# Implementing bilateral trade in a global landuse model

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# The effect of oil price increases on agricultural trade: Simulations with a global landuse model

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## 1 Introduction

Since international trade plays such a crucial role in satisfying global demand for agricultural goods, many models focused on agriculture have gone through the trouble of implementing trade. Some of the models which have incorporated trade are the "AGLINK-COSIMO model" from FAO and OECD [8], the "Common Agricultural Policy Regionalised Impact" model (CAPRI) [2], the "World Agricultural Trade Simulation Model" (WATSIM) [5] and the "International Model for Policy Analysis of Agricultural Commodities and Trade" (IMPACT) [9].
In contrast to these models, we have focused on bilateral, real data and implemented trade by introducing transport costs and trade barriers taken from GTAP in the goal function. This means that trade for all agricultural goods and between all regions is free and only controlled through the spefic costs on each trade route. With this approach we are able to estimate different effects of, e.g. climatic changes or availablity of natural resources on international trade more realistically. But more specifically, we are able to simulate effects of changes in transport costs and trade barriers on trade, food prices and natural resources.

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# 2 Methods and data

## 2.1 Model description

MAgPIE is a global, spacially explicit landuse model which has been developed at the ”Potsdam Institute for Climate Impact Reseach” and is extensively described in [6]. The model works in a dynamic, recursive mode and covers on the demand side ten world regions (see Table 1) and on the production side a varilable size of up to 2178 grid cells[1]. The core of the model is a cost minimization function, which minimizes the production cost for 25 agricultural goods for each of the regions. The required calories are produced by 15 food crops, 5 livestock products and fiber, additionally there is feed and bioenergy (see Table 2).

| **Regions** | **Description** |
|---|---|
| AFR | Sub-Saharan Africa |
| CPA | Centrally planned Asia (including China) |
| EUR | Europe (including Turkey) |
| FSU | Former Soviet Union |
| LAM | Latin America |
| MEA | Middle East/ North Africa |
| NAM | North America |
| PAO | Pacific OECD (Japan, AUS, NZL) |
| PAS | Pacific Asia |
| SAS | Southern Asia (incl. India) |

Table 1: Description of the different economic regions

3 categories of costs arise for the production: factor requirement costs; yield increasing technical change costs (as described in [3]) and land conversion costs. One special feature of MAgPIE is the fact that it is coupled to the grid-based dynamic vegetation model LPJmL[1], which simulates the potential crop yields on which the production in MAgPIE is based. The model simulates time steps of 10 years and uses in each period the optimal land-use pattern from the previous period as starting point.

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[1] These cells cover the terrestrial part of the globe.

| | |
|---|---|
| **food crops** | temperate cereals, maiz, tropical cerals,<br>rice, soybean, rapeseed, groundnut,<br>sunflower, pulses, potato,<br>cassava, sugarbeet, sugarcane, other oilcrops,<br>vegetables, fruits, nuts (one category) |
| **fiber** | cotton |
| **bioenergy** | trees, gras |
| **livestock** | ruminant meat, pigs, eggs, milk, chicken |
| **input f. livestock** | foodr, pasture |

Table 2: Production activities in MAgPIE

In the original MAgPIE version, trade is simulated endogenously by giving each region a minimum self sufficiency ratio and letting the model allocate the rest of the production to other regions according to comparative advantages. This version of MAgPIE implements bileteral trade by including transport costs into the cost minimization function.

In the following the extensions made in order to implement bilateral trade are described in detail. The goal function minimizes the total costs of producing the exogenously given demand of every region, including the bilateral transport costs from one region to another.

$$\sum_{i}\sum_{j}\sum_{inp}\sum_{act} x_{i,j,inp,act} \cdot c_{i,inp,act} + \sum_{e}\sum_{i}\sum_{good} y_{e,i,g} \cdot t_{e,i,g} \tag{1}$$

where $i$ are the economic regions, $j$ are the single cells in each region, $inp$ are the inputs (factor requirements, technical change and land conversion costs), $act$ are the production activities, $x_{i,j,inp,act}$ are the levels of the different production activities (livestock and crops), $c_{i,inp,act}$ are the costs for these activities, $y_{e,i,g}$ is the amount of each good shipped from export region $e$ to import region $i$ and $t_{e,i,g}$ are the transport costs per ton and traded good specific to each route (transport costs inside one region are zero).

The first constraint requires that incoming shipments from all export regions to one import region (there is of course the possibility that a country imports its own products) should be greater or equal than the exogenously given demand of food calories $d\_food_{i,g}$.

$$\sum_e y_{e,i,g} \geq d\_food_{i,g} \text{ for all } i \text{ and all } g \tag{2}$$

Outgoing shipments from one export region to all import regions are not allowed to exceed the production in the export region region.

$$\sum_i y_{e,i,g} \leq \sum_j \sum_{inp} x_{e,j,inp,act} \cdot y\_food_{e,j,inp,act} \quad \text{for all } e \text{ and all } act \tag{3}$$

where $y\_food_{e,j,inp,act}$ is the food energy delivery for each cell and production activity.

In the first period the production of each region is fixed to exogenously given subsistence levels. In the following periods all goods can be traded freely between all regions.

## 2.2 Trade and transport cost data

The bilateral transport costs between the ten world regions and for each of the goods at stake are derived by combining transport margins from GTAP (Global Trade Analysis Project) [7] and producer prices from the FAOSTAT statistics database .

The transport margin, that means that part of the total cost of a good which is needed for transportation, is calculated by subtracting the bilateral exports at world prices FOB (Cost Insurance and Freight) from the bilateral imports at world prices CIF (Free On Board).

> *transport margin (\$) =*
> *bilateral exports (\$) - bilateral imports (\$)*

The bilateral export volume in tons[2] is calculated by using bilateral exports at market prices and dividing it by the producer price for each good taken from FAOSTAT.

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[2] The export values are used rather than the import values since they do not include taxes, insurance and the transport margin and are therefore closer to the actual traded values

*bilateral export (ton) = export ($)/producer prices ($ /ton)*

Unfortunately many of the GTAP data are flawed, mostly because of reporting errors, which cannot only be seen by impossible transport prices per ton of zero but also by the unrealistic share in the imported value of goods. [4], using data from the Maritime Transport Costs Database, find ad valorem transport costs for agricultural goods of 10.89 percent. The categorie of goods with the lowest value is crude oil which has ad valorem transport costs of 4 %. To filter out flawed data from the GTAP database we have now defined a rule, that only transport margins which are at least 4% of the import value and at most twice as high as the ad valorem rate given by Korinek (that is 20%) pass the test of not being flawed. We are aware that the different agricultural goods in MAgPIE have partly different ad valorem rates, but the filter used is very generous and works well as a first approximation. To fill the resulting gaps in the transport cost data we apply two consecutive methods. First we use, when available, mirror data, that means that missing transport margins are substituted with the transport margin from the return route[3]. This is of course not the perfect solution since there are differences in transport costs on different directions of the same route depending on the regions being import or export regions, but it is nevertheless a good approximation. The resulting data gaps are now filled with interpolated values, which are interpolated on the base of all the goods on a specific route.

Data for trade barriers are also taken from GTAP, import duties are derived as difference between bilateral imports at market prices and bilateral imports at World prices, export duties are derived as the difference between bilateral exports at world prices and bilateral exports at market prices[4]. To filter out flawed data, we assume that trade routes with an export volume of a specific good of under one percent of the entire export volume have a high probability of reporting errors, we therefore substitute these data with the highest import and export duty in this category.

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[3] This method is widely used to resolve data gaps, e.g. by the United Nations

[4] Transforming them to dollar per ton values is done in the same way as explained above

## 2.3 Model validation

In order to show that MAgPIE_trade is able to reproduce real export data, we compare model output for the year 1995 to GTAP data for 1994[5]. In the following we concentrate on all agricultural goods included in the category food crops[6]. While GTAP data are in US$, the output of MAgPIE_trade is in ton, in order to be able to validate the model results against the GTAP data we have converted MAgPIE_trade output in US$ by multiplying tons by producer prices ($/ton) derived from FAOSTAT.

The entire export of food crops added up to 25 billion US$ in 1995, whereas MAgPIE_trade results show an export volume of food crops of 29.1 billion US$, this is about 30% more than reported in the GTAP data. The figure 1 compares export values for food crops for the ten world regions in MAgPIE_trade (see Table 1), the resulting R square is 0.8987 with $p < 0.00001$. Reasons for the fact that there is no 100% match between MAgPIE_trade and GTAP data are: there is no calibration, converting the MAgPIE_trade output into US$ adds additional uncertainty, an optimization model with limited constraints will always do better than reality and there will always be reporting errors in the data.

In figure 2 historic regional export values from the years 1961-2008 from FAOSTAT are compared to MAgPIE_trade simulations from the base year 1995 to 2045. For the major exporting regions like North America, Latin America and Europe and the middle sized export regions like Africa, China, Pacific OECD and Pacific Asia the export trend over time is reproduced quite well by MAgPIE_trade. While the smaller export regions (Former Soviet Union, South Asia, Middle East Asia) do not continue the export trend but have a tendency of decreasing export at first and than overestimating the trend. This is probably due to the fact that MAgPIE_trade cannot deal so well with small export amounts, since there are not only a small part of the overall export but an even smaller part of the overall production.

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[5] To make things easier, we just assume that the 1994 data are a close enough approximation to the 1995 data (since there exist no GTAP data for 1995) and will also refer from now on only to the year 1995.

[6] See Table 2 for a detailed list of agricultural goods belonging to food crops.

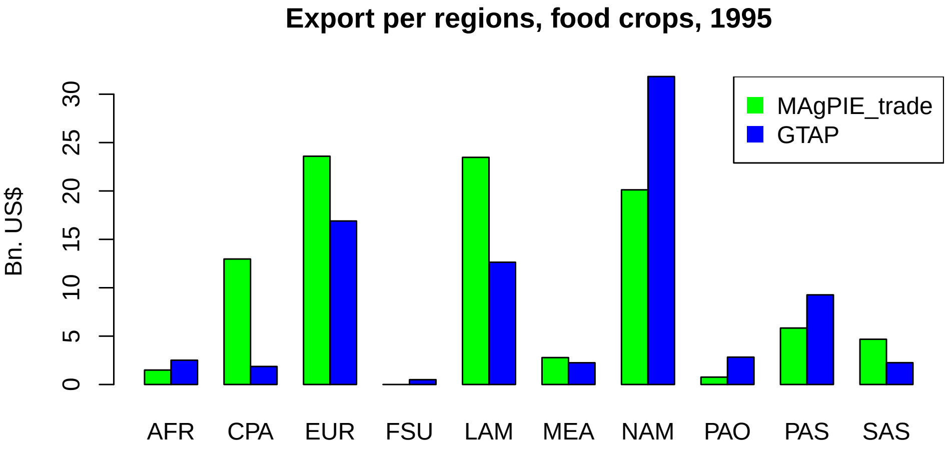

Figure 1: Regional comparison of MAgPIE_trade and GTAP exports

# 3 Model applications for oil price scenarios until 2045

## 3.1 Sensitivity analysis

In order to see if and how much the model reacts to changes in transport costs we conducted a sensitivity analysis, where for the year 1995 the transport costs for food crops were increased from the original transport costs to tenfold the transport costs. The model reacts most sensitive to these changes at the lower range of cost increases (a doubling of costs leads to a 40% decrease in global exports) and influences export values relatively little from a fivefold increase in transport costs on. The regional exports react also sensitive to increases in transport costs, whereas North America increases exports relatively little and China, Latin America and Europe decrease their exports considerably. (See Figures 3 and 4).

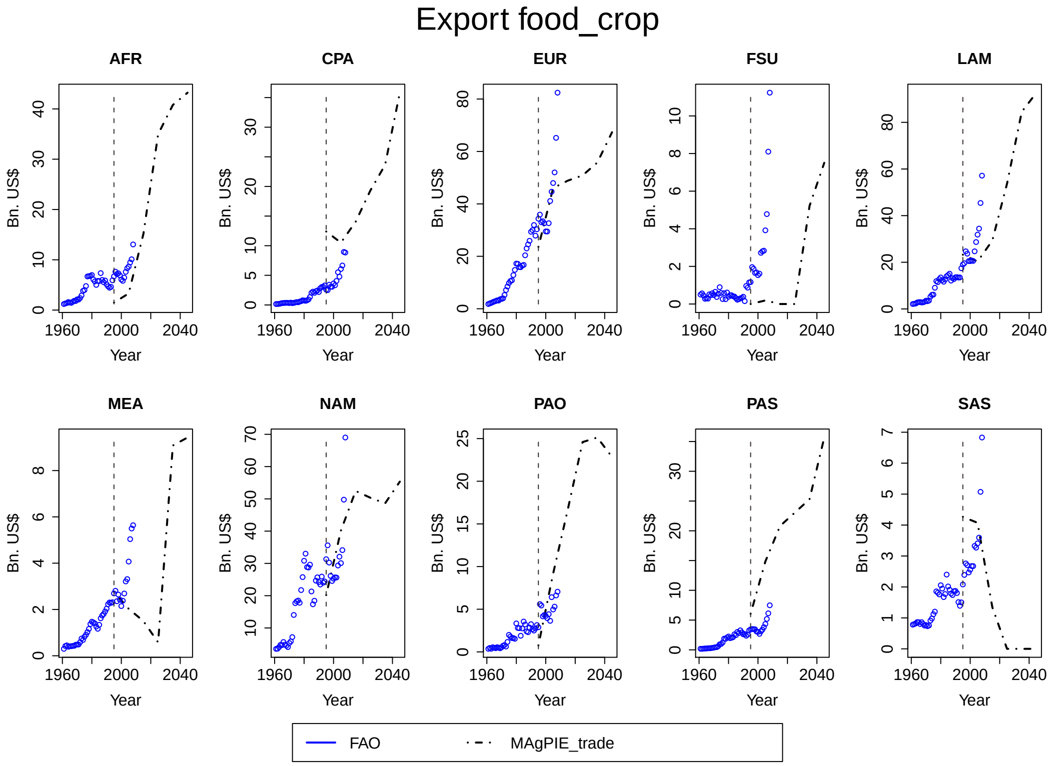

Figure 2: Regional comparison of MAgPIE_trade and FAO exports over time

## 3.2 The impact on exports

Due to its special properties of being a finite resource where the point of maximal extraction is still undetermined, prices for oil are more volatile than price of other goods, this is valid today, but even more so in the future. In order to grasp this high uncertainty we conducted three oil price scenarios with which we want to simulate the effect of future oil price changes on exports and the effect of the resulting changes on food prices and natural resources. Our baseline scenario are the predictions of the International Energy Agency, than we assume a low oil price scenario where prices are kept constant on the current price level and an high oil price scenario. For the price scenarios where prices increase over time, we assume that the price increase speeds up over time and reaches the highest rate of change at the

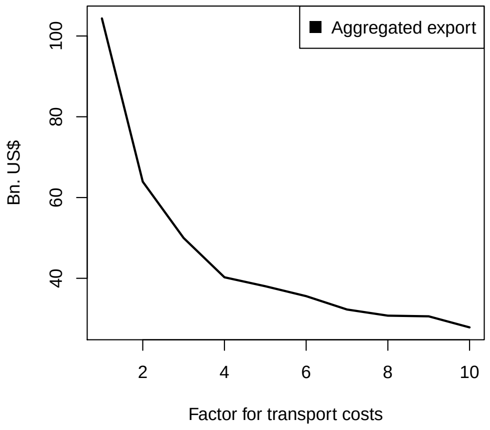

Figure 3: Sensitivity analysis: global export, food crops, 1995

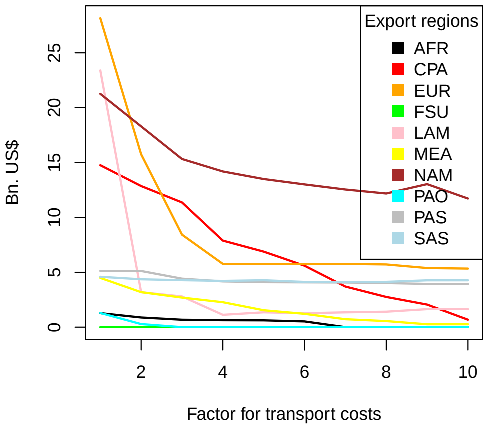

Figure 4: Sensitivity analysis: regional export, food crops, 1995

end of our scenario[7] (See Figure 5).
In figure 6 the resulting changes in export values for the three scenarios are shown. As to be expected export values increase most for constant oil prices over time and least in the high oil price scenario. In 2045 the exported value of food crops in the case of the high oil price scenario is 22% lower than the baseline scenario and keeping oil prices constant results in a 44% lower export value.

## 3.3 The impact on food prices and natural resources

The effect on export values is only part of this exercise, even more interesting is the effect of oil price induced transport costs on food prices, natural resources and technical change. In figure 7 regional, relative changes in food price index, landuse area, water shadow price and technical change rates in 2045 are shown. The red bars show the change relative to the baseline scenario assuming a high oil price scenario, the yellow bars show the relative

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[7] The high oil price scenario has been calculated by assuming the price for 1995 equal to the other scenarios and assuming a three times higher price for oil than the baseline scenario in 2045. The increase in between these two time steps has been calculated in order for the oil price to increase exponentially.

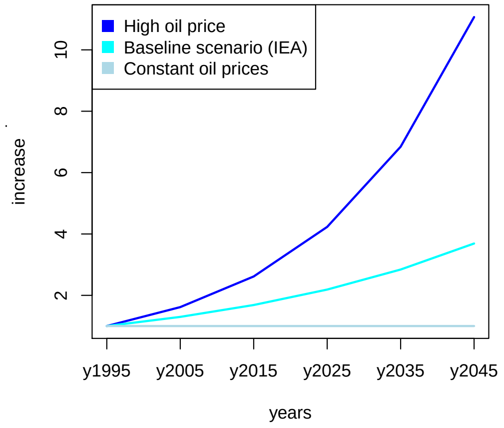

Figure 5: Oil price increases for the three different scenarios

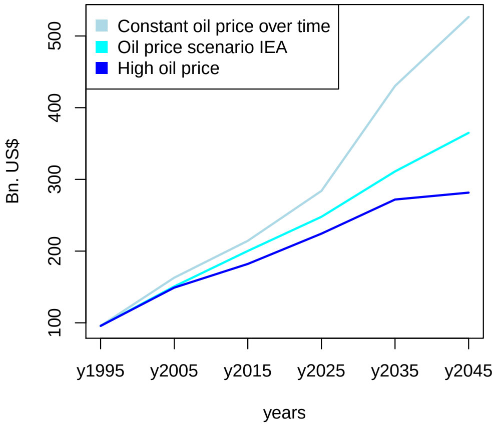

Figure 6: Development of global export of food crops for the three scenarios

difference between the baseline and the constant oil price scenario. The effect on the food price index is the most distinct. All food prices are higher in 2045 for an the high oil price scenario. The global average increase of prices for food crops when assuming an high oil price in the future is 10%, while keeping prices constant results in an decrease in prices of 5%. Area used for agricultural production increases most for the importing region Former Soviet Union in case export decreases due to oil price increases and is relativly little influenced in almost all other regions. This is probably due to the fact that necessary production increases can also be achieved over technical change. Water shadow prices increase on average 14% if oil prices increase and decrease 4% when oilprices are kept constant. But water scarcity should be looked at regionally and there we see that regions with highest water scarcity are also the ones suffering most under the increase in transport costs.

## 3.4 Conclusions

To look at the impact that oil price induced transport costs have on exports and resulting from these export changes on food prices and natural resources gives only a very limited picture of reality since oil prices influence much

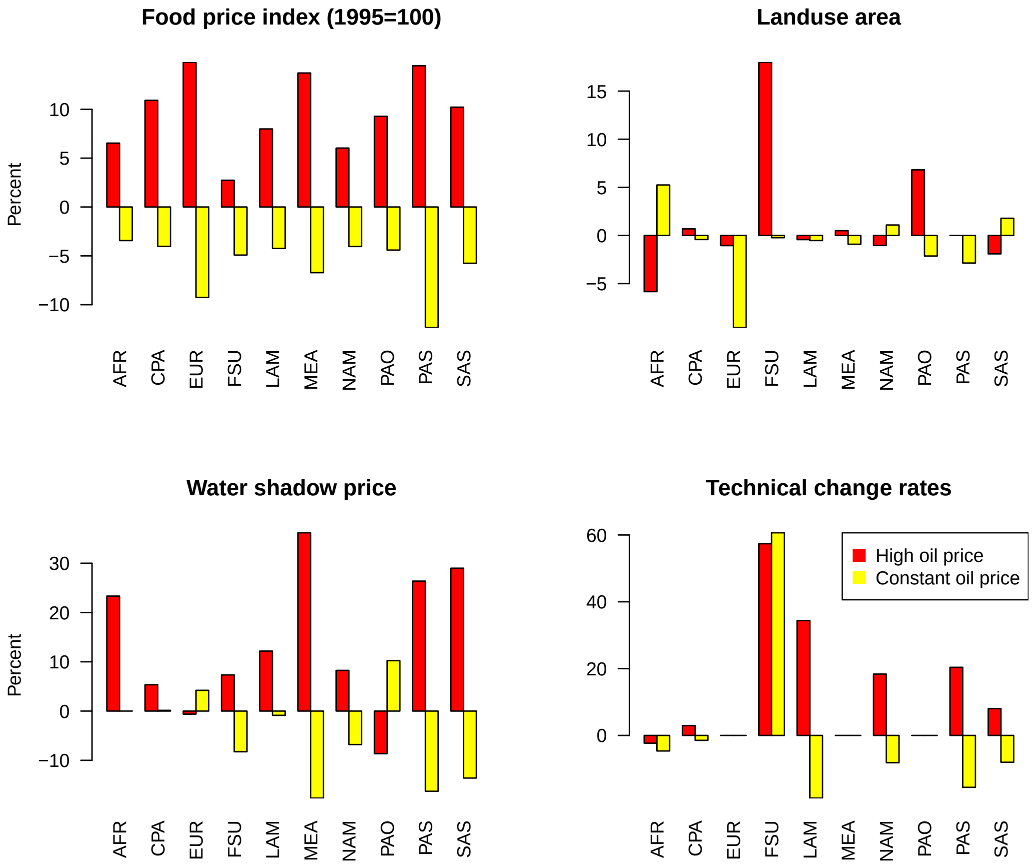

Figure 7: Development of global export of food crops for the three scenarios

more than just tranport costs. But neglecting all this and concentrating on the effects of transport costs, we see that tripling the oil price compared to the baseline scenario, leads to an average increase of food crop prices of 10% and to an over 20% water shadow price increase in water scarce regions as Africa, Middle East Asia, Pacific Asia and South Asia.

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