A Spatial Mathematical Model Analysis of the Linkage between Agricultural Trade and Deforestation

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Abstract

Like agricultural trade, deforestation has increased tremendously throughout the past five decades. We analyse the linkage between both factors by applying trade and forest policy scenarios to the global land-use model MAgPIE ("Model of Agricultural Production and its Impact on the Environment"). The model predicts global landuse patterns in a spatially explicit way and uses endogenously derived technological change and land expansion rates. Our study is the first which combines global trade analysis with a spatially explicit mapping of deforestation. By implementing self-sufficiency rates in the regional demand and supply equations, we are able to simulate different trade settings. Our baseline scenario fixes current trade patterns until the year 2045. The three liberalisation scenarios assume a path of increasing trade liberalisation which ends with no trade barriers in 2045 and they differ by applying different forest protection policies.

Regions with comparative advantages like Latin America for oilcrops and China for cereals will export more. Whereas, Latin America will buy this competitiveness by converting large parts of its Amazonian rainforest into cropland, China will benefit most due to its decreasing food demand after 2025. In contrast, regions like the Middle East, North Africa and South Asia face the highest increases of imports. Forest protection policies lead to higher technological change rates. In absence of such policies, investments in agricultural Research & Development are the most effective way for protecting the forest.

1. Introduction

During the last decades the trade volume of agricultural goods has increased tremendously. Whereas between 1950 and 1955 every year an agricultural value of around 80 billion US$ was exported, it increased to an annual average of 827 billion US$ in the period from 2005 to 2008 (FAOSTAT, 2010). Two developments are responsible for this trend. First, globalization has reduced transport and transaction costs for trading significantly (Anderson, 2010). Second, agricultural trade has been liberalized after the huge domestic support following the Second World War (Josling et al., 2010). The consequences of these developments in economic and environmental terms are discussed controversial.

One important issue in this contextz is deforestation resulting from cropland expansion. According to Nielsen (2006) half of the tropical forest has been cleared since the Second World War which amounts to almost 800 mio. ha. How much of this is cleared because of cropland expansion is strongly debated. The World Bank estimates 60% of deforestation is due to agricultural expansion (World Bank, 1991). A more recent study about deforestation in Brazil indicates lower rates (Morton et al, 2006). At the same time the study emphasize on the high correlation between deforestation and higher crop prices. Although some sources indicate a decreasing deforestation rate (FAO, 2000 and Kauppi et al, 2006), the remaining forest, especially the rainforest, is in severe danger due to the increasing demand for food. Main consequences are an increased release of carbon emissions, socio-economic damages for the local population and loss of biodiversity.

Recent studies bring more light into the debate of the consequences of increased trade for the environment and more specifically, deforestation. DeFries et al (2010) indicate based on satellite data that forest loss is largely driven by urban population growth and exports of agricultural products. Meyfroidt et al (2010) point out the importance of integrating agricultural trade in international deforestation policies. Other studies use a modeling approach to show future effects of trade liberalization. Verburg et al. (2009) used the coupled LEITAP-IMAGE model to analyze the impacts of trade liberalisation on greenhouse gas (GHG) emissions. They conclude that GHG emissions increase by about 6% in 2015, when full trade liberalisation by 2015 is compared with the “no-new policy scenario” from OECD. Similar studies by van Meijl et al. (2006) and Eickhout et al. (2009) show that trade liberalisation leads only to small land-use shifts in Europe but dramatic shifts in Africa and other developing regions resulting in negative implications for the environment.

Our study follows a similar modeling approach by including economic and environmental aspects in a global landuse model. However, it has some distinctive features which makes it unique in this research area. We use a spatially explicit economic landuse model, called MAgPIE ("Model of Agricultural Production and its Impact on the Environment") to run different trade volume scenarios. This makes it possible to generate spatial explicit maps on a 0.5 degree resolution which helps to locate the results on a sub national level. To our knowledge no study before has mapped results from trade analysis in this distinctive way. Our global landuse model differs significantly to comparable model frameworks like the LEITAP-IMAGE model by considering the interplay of land expansion and yield increasing technological change in an endogenous way (Dietrich et al., 2010b).

The main goal of our study is to investigate the consequences of different trade volume scenarios and forest protection policies on trade balances, deforestation and technological change rates over the coming four decades. To do so, we first explain the model framework and outline the method of trade simulation as well as the applied scenarios. Chapter three illustrates the results of the analysis which are discussed in chapter four.

2. Methods and Data

2.1 The Model

The global land-use model MAgPIE ("Model of Agricultural Production and its Impact on the Environment") is a recursive dynamic optimization model with a cost minimization objective function (Lotze-Campen et al., 2008; Lotze-Campen et al., 2010; Popp et al., 2010). The spatial explicit programming allows to model the supply side of the model with cell resolutions up to 0.5 degree (approximately 50x50km grid).

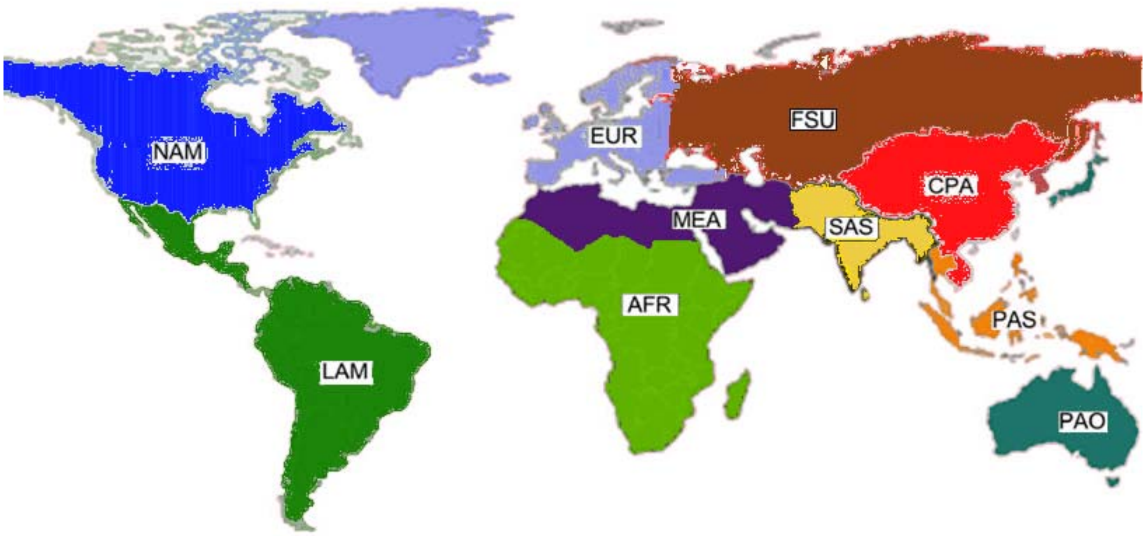

Figure 1: The ten world regions in MAgPIE [1]

The demand side is represented by ten world regions (see Figure 1). The required calories in the demand categories are derived from future population (CIESIN et al., 2000) and income growth scenarios (World Bank, 2001). These data are regressed on cross-sectional basis with country data on food and non-food energy intake. The resulting demand calories are produced by 16 cropping and 5 livestock activities (see Table 1). MAgPIE simulates time steps of 10 years (starting in 1995) and uses in each period the optimal land-use pattern from the previous period as a starting point.

Four categories of costs arise for the production: factor requirement costs; yield increasing technical change costs, land conversion costs and transport costs. The model is optimized by minimizing these four cost components on a global scale. MAgPIE can invest in yield-increasing technological change or in land expansion in order to meet future agricultural demand quantities. The endogenous implementation of technological change (TC) is based on a surrogate measure for agricultural landuse intensity (Dietrich

[1] AFR = Sub-Sahara Africa, CPA = Centrally Planned Asia (incl. China), EUR = Europe (incl. Turkey), FSU = Former Soviet Union, LAM = Latin America, MEA = Middle East and North Africa, NAM = North America, PAO = Pacific OECD (Australia, Japan and New Zealand), PAS = Pacific Asia, SAS = South Asia (incl. India)

et al., 2010a). This measure is related to empirical data on investments in TC, like Research & Development and infrastructure investments (Dietrich et al., 2010b). The other alternative for MAgPIE to increase production is to expand into cropland from a pool of non-agricultural land. The expansion involves land-conversion costs which account for the preparation of new land and the basic infrastructure investments. Investments into new cropland will be relevant if it is cheaper than technological change or the shadow price minus the land conversion costs of the new land is higher than the shadow price of existing cropland.

category	**production activities**		
cereals	temperate cereals (tece)	maize	tropical cereals (trce)
rice	rice		
oilcrops	soybean	rapeseed	groundnut
	sunflower	oil palm	
pulses & roots	pulses	potato	cassava
sugar	sugar beet	sugar cane	
others	cotton	others	
livestock	ruminant meat	pig meat	poultry meat
	egg	milk	

Table 1: Production activities in MAgPIE[2]

The biophysical inputs (e.g. yields) for MAgPIE are derived from the grid-based dynamic vegetation model Lund-Potsdam-Jena with managed land (LPJmL) (Bondeau et al., 2007). LPJmL is a process based model which considers soil, water and climatic conditions, like CO_2, temperature and radiation in an endogenous way. The inclusion of the hydrological cycle and a global map of irrigated areas (Döll and Siebert, 2000) allow LPJmL to differentiate between rainfed and irrigated yields. Irrigated areas receive their additional water from the natural runoff and its downstream movement according to the river routing in LPJmL (Rost et al., 2008; Gerten et al., 2004). Besides crop yields, LPJmL delivers this water discharge value for each grid cell as a possible constraint for further irrigation area expansion in MAgPIE.

[2] Abbreviations for crop types: tece = temperate cereals, trce = tropical cereals, groundn = groundnuts, sunfl = sunflower, scane = sugar cane, sbeet = sugar beet

2.2 Trade Implementation

We have implemented international trade in MAgPIE by using self sufficiency ratios. Self-sufficiency ratios describe how much of the regional agricultural supply quantity has to be produced within a region. For example, a ratio for cereals of 0.65 means that 65% of cereals are produced domestically, whereas 35% are imported. To represent the trade situation of 1995 we have calculated the self-sufficiency ratios for each region and production activity from the food balance sheets of FAO for the year 1995 (FAOSTAT, 2010). The following equations document the implementation in MAgPIE. Equation (1) shows the global food balance, where the aggregated regional supply *S* has to be equal or bigger than the aggregated regional demand *D*.

Global constraint:

$$\sum_{j \in i} S(j,k) \geq \sum_{i} D(i,k) \qquad (1)$$

with *i* and *j* as regions and *k* production activities.

Subsequently, we have introduced excess demand and supply equations. The global quantity of excess demand for each crop (k) is calculated by subtracting domestic demand from domestic production for the importing countries *im* (equation 2). Domestic production is calculated by multiplying domestic demand with the self sufficiency ratio *s*. This excess demand is distributed to the exporting regions *ex* according to their export shares *exshr* (equation 3). The export shares are taken from FAO as well.

Excess Demand:

$$XD(k) = \sum_{i} D(im,k) \cdot (1 - s(im,k)) \cdot r \qquad (2)$$

Excess Supply

$$XS(ex,k) = XD(k) \cdot exshr(ex,k) \qquad (3)$$

The trade balance equation (4) determines that the sum of the regional supply has to be bigger or equal than the total supply of the exporting regions and the total supply of the importing regions, if r is equal to one. The lower letter r stands for trade balance reduction and determines the amount of fixed traded excess demand. If r is below one the total supply of the importing regions is reduced and the rest of it will be allocated according to comparative advantage criteria. If r is equal to zero, just the total supply of the exporting regions is considered for this equation.

Trade Balance Equation:

$$\sum_{j \in i} S(j,k) \geq D(ex,k) + XS(ex,k) + (D(im,k) \cdot s(im,k) \cdot r) \qquad (4)$$

The same procedure is shown in Figure 2 in a more illustrated way. We have two trading pools. The distribution of the first pool is fixed and determined by the export shares. The distribution of the second pool is free according to comparative advantage criteria and follows equation (1). The parameter r defines the share of trade which will flow in the first pool. If r is equal to 1, all of the excess demand will be distributed according to the fixed export shares to the exporting regions. If r is equal to 0, all trading quantity will end up in the second pool and is distributed according to comparative advantage criteria.

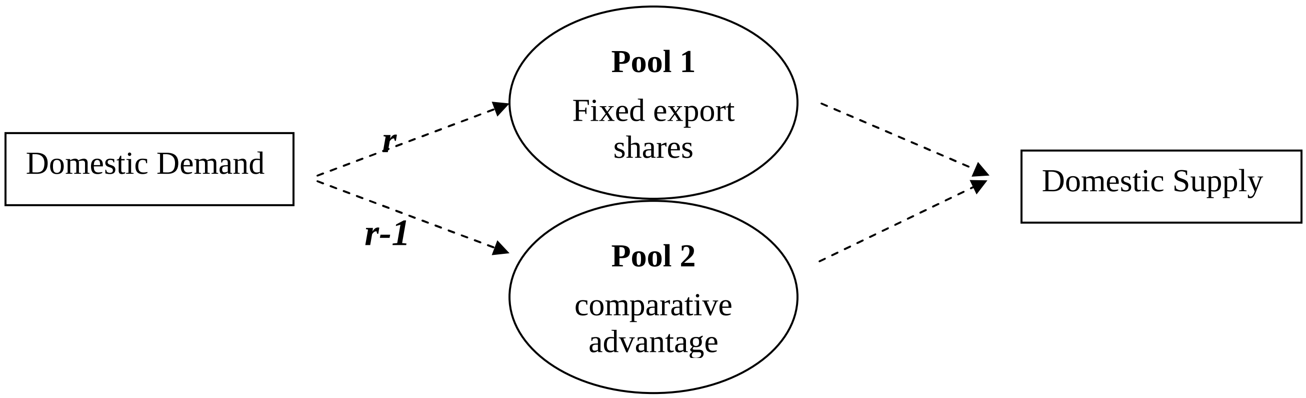

Figure 2: Trading pools in MAgPIE

2.3 Scenarios

The baseline scenario (bau) keeps the self sufficiency rates constant over time and simulates constant trade shares over time. Forest is not protected and MAgPIE is allowed to convert all forest into cropland against payment. Besides the baseline scenario, we consider three scenarios with full trade liberalization in 2045. They all allow for full trade liberalisation in 2045 by reducing the self sufficiency rates to zero over time. The quite ambitious goal is that the world will be fully liberalized in 2045 and everything is traded according to comparative advantage rules. The first liberalization scenario (lib), assumes as in the baseline scenario, no forest protection. The liberalization scenario plus 50% forest protection (lib_sf50) gives only 50% of the forest in each cell free to be converted into cropland. Finally, the liberalization scenario plus 100% forest protection (lib_sf100) does not allow for any cropland conversion from forest area.

As explained in the previous chapter trade is simulated by changing the factor r. Table 2 gives the values for *r* in each period and scenario. As mentioned, the baseline scenario keeps the self sufficiencies for 1995 constant over time. Therefore, the value for *r* is 1 in all time steps. In the liberalisation scenario *r* is reduced continuously to 0 in 2045.

Year	**1995**	**2005**	**2015**	**2025**	**2035**	**2045**
baseline scenario	1	1	1	1	1	1
liberalisation scenarios	1	0.8	0.6	0.4	0.2	0

Table 2: Trade Scenarios

3. Results

3.1 Trade Balances

Trade balances (in million tones) are calculated by taking the difference between export and import within a region. Figure 3 shows trade balances for cereals (incl. rice) and oilcrops. The ten world regions are separated by different colors. The baseline scenario with constant trade on the left is compared with the three liberalization scenarios covering different forest protection policies.

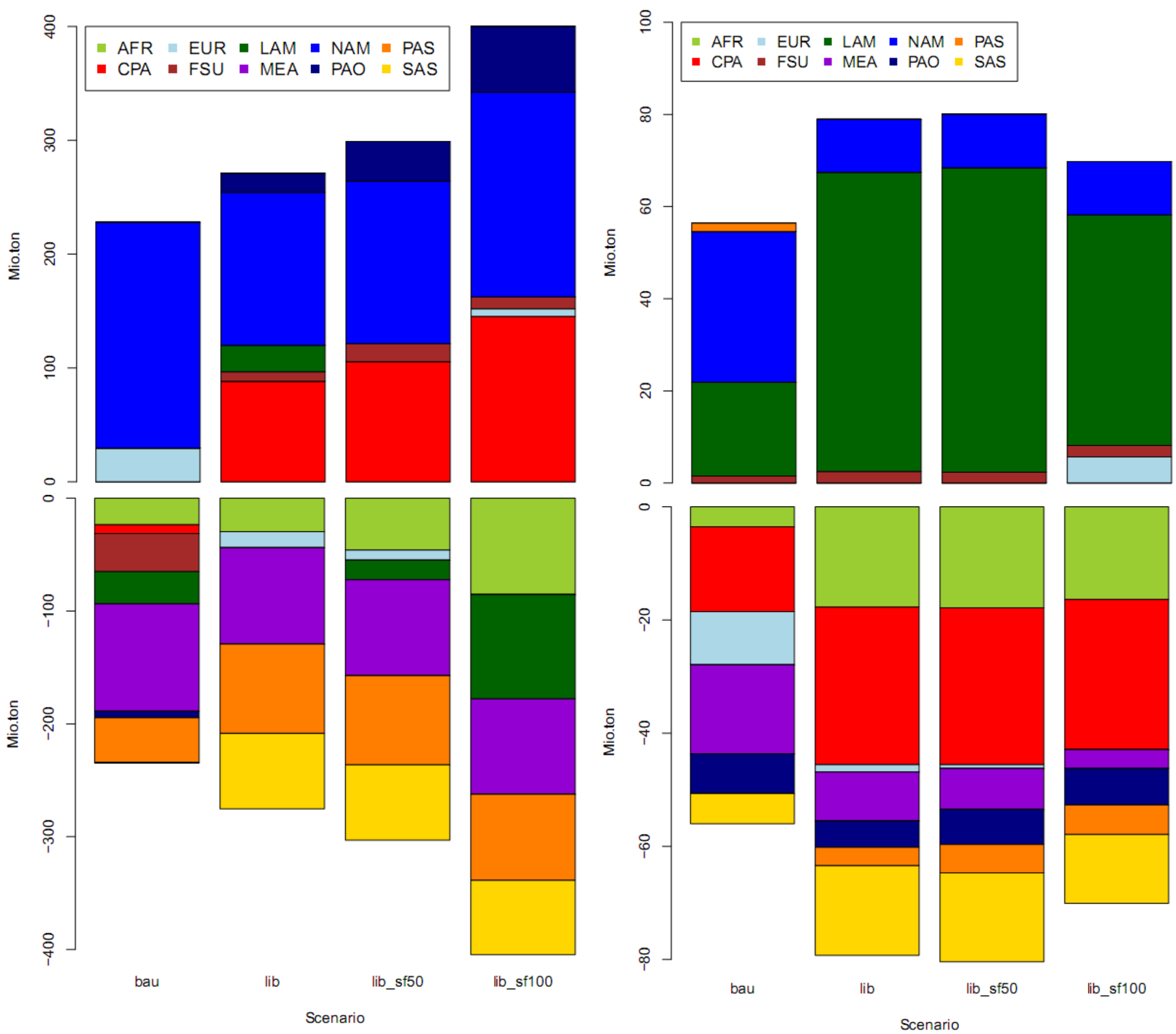

Figure 3: Annual Trade Balance (average from 2005 to 2045) for cereals (incl. rice) and oilcrops for the ten world regions in the baseline scenario and the three liberalization scenarios

In the baseline scenario, EUR and NAM dominate the cereal market. The imports are shared among the other regions, lead by MEA. This situation changes in the liberalization scenarios when CPA, PAO, LAM and FSU join the export group at the expenses of EUR, who becomes partly a net importer. Especially, CPA and PAO take a large share of the export market. On the import side AFR, PAS and SAS increases their quantities most with more liberalization and more forest protection. The same holds for the overall trade

volume, which increases to over 400 mio. tons in the liberalization scenario with full 100% forest protection (compared to 230 mio. tons in the baseline).
Focusing on oilcrops, these crops are mostly dominated by NAM and LAM. With more trade LAM increases its export volume significantly (increase of more than three times. However, if then forest is fully protected the export share decreases considerably. On the import side CPA, AFR and SAS face the highest increases if more trade liberalization is applied. The overall trade volume in oilcrops increases from around 55 mio tons to 80 mio tons, in the case of liberalization. It stays constant, if 50% of the forest is protected and decreases if to 70 mio tons if forest is fully protected.

3.2 Land expansion and Deforestation

Figure 4 illustrates the cumulative amount of crop land expansion into forest land (in relative landuse shares) from 2005 till 2045. The most affected area will be the Central African rainforest, followed by the Amazonian rainforest and the rainforest in Indonesia. The central rainforest of Amazonia is not affected. Some land expansion takes place in the Savannah Region of West Africa, in North Australia, Canada and North Russia.

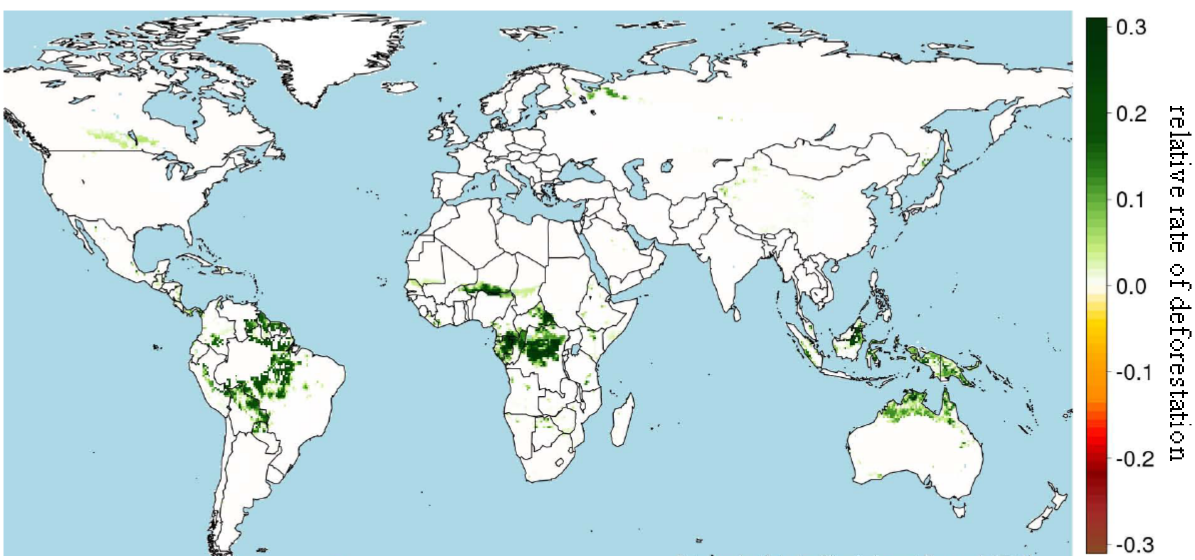

Figure 4: Relative rate of cropland expansion (change in landuse share of all crops) per grid cell (0.5°) in the baseline scenario between 2005 till 2045

Figure 5 illustrates the difference in cropland expansion between the baseline scenario and the respective liberalization scenarios. In the liberalization scenario, much more cropland will be expanded into rainforest in Brazil and neighboring countries to the North and West. No further expansion will take place in Africa and the expansion in Australia is much reduced and also in the Savannah Region of West Africa no cropland expansion takes place. If 50 % of the forest will be protected, MAgPIE is forced to reduce a maximum of 50% of the forest in each cell. Therefore, expansion rates in LAM, AFR and PAS are reduced. In Latin America, MAgPIE can expand into unused forest in the central rainforest. Furthermore, MAgPIE increases its share of cropland in North Australia. If forest is fully protected, almost no expansion will take place in AFR, LAM and PAS but North Australia will increase even more.

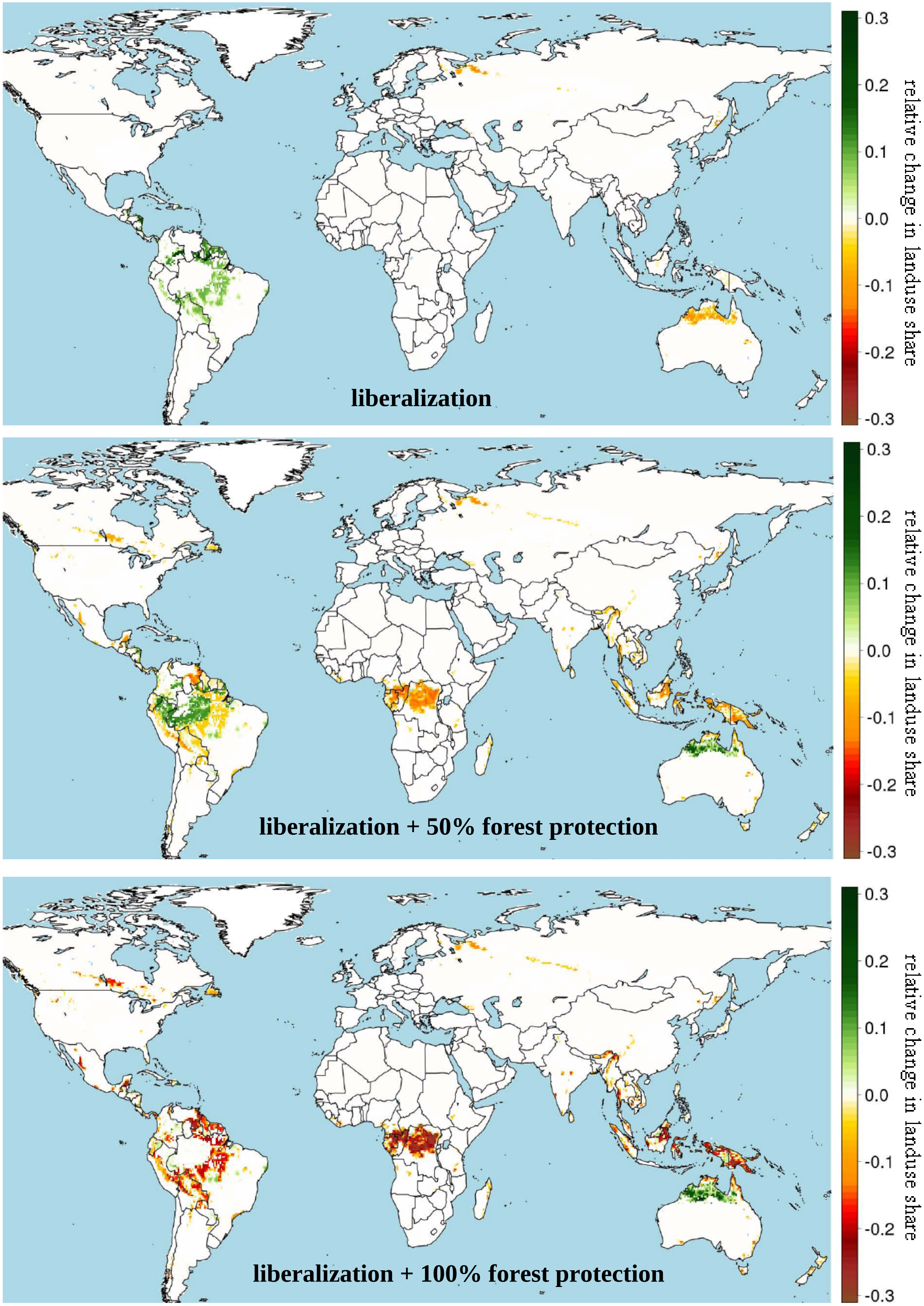

Figure 5: Relative change in cropland per grid cell (0.5°) between the baseline scenario and the three liberalization scenarios in 2045

3.3 Technological Change

Figure 6 shows the technological change rates of the ten world regions. In the case of EUR, FSU, MEA, NAM and SAS, technological change is highest under current trade patterns (baseline scenario). In all cases, except LAM, technological change is reduced if trade is liberalized. If forest is protected, technological change rates increase considerably. Especially, AFR, CPA, PAS and SAS face high rates over 1% per year. LAM show continuous increases with more trade liberalization and more forest protection.

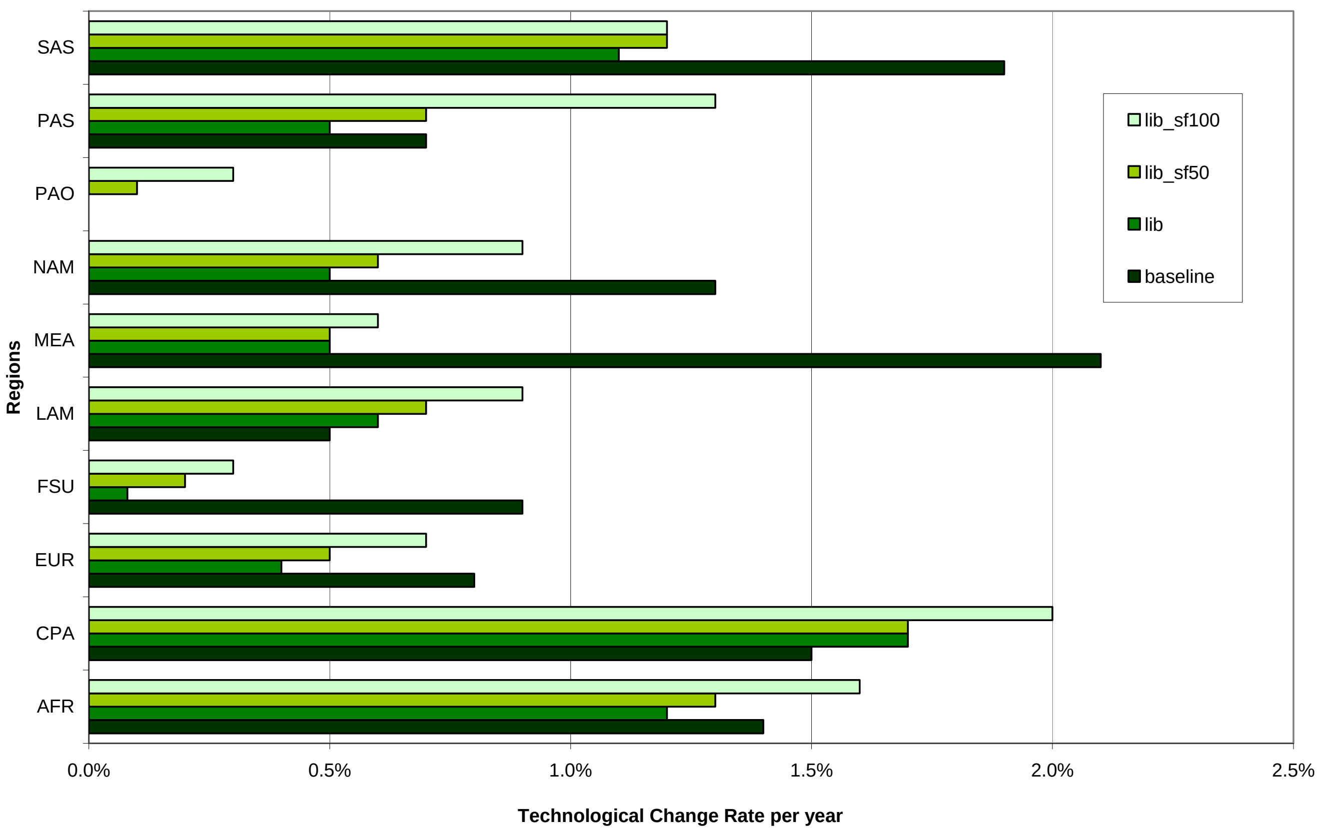

Figure 6: Average annual technical change from 2005 to 2045 for the baseline scenario (dark green) and the different liberalization scenarios

4. Discussion

Trade has increased significantly throughout the past decades and it is likely to increase more in the future. At the same time deforestation due to cropland expansion has increased as well and affects the local environmental system as well as the global climate system through increased carbon emissions. The questions arise how this increase in trade volume affects deforestation rates and how different forest protection policies influence trade.

With the help of the global land use model MAgPIE we analyze the effects of trade liberalization and different forest protection policies. The model runs on a spatially explicit resolution of 0.5 degrees. Compared with other land use models it has the advantage that technological change and land expansion are implemented in an endogenous way. Increasing their rates will lead to additional costs, which are optimized together with production costs. A drawback of the model is the currently missing link between pasture and cropland expansion. Since the interaction between both is crucial, future model development will concentrate on this link to get more accurate results.

Nonetheless, our analysis gives us valuable insights. Results show that Latin America, Central Africa and Pacific Asia significantly increase cropland area under constant trade assumptions and no protection policies. Under full trade liberalization Latin America, due to its comparative advantage, is the only region who expands even more into forest land and requires higher technological change (TC) rates than in the baseline scenario. Other expansion regions, like AFR and PAS, keep their expansion rates constant. For them it is cheaper to reduce their TC rates than to reduce cropland expansion. Both regions will invest much more into TC under these conditions. Land-scarce regions like the Middle East, North Africa and South Asia face the highest increases of imports. With more liberalisation they have a lower pressure to increase their productivity, resulting in significantly lower technological change rates. Besides Latin America, China benefits from trade liberalization most due to its high TC rates and its lower population pressure after 2025 resulting in lower domestic demand.

From our analysis we draw several conclusions. First, more liberalization leads to a net increase of deforestation driven by Latin America. For regions with higher imports it seems to be more beneficial to reduce their investments in TC, then to reduce their land expansion rates. Second, policies to reduce deforestation, like for example REDD (Reducing Emissions from Deforestation in Developing Countries), lead to higher TC investment in order to fulfill the increasing demand and to huge environmental benefits. Regions with rainforest loose competitive advantages. Third, besides policies the most efficient way for any region to reduce environmental and climate damages and to profit from further trade liberalization is to invest more into agricultural Research & Development in order to increase yields and the efficiency of the whole agricultural system.

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