VALIDATING PREDICTED GLOBAL LAND USE CHANGES IN THE EPPA MODEL[#]

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Introduction

In recente years there have been a number of attempts to model land use changes in general and partial equilibrium approaches. One of the motivation to it was the concerns about the implications of worldwide bioenergy production in recent years. Some of the initial studies about it, as Reilly and Paltsev (2007), did not account explicitly for competition among different land uses, and followed a standard approach for accounting of inputs in a CGE framework where the quantity of land service available annually is represented by the total rental value of land. The approach followed economic convention of aggregating land of different productivities based on rental value and data on annual returns to land. While a start, the approach does not provide a direct connection to physical quantity of land use in hectares, or the capability to make use of agro-engineering data on regional production potential. In particular, Reilly and Paltsev (2007) assumed the same land productivity in biomass production across all regions in terms of land input in rental value units.

Moving from a single land input to multiple land classes requires a modeling approach to represent the ability to shift land from one use to another. Several studies have represented land use competition among different use categories. These include Adams *et al*. (1996), Darwin (1995), Ianchovichina *et al*. (2001), Ahammad and Mi (2005) and Golub *et al*. (2006). These studies have used a Constant Elasticity of Transformation (CET) function to represent the allocation of land among different uses. A land supply elasticity of each type is implied by the elasticity of substitution and implicitly reflects some underlying variation in suitability of each land type for different uses and the cost to or willingness of owners to switch land to another use. More recent developments and applications of land use changes in general equilibrium include Melillo et al. (2012) and Hertel et al. (2012). Partial equilibirum models also are being developed and applied to investigate land use changes, as MAgPIE (2008; Popp et al. 2010), GLOBIOM (Havlik et al., 2011) and GCAM (Thompson et al., 2011).

Although land use modeling is developing fast, there is no general agreement about its outcomes. Validation has been missing from most of the model exercises and there is no agreement among results from alternative approaches. This paper aims to implement alternative assumptions about land use changes in a computable general equilibrium model and compare their outcomes with observed data from the last decade.

We investigate land use changes at global level in a Computable General Equilibrium (CGE) framework. We test three alternative approaches regarding the economic processes governing land use transitions. Land use changes are modeled assuming that economic agents are concerned with the choice of the best use in order to maximize its profits and need to cover explicitly the costs of conversion from one use

[#] Preliminar version, please do not quote.

type to another, but the underling assumptions about the conversion costs change with the approach. The first approach considers only the pure costs of conversion in the land use decision. The second is calibrated based on the observed land supply response from past decades. The last one explicitly considers environmental services used by consumers related to recreational activities as opportunity costs to convert natural land.

The land use approaches are tested in the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev *et al.*, 2005) and compared with reality considering the 1997 - 2010 period. Special attention is given to broad land use categories, as cropland and pastures, and the deforestation of natural forest areas. We perform some sensitivity tests to illustrate the importance of several key parameters necessary to represent the land use change phenomena. We then discuss important aspects affecting the modeling validation and uncertainty in data and modeling strategies, as the temporal horizon of the equilibrium in CGE modeling and some recent changes in land use trends that are usually incorporated in the models *a posteriori* when some confidence is acquired in the persistency of such changes.

Method

We departure from the MIT Emissions Prediction and Policy Analysis (EPPA) model described in Paltsev *et al.* (2005). EPPA is a recursive-dynamic multi-regional computable general equilibrium (CGE) model of the world economy. The GTAP data set provides the base information on Social Accounting Matrices and the input-output structure for regional economies, including bilateral trade flows, and a representation of energy markets in physical units as shown in Table 1 (Hertel, 1997; Dimaranan and McDougall, 2002). We aggregate the data into 16 regions and 21 sectors.

Other important data sources in EPPA are data on greenhouse gas (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) and air pollutant emissions (SO_2, NO_x, black carbon, organic carbon, NH_3, CO, VOC), which are based on United States EPA Table 1. Regions and Sectors in the EPPA4 model inventory data and projections, and advanced energy technology sectors which have been developed using engineering cost estimates and data on conversion efficiencies as discussed further below.

Table 1. Regions and Sectors in the EPPA4 Model

Country/Region	Sectors
Annex B	***Non-Energy***
United States (USA)	Crops (CROP)
Canada (CAN)	Livestock (LIVE)
Japan (JPN)	Forestry (FORS)
European Union+ (EUR)	Services (SERV)
Australia/New Zealand (ANZ)	Energy Intensive Products (EINT)
Former Soviet Union (FSU)	Other Industries Products (OTHR)
Eastern Europe (EET)	Industrial Transportation (TRAN)
Non-Annex B	Household Transportation (HTRN)
India (IND)	***Energy***
China (CHN)	Coal (COAL)
Indonesia (IDZ)	Crude Oil (OIL)
Higher Income East Asia (ASI)	Refined Oil (ROIL)
Mexico (MEX)	Natural Gas (GAS)
Central and South America (LAM)	Electric: Fossil (ELEC)
Middle East (MES)	Electric: Hydro (HYDR)
Africa (AFR)	Electric: Nuclear (NUCL)
Rest of World (ROW)	***Advanced Energy Technologies***
	Electric: Biomass (BELE)
	Electric: Natural Gas Combined Cycle (NGCC)
	Electric: NGCC with CO_2 Capture and Storage (NGCAP)
	Electric: Integrated Coal Gasification with CO_2 Capture and Storage (IGCAP)
	Electric: Solar and Wind (SOLW)
	Liquid fuel from biomass (BOIL)
	Oil from Shale (SYNO)
	Synthetic Gas from Coal (SYNG)

Note: Detail on the regional composition is provided in Paltsev *et al.* (2005). CROP, LIVE, FORS SER, EINT, OTHR, COAL, OIL, ROIL, GAS sectors are aggregated from the GTAP data (Dimaranan and McDougall, 2002), TRAN and HTRN sectors are disaggregated as documented in Paltsev et al. (2004), HYDR and NUCL are disaggregated from electricity sector (ELY) of the GTAP dataset based on EIA data (2006), BELE, NGCC, NGCAP, IGCAP, SOLW, BOIL, SYNO, SYNG sectors are advanced technology sectors that do not exist explicitly in the GTAP dataset

The base year of the model is 1997, what allow us to compare model predictions with observed data for the 2000 decade. EPPA simulates the economy recursively at 5-year intervals from 2000 to 2100. Economic development in 2000 and 2005 is calibrated to the actual GDP growth data. Production and consumption sectors in EPPA are represented by nested Constant Elasticity of Substitution (CES) functions, which include the Cobb-Douglas and Leontief special cases. The model is written in the GAMS software system and solved using the MPSGE modeling language (Rutherford, 1995). The model was developed to examine climate and energy policy applications such as those in Reilly *et al.* (1999), Paltsev *et al.* (2003), Babiker, Reilly and Metcalf (2003), Reilly and Paltsev (2006), Paltsev *et al.*, 2007, and CCSP (2007).

Given the focus on energy and climate change policy, the EPPA model uses additional exogenous data to disaggregates the GTAP data for transportation to include household transport (i.e. personal automobile), the electricity sector to represent existing supply technologies (e.g. hydro, nuclear, fossil), and includes several alternative energy supply technologies (e.g. shale oil, wind/solar, biomass) not extensively used or available in 1997 but that could potentially be demanded at larger scale in the future depending on energy prices and/or climate policy conditions. To represent such technologies, the model takes in account detailed bottom-up engineering parameters. The parameterization of these sectors is described in detail in Paltsev *et al.* (2005).

Future scenarios are driven by economic growth that results from savings and investments and exogenously specified productivity improvement in labor, energy, and land. Growth in demand for goods produced from each sector including food and fuels occurs as GDP and income grow. Stocks of depletable resources fall as they are used, driving production to higher cost grades. Sectors that use renewable resources such as land compete for the available flow of services from them, generating rents. These together with policies, such as constraints on the amount of greenhouse gases, change the relative economics of different technologies over time and across scenarios. The timing of entry of advanced technologies such as cellulosic bio-oi, is endogenous when they become cost competitive with existing technologies.

EPPA has been widely applied to address energy, agriculture, and climate change policy. It represents five broad land use categories, including natural areas explicitly. It allows for future conversion to agricultural land when economic conditions favor it. The modeling approach to represent the land use competition among different use categories differs from most of other CGE models that have used a Constant Elasticity of Transformation (CET) function. As CET functions are share preserving, radical changes in land use does not occur, making short term projections more "realistic." However, for longer term analysis where demand for some uses could expand substantially (as the case of biofuels in some countries), the CET approach may limits land use change. It also does not explicitly account for conversion costs, nor does it address the value of the stock of timber on virgin forest land that substitutes for forest harvest on managed forest land.

We therefore explicitly address the cost of conversion to transform land from one type to another. The advantages include the ability to track land area consistently in a general equilibrium framework, explicitly represent conversion costs and to account for the harvest of timber on virgin forest land. The approach implies that intensively managed land (i.e. cropland) can be "produced" from less intensively or unmanaged land.

The crops sector and the two biomass sectors (liquids and electric) compete for cropland. Pasture land is used exclusively in the livestock sector, and harvested forest land is used exclusively in the forest sector. Natural grass land and natural forest land enters the utility of the representative agent, for which it has "non-use" value.

For land rent data we make use of Lee et al. (2005) which was developed for the purpose of providing a correspondence between physical quantity of land and its rental value in the economic data in the GTAP dataset. They do not attribute any rental value to land that is not in current use – unmanaged forest and grassland, nor do they separate out the physical quantities of these land types. To separate out unmanaged land that is not producing any current income flow we use the data base of Hurtt *et al.* (2006), which is an elaboration of the underlying physical data used in Lee *et al.*, 2005. We also use data available from Sohngen's WEB site at Ohio State (Sohngen, 2007) about natural forest conversion costs based from equilibrium conditions to estimate timber and "non-use" values on natural areas.

The observed land supply response approach mimics the increasing costs associated to larger forest deforestation in a single period, in terms of building additional infrastructure, transport the timber to markets and so on. Also it represents additional institutional costs in the economies in terms of environmental legislation and consumer pressures to conservationism, contributing to slow down intense transformation of natural ecosystems.

To represent environmental services in the model we expand traditional economic accounts to represent demand for hunting, fishing, and wildlife viewing (Antoine, Gurgel and Reilly 2008). To do this we create household production activities where household time (leisure) is combined with other goods and forest land to produce outdoor recreation services used by the household. Data on expenditures on hunting, fishing, and wildlife viewing and to maintain public parks and recreational areas for the US are available (US Census Bureau 2000). We use a benefits transfer approach for other regions, scaling the outdoor recreation services sectors to the recreation sector in GTAP to equal the share of these sectors of the US recreation sector in each region.

Results

Table 1 presents global land use and land use changes results for the 2000 decade from EPPA runs as also data from FAO. There are some difficulties in comparing global land use FAO data with EPPA numbers, since FAO land use categories are not the same as in EPPA. It helps to explain the differences in the base year land use data (1997) between EPPA and the FAO land use database. Also, as EPPA is based on TEM, which is calibrated to reproduce Hurtt *et al.* (2006) data, there is no reason to believe the numbers will match at the base year. In this way, all three land use categories displayed in Table 1 are higher in EPPA than in FAO. Regarding global land use changes, EPPA OLSR seems to reproduce quite well the decrease in pasture areas observed in FAO data. However, deforestation in all versions of EPPA is much stronger than in FAO. Considering that EPPA forest areas are larger, higher deforestation means that EPPA numbers are moving toward FAO numbers. Cropland areas in EPPA are growing substantially (more than 10 million per year), but FAO numbers do not confirm such result.

Table 1 – World Land Use (billion ha)

		Area (billion of ha)				5 year land use changes (billion ha)		
		1997	2000	2005	2010	2000	2005	2010
FAO	Pasture*	3,2	3,2	3,2	3,1	0,00	-0,04	-0,03
	Arable Land	1,3	1,3	1,3	1,3	0,00	0,01	0,00
	Forest Area	4,0	4,0	4,0	3,9	-0,02	-0,02	-0,02
EPPA Recreation	Pasture	3,4	3,5	3,5	3,5	0,07	0,01	-0,01
	Cropland	1,6	1,7	1,7	1,8	0,06	0,06	0,12
	Forest Area	4,8	4,6	4,6	4,5	-0,14	-0,07	-0,11
EPPA PCCR	Pasture	3,5	3,6	3,7	3,7	0,10	0,08	0,06
	Cropland	1,6	1,7	1,7	1,8	0,06	0,06	0,12
	Forest Area	4,8	4,6	4,5	4,3	-0,16	-0,14	-0,19
EPPA OLSR	Pasture	3,5	3,5	3,5	3,4	0,03	-0,04	-0,03
	Cropland	1,6	1,7	1,7	1,8	0,06	0,06	0,12
	Forest Area	4,7	4,6	4,6	4,5	-0,10	-0,01	-0,05

Source: FAO and EPPA results

* FAO category "Permanent Meadows and Pastures"

Preliminar Regional results (not shown here) indicate that the EPPA model can reasonably reproduces the long term trends of broad land use types worldwide in the 2000 decade under some of the three alternative approaches tested, depending of the specific land use category considered and its regional location. We then believe that our modeling effort can effectively contribute to address policy questions related to the interrelation of land use, energy and climate in the future.

Conclusions

Land use modeling is developing fast in recent years, although there is no general agreement about its outcomes. Validation has been missing from most of the model exercises and there is no agreement among results from alternative approaches. We investigate land use changes at global level in a Computable General Equilibrium (CGE) framework. We have tested three alternative approaches regarding the economic processes governing land use transitions in the EPPA model. Our preliminary results show that there is large disagreement between land use data in economic models, usually obtained from detailed spatial research about historical land use patterns, and FAO data, obtained mostly from country official data. It poses some difficulties in validation exercises of this type. Besides that, land use change patters in EPPA suggests larger deforestation than implied by FAO database.

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