of which is extensively grazed by livestock. Australia – a continent dominated by desert and extensive grazing as well, is not far behind at $4/ha. average land rent.

6. *Summary and Conclusions*

In summary, creating a global land use data base is an ambitious exercise. Fortunately, we now have such data bases available for agriculture and forestry, as highlighted in the two preceding chapters[9]. However, even with these data in hand, incorporation of this information into a globally consistent, general equilibrium framework poses significant challenges. This chapter has outlined one approach to this problem. It involves taking the aggregate agricultural land rents in the GTAP data base as given and sharing them out based on estimates of productivity (yields) across crops and AEZs. A preferable approach would involve direct observation of land rents, by crop and AEZ, but unfortunately these data are not currently available on a global basis. However, as the work of Mendelsohn et al. progresses, there may be greater scope to draw on this research to construct an improved, globally consistent data base of land rents in agriculture and forestry.

In the case of livestock, our estimates could be improved upon by capitalizing on recently available data reporting the geographic distribution of livestock output, worldwide (GET REFERENCE FROM NAVIN). This would substitute for our current assumption that the relative productivity of a given AEZ in livestock production, within any given country, is proportional to that AEZ's productivity in feedstuff production.

Finally, there is the more fundamental issue of how the AEZs are defined. Ideally we would like to eliminate AEZ's and simply work with each country's land endowment fully disaggregated at the grid-cell level. However, this poses significant computational and data

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management challenges for the CGE models and likely remains a few years off for the majority of CGE analyses at the global level. In the meantime, some experimentation with further disaggregation of AEZs (e.g., using shorter Lengths of Growing Periods) would be useful.

7. References

Alexandratos, N. (1995). *World Agriculture towards 2010,* 488 pp., Food and Agric. Organization of the United Nations, Rome, Italy.

Bonan, G.B. (1999). Frost followed the plow: impacts of deforestation on the climate of the United States, *Ecological Applications*, *9* (4), 1305-1315.

Bonan, G.B. (2001). Observational evidence for reduction of daily maximum temperature by croplands in the Midwest United States, *Journal of Climate*, *14* (11), 2430-2442.

Brovkin, V., A. Ganopolski, M. Claussen, C. Kubatzki, and V. Petoukhov. (1999). Modelling climate response to historical land cover change, *Global Ecology and Biogeography*, *8* (6), 509-517.

Darwin, R., M. Tsigas, J. Lewandrowski and A. Raneses (1995). World Agriculture and Climate Change: Economic Adaptations, *Agricultural Economic Report #703,* Washington, D.C.: USDA.

Dimaranan, B. V., and McDougall, R. A., Edt. (2002). *Global Trade, Assistance, and Production: the GTAP 5 Database.* Center for Global Trade Analysis, Purdue University, West Lafayette, IN 47907, U.S.A.

Dimaranan, B. V. and McDougall, R. A., Edt. (2007). *Global Trade, Assistance, and Production: The GTAP 6 Data Base*, Center for Global Trade Analysis, Purdue University, West Lafayette, IN47907, U.S.A.

FAO. (2000). Land Cover Classification System: Classification Concepts and User Manual (with CD-Rom). Rome: Food and Agriculture Organization (FAO) of the United Nations.

FAO. (2003). State of the World's Forests 2003. Food and Agricultural Organization (FAO) of the United Nations (UN), Rome, Italy. (http://www.fao.org/DOCREP/005/Y7581E/Y7581E00.HTM)

FAO. (2004). FAOSTAT data, Food and Agriculture Organization of the United Nations, (available at http://apps.fao.org).

FAO/IFPRI/SAGE/CIAT (2003) AgroMAPS: A Global Spatial Database of Agricultural Land-Use Statistics Aggregated by Sub-national Administrative Districts, Food and Agriculture Organization (FAO), United Nations; International Food Policy Research Institute (IFPRI); Center for Sustainability and the Global Environment (SAGE), University of Wisconsin-Madison; International Center for Tropical Agriculture (CIAT). Website: http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp.

FAO and IIASA. (2000). Global Agro-Ecological Zones - 2000. Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy, and International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Fischer, G., van Velthuizen, H., Shah, M., and Nachtergaele, F. (2002). Global Agro-Ecological Assessment for Agriculture in the 21st Century: Methodology and Results (Research Report RR-02-02). Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA) and Food and Agriculture Organization (FAO) of the United Nations (UN).

Foley, J.A., M.H. Costa, C. Delire, N. Ramankutty, and P. Snyder. (2003). Green Surprise? How terrestrial ecosystems could affect earth’s climate, *Frontiers in Ecology and the Environment, 1* (1), 38-44.

GTAP Website. (2002). Workshop: Incorporation of Land Use and Greenhouse Gas Emissions into the GTAP Database. Center for Global Trade Analysis (GTAP), Purdue University, West Lafayette, IN 47907, U.S.A. Available:

http://www.gtap.agecon.purdue.edu/databases/projects/Land_Use_GHG/MIT_Workshop/default.asp.

Hertel, T. W. (eds.). (1997). *Global Trade Analysis: Modeling and Applications*. Cambridge University Press.

Haxeltine, A. and I. C. Prentice. (1996). "BIOME3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability, and Competition Among Plant Functional Types." *Global Biogeochemical Cycles* 10(4): 693-709.

IPCC. (1996). *Climate Change 1995: The Science of Climate Change*: Intergovernmental Panel on Climate Change (IPCC) Cambridge University Press, Cambridge, United Kingdom.

Lee, H.-L., Hertel, T. W., Sohngen, B., Ramankutty, N., and U.S. Environmental Protection Agency. (2005, forthcoming). GTAP Greenhouse Gases Emissions Data Base. Center for Global Trade Analysis, Purdue University, West Lafayette, IN47907, U.S.A.

Leff, B., N. Ramankutty, and J. Foley, Geographic distribution of major crops across the world, *Global Biogeochemical Cycles*, *18*, GB1009, doi:10.1029/2003GB002108, 2004.

Loveland, T.R., B.C. Reed, J.F. Brown, D.O. Ohlen, J. Zhu, L. Yang, and J.W. Merchant. (2000). Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1-km AVHRR Data, *International Journal of Remote Sensing*, *21* (no. 6/7), 1303-1330.

McGuire, A.D., S. Sitch, J.S. Clein, R. Dargaville, G. Esser, J. Foley, M. Heimann, F. Joos, J. Kaplan, D.W. Kicklighter, R.A. Meier, J.M. Melillo, B.M. III, I.C. Prentice, N. Ramankutty, T. Reichenau, A. Schloss, H. Tian, L.J. Williams, and U. Wittenberg. (2001). Carbon balance of the terrestrial biosphere in the twentieth century: Analyses of CO2, climate and land-use effects with four process-based ecosystem models., *Global Biogeochemical Cycles*, *15*, 183-206.

Mendelsohn, R., P. Kurukulasuriya, A. Basist, F. Kogan, and C. Williams. (2005). Climate Analysis with Satellite versus Weather Station Data. Unpublished working paper.

Monfreda, C., N. Ramankutty, and Foley, J.A. (2006). Farming the Planet 2: The Geographic Distribution of Crop Areas and Yields in the Year 2000. Mimeo; SAGE: University of Wisconsin Madison.

Myhre, G., and A. Myhre. (2003). Uncertainties in radiative forcing due to surface albedo changes caused by land-use changes, *Journal of Climate*, *16* (10), 1511-1524.

National Geographic Maps. (2002). A World Transformed, Supplement to National Geographic September 2002, National Geographic Society, Washington, D.C.

Ramankutty, N., and J.A. Foley. (1998). Characterizing Patterns of Global Land Use: An Analysis of Global Croplands Data, *Global Biogeochemical Cycles*, 12, 667-685.

Ramankutty, N., and J.A. Foley. (1999). Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992, *Global Biogeochemical Cycles*, *13*, 997-1027.

Ramankutty, N., J.A. Foley, J. Norman, and K. McSweeney. (2002a). The global distribution of cultivable lands: current patterns and sensitivity to possible climate change, *Global Ecology and Biogeography*, *11* (5), 377-392.

Ramankutty, N., J.A. Foley, and N.J. Olejniczak. (2002b). People on the land: Changes in Population and Global Croplands During the 20th Century, *Ambio*, *31 (3)*, 251-257.

Ramankutty, N., Hertel, T. W., Lee, H.-L. and Rose, S. (2005). Global Land Use and Land Cover Data for Integrated Assessment Modeling. Book chapter for the Snowmass Conference, Snowmass, CO, July 2004. Paper available at the GTAP website: http://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1635.

Sedjo, R.A. and K.S. Lyon. (1990). *The Long Term Adequacy of the World Timber Supply*. Washington, D.C.: Resources For the Future.

Small, C. (2003). Global Population Distribution and Urban Land Use in Geophysical Parameter Space. *Earth Interactions*, **8** (Paper 8), doi: 10.1175/1087-3562 (2004) 008 <0001:GPDAUL> 2.0.CO;2.

Sohngen, B., R. Mendelsohn, and R. Sedjo. (1999). "Forest Management, Conservation, and Global Timber Markets." *American Journal of Agricultural Economics*. 81: 1-13.

Sohngen, B., and Tennity, C. (2004). Country Specific Global Forest Data Set V.1. *memo.* Department of Agricultural, Environmental, and Development Economics, Ohio State University, Columbus, OH 43210, U.S.A.

United Nations. (1991). Provisional Central Product Classification, Statistical Paper Series M No. 77, Sales No. E.91.XVII.7. New York: United Nations Publishing Division.

Yang, D.W., S. Kanae, T. Oki, T. Koike, and K. Musiake. (2003). Global potential soil erosion with reference to land use and climate changes, *Hydrological Processes*, *17* (14), 2913-2928.

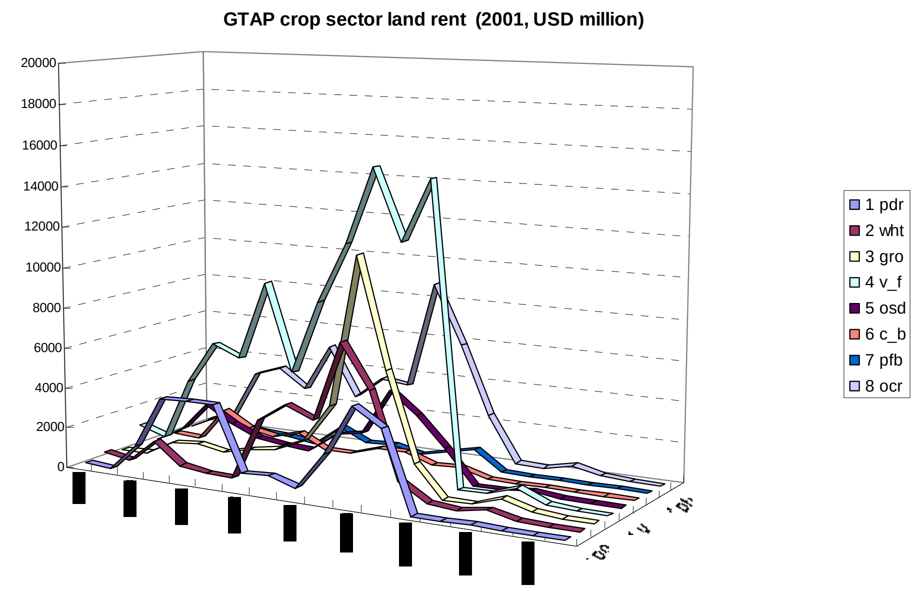

Figure 1. Crop sector land rent allocation among AEZs: world total

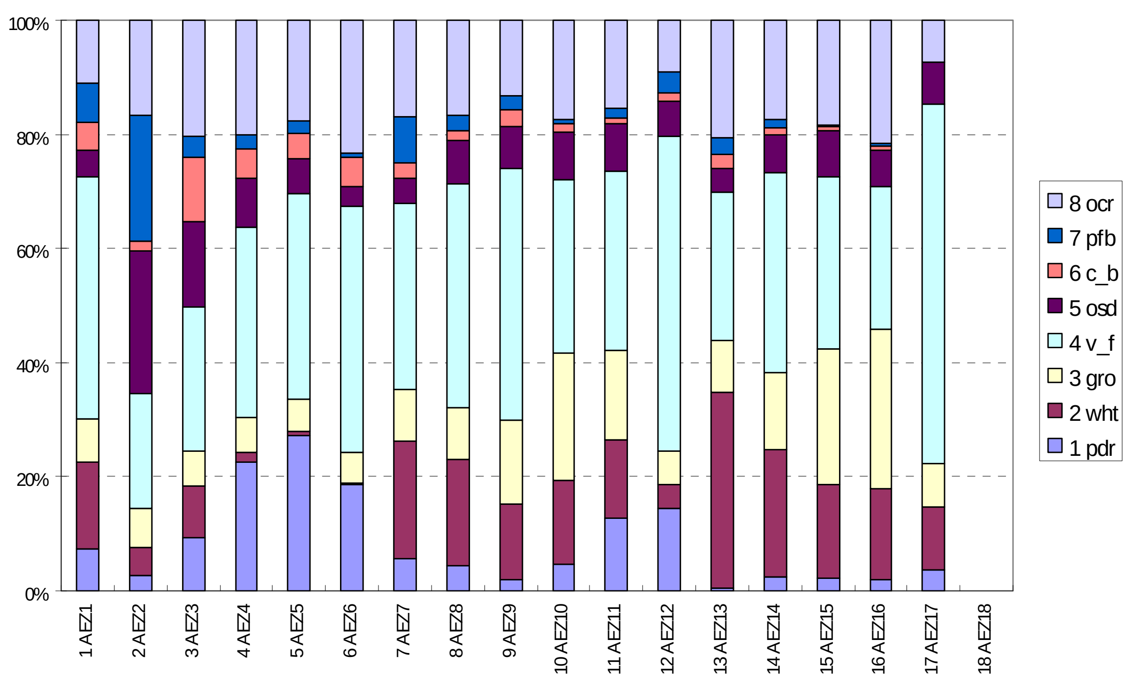

Figure 2. Distribution of crop sector land rent within each AEZ: world total

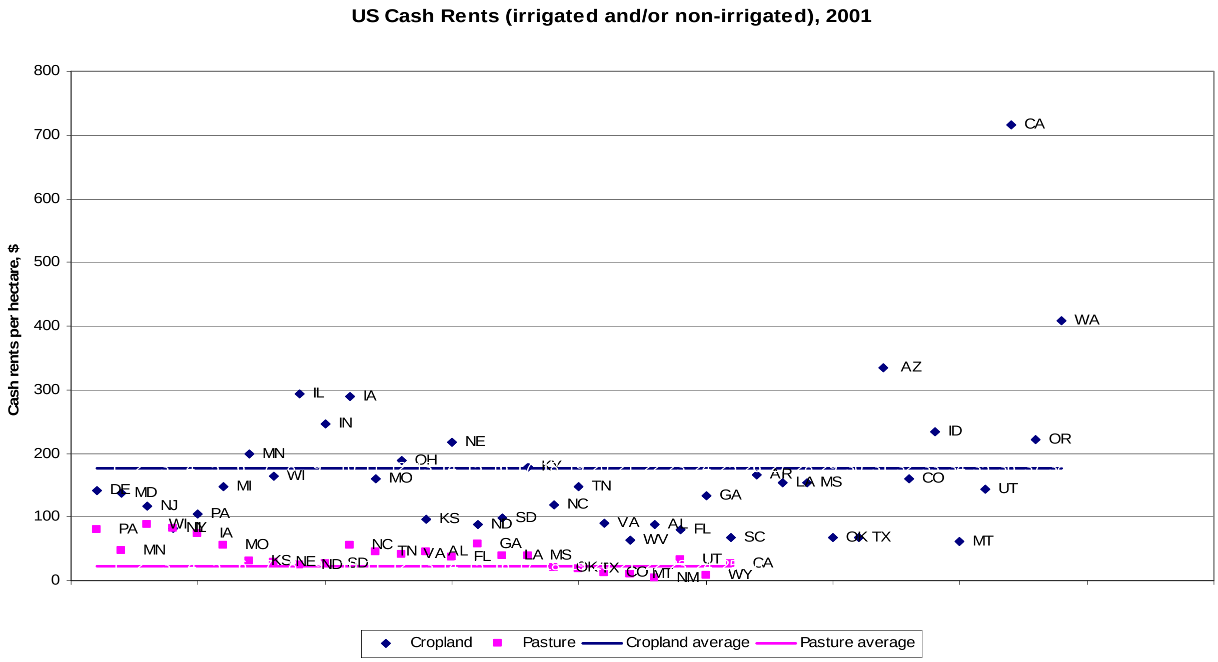

Figure 3. USDA estimated cash rents for cropland and pasture, by state

Note: AZ, WA and CA: only irrigated cropland.

Source: Agricultural Cash Rents, 2001.

http://usda.mannlib.cornell.edu/reports/nassr/other/plrbb/rent0701.pdf

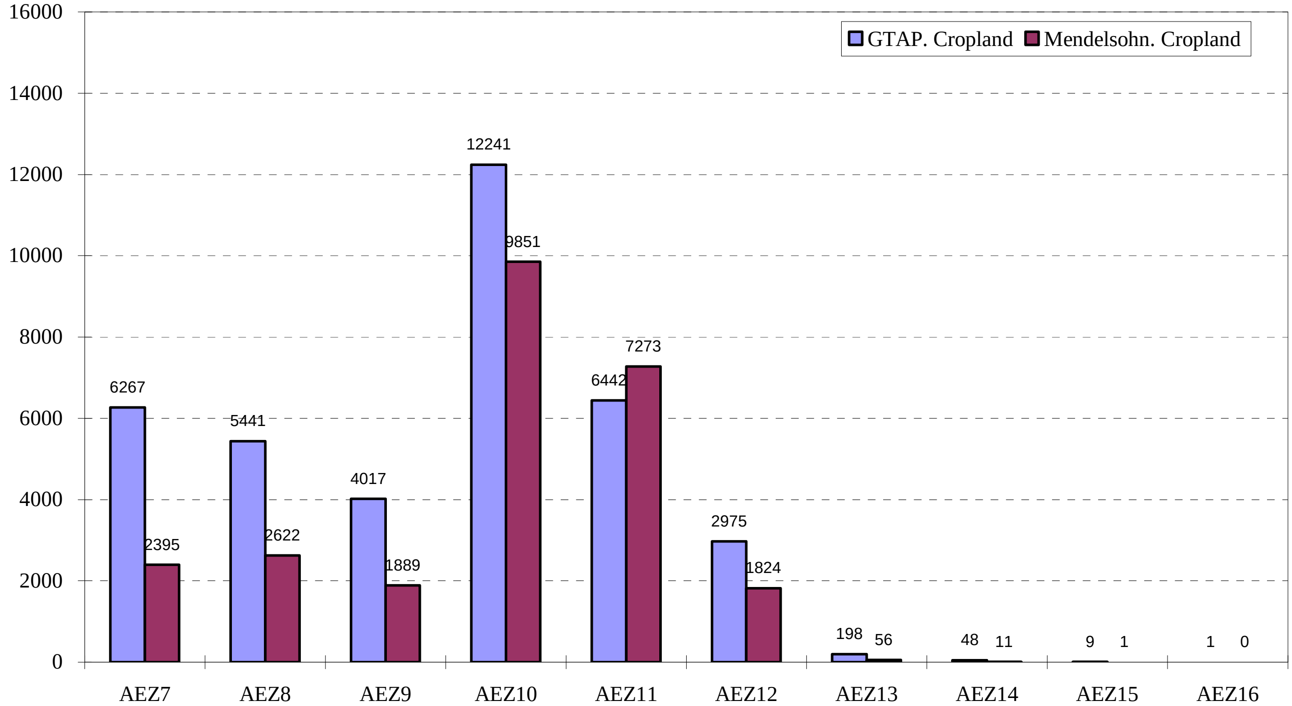

Figure 4. U.S. cropland rents, 2001 US$ million: GTAP v.s. Mendelsohn et al.

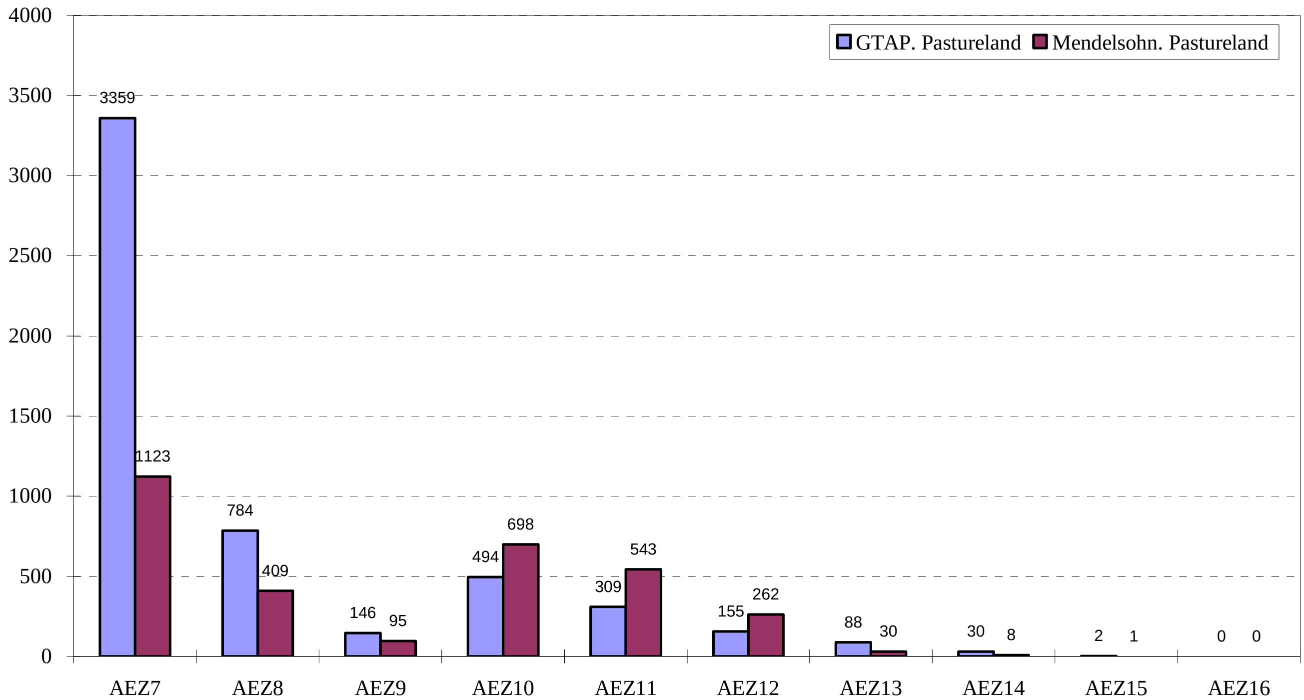

Figure 5. U.S. pasture land rents, 2001 US$ million: GTAP v.s. Mendelsohn et al.

Table 1. GTAP crop sector land rents: VFM, world total, v6.0 (unit: million US Dollar)

Unit: million USD	1 pdr	2 wht	3 gro	4 v_f	5 osd	6 c_b	7 pfb	8 ocr	Total
1 AEZ1	200	419	209	1171	127	133	192	301	2751
2 AEZ2	102	180	251	738	914	68	810	607	3669
3 AEZ3	1429	1347	948	3805	2278	1701	563	3081	15151
4 AEZ4	3964	308	1096	5880	1485	908	442	3557	17639
5 AEZ5	4018	100	854	5309	919	652	333	2608	14794
6 AEZ6	3979	88	1156	9212	748	1070	189	4976	21418
7 AEZ7	851	3111	1371	4909	665	394	1222	2551	15075
8 AEZ8	943	4056	1973	8529	1647	353	601	3617	21720
9 AEZ9	529	3475	3835	11513	1912	779	673	3450	26167
10 AEZ10	2349	7378	11286	15274	4192	814	347	8776	50416
11 AEZ11	4794	5225	5905	11819	3148	330	651	5827	37698
12 AEZ12	3905	1129	1601	14891	1674	408	983	2431	27022
13 AEZ13	4	253	67	191	32	19	22	151	737
14 AEZ14	15	139	83	219	42	7	9	109	623
15 AEZ15	51	380	547	693	185	17	5	423	2300
16 AEZ16	9	70	122	110	28	3	2	95	440
17 AEZ17	0	0	0	2	0	0	0	0	3
18 AEZ18	0	0	0	0	0	0	0	0	0
19 UnSkLab	32068	20958	23429	144287	19326	9155	8751	56618	314591
20 SkLab	336	529	718	2853	549	190	195	2008	7377
21 Capital	12749	10805	13011	59377	12011	5277	4771	33732	151733
22 NatRes	0	0	0	0	0	0	0	0	0
Total	72293	59951	68460	300780	51882	22277	20760	134920	

Table 2. GTAP livestock sector land rents: VFM, world total, v6.0 (unit: million US Dollar)

Unit: million USD	9 ctl	10 oap	11 rmk	12 wol	Total
1 AEZ1	271	0	194	64	529
2 AEZ2	151	0	492	55	698
3 AEZ3	164	0	2227	143	2534
4 AEZ4	569	0	1111	69	1749
5 AEZ5	1440	0	849	29	2318
6 AEZ6	1129	0	699	41	1869
7 AEZ7	4050	0	3398	448	7896
8 AEZ8	1272	0	1889	221	3382
9 AEZ9	724	0	1056	109	1889
10 AEZ10	1838	0	5042	180	7060
11 AEZ11	1231	0	2271	106	3608
12 AEZ12	948	0	790	212	1950
13 AEZ13	606	0	343	115	1064
14 AEZ14	357	0	527	99	983
15 AEZ15	629	0	1627	150	2406
16 AEZ16	158	0	297	31	487
17 AEZ17	1	0	0	0	2
18 AEZ18	0	0	0	0	0
19 UnSkLab	26517	54219	31236	3481	115453
20 SkLab	938	1106	1063	68	3174
21 Capital	25348	22520	20032	1449	69348
22 NatRes	0	0	0	0	0
Total	68342	77845	75143	7068	228397

Table 3. GTAP land rents: VFM of forestry sector, world total, v6.0 (unit: million US Dollar)

Unit: million USD	13 frs
1 AEZ1	30
2 AEZ2	24
3 AEZ3	196
4 AEZ4	494
5 AEZ5	516
6 AEZ6	1125
7 AEZ7	98
8 AEZ8	116
9 AEZ9	622
10 AEZ10	1703
11 AEZ11	1004
12 AEZ12	2014
13 AEZ13	14
14 AEZ14	322
15 AEZ15	711
16 AEZ16	125
17 AEZ17	2
18 AEZ18	0
19 UnSkLab	32899
20 SkLab	914
21 Capital	37713
22 NatlRes	0
Total	80641

Table 4. U.S. per hectare land rent: GTAP v.s. Mendelsohn et al.

	GTAP land rent (VFM), unit: million 2001 US$		SAGE land cover, unit: 1000 ha.		Derived per ha. Land rent, unit: 2001 US$/ha.		Pasture/Cropland per ha. land rent ratio	Mendelsohn, unit: 2001 US$/ha.		Pasture/Cropland per ha. land rent ratio	Mendelsohn, land rent, unit: million 2001 US$	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
							= (F)/(E)			= (I)/(H)	= (H)*(C)	= (I)*(D)
	Cropland	Pastureland	Cropland	Pastureland	Cropland	Pastureland		Cropland	Pastureland		Cropland	Pastureland
AEZ1												
AEZ2												
AEZ3												
AEZ4												
AEZ5												
AEZ6												
AEZ7	6267	3359	35343	144140	177	23	0	68	8	0	2395	1123
AEZ8	5441	784	27477	36932	198	21	0	95	11	0	2622	409
AEZ9	4017	146	14266	5488	282	27	0	132	17	0	1889	95
AEZ10	12241	494	50145	16688	244	30	0	196	42	0	9851	698
AEZ11	6442	309	38048	11674	169	26	0	191	47	0	7273	543
AEZ12	2975	155	16258	7055	183	22	0	112	37	0	1824	262
AEZ13	198	88	1861	7488	106	12	0	30	4	0	56	30
AEZ14	48	30	327	2109	146	14	0	32	4	0	11	8
AEZ15	9	2	24	141	384	16	0	37	5	0	1	1
AEZ16	1	0	2	2	590	0	0	32	12	0	0	0
AEZ17												
AEZ18												
All land	37639	5368	183753	231718	205	23	0	118	12	0	25922	3169

Table 5. GTAP agriculture per hectare land rent, unit: 2001 US$/ha.

GTAP regions	GTAP VFM unit: million 2001 USD	SAGE Land cover unit: 1000ha.	Average per ha. land rent
5 Hon Kong	413	286	1444
7 Korean, republic of	8619	9495	908
52 Switzerland	1478	4037	366
48 Netherlands	1033	3220	321
13 Singapore	91	310	294
39 Denmark	1262	5216	242
19 Sri Lanka	1674	7072	237
6 Japan	8702	39938	218
42 Germany	7843	36576	214
46 Italy	5776	29358	197
17 Bangladesh	2762	15334	180
38 Belgium	542	3544	153
37 Austria	1229	8159	151
12 Philippines	4433	29996	148
18 India	45305	309374	146
41 France	7693	55032	140
35 Rest of FT of the Americas	1323	9707	136
43 United Kingdom	3585	26429	136
56 Bulgaria	1279	11155	115
59 Czech Republic	905	8018	113
44 Greece	1179	12706	93
62 Poland	2900	31557	92
14 Thailand	4687	51464	91
45 Ireland	713	7992	89
60 Hungary	776	9272	84
63 Romania	1880	24190	78
57 Croatia	454	6357	71
50 Spain	3575	50117	71
49 Portugal	716	10976	65
15 Viet Nam	1719	30607	56
55 Albania	146	2804	52
20 Rest of South Asia	8893	172583	52

Table 5 (continued)

GTAP regions	GTAP VFM unit: million 2001 USD	SAGE Land cover unit: 1000ha.	Average per ha. land rent
36 Rest of the Caribbean	598	12108	49
4 China	46984	959967	49
10 Indonesia	8576	179528	48
64 Slovakia	232	4905	47
22 U.S.A.	44235	944153	47
23 Mexico	9024	201568	45
65 Slovenia	104	2364	44
34 Central America	2220	57628	39
11 Malaysia	1214	35898	34
54 Rest of Europe	592	17742	33
40 Finland	1014	34690	29
32 Uruguay	474	19022	25
27 Venezuela	2295	92272	25
71 Turkey	1729	80189	22
16 Rest of Southeast Asia	2483	115475	22
51 Sweden	935	45343	21
25 Colombia	2335	118348	20
31 Chile	1499	85476	18
2 New Zealand	533	31253	17
66 Estonia	80	4681	17
68 Lithuania	133	8307	16
86 Uganda	335	21085	16
53 Rest of EFTA	710	45562	16
73 Morocco	624	43195	14
74 Tunisia	210	15911	13
70 Rest of Form. Soviet Union	6536	498236	13
29 Argentina	3469	281209	12
9 Rest of East Asia	1912	166020	12
26 Peru	1370	132233	10
67 Latvia	59	6441	9
72 Rest of Middle East	4232	527500	8
28 Rest of Andean Pact	994	133998	7

Table 5 (continued)

GTAP regions	GTAP VFM unit: million 2001 USD	SAGE Land cover unit: 1000ha.	Average per ha. land rent
79 Malawi	67	10247	7
75 Rest of North Africa	2898	494191	6
77 South Africa	662	124641	5
81 Tanzania	483	91472	5
33 Rest of South America	396	85625	5
21 Canada	4459	991138	5
3 Rest of Oceania	178	41579	4
83 Zimbabwe	169	40476	4
30 Brazil	3412	852846	4
1 Australia	3023	784874	4
85 Madagascar	197	61660	3
87 Rest of Sub-Saharan Africa	3483	1422515	2
69 Russia	4033	1689470	2
82 Zambia	98	74768	1
80 Mozambique	101	79791	1
78 Rest of South African Customs Union	66	87524	1
76 Botswana	42	58571	1
84 Rest of Southern African Development Community	230	362519	1
8 Taiwan	1714	0	N/A
24 Rest of North America	7	0	N/A
47 Luxembourg	83	0	N/A
58 Cyprus	27	0	N/A
61 Malta	14	0	N/A
Total	307160	13299093	