Impacts of agricultural research-led productivity on land-use change

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This document reports the results of using the Global Trade Analysis Project (GTAP) Model to analyze the global economic effects of agricultural productivity through three different simulations that are of interest to the CGIAR-SPIA Secretariat.

The first simulation is a re-analysis of the counterfactuals specified in Evenson and Rosegrant (2003), which in turn are based on Evenson (2003)'s estimates of the contributions of crop genetic improvement (CGI) in the growth in total factor productivity (TFP) of a broad group of staples in the developing world. Following Evenson and Rosegrant (2003), this simulation seeks to answer how agricultural prices, production, consumption, and trade would have been different in the year 2004 if the developing world had not experienced the agricultural productivity growth attributable to the establishment of National Agricultural Research Systems (NARS) and International Agricultural Research Centers (IARCs).

The other two simulations focus on oilseeds in Brazil, Indonesia, and Malaysia. In the case of Brazil, soybean productivity has grown significantly since 1990. Thus, the second simulation investigates how different prices, production, and land use would have been in the year 2004 if productivity in Brazilian soybeans had stagnated at 1990 levels. Contrary to the two previous counterfactuals, productivity growth in oil palm in Indonesia and Malaysia has been quite limited. Because of this, the third simulation asks what would be the productive effects of an increase in the

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productivity of the oil palm sector in Malaysia and Indonesia similar to the increase experienced by Brazilian soybeans in the period 1990-2004.

The next section describes the modeling framework, emphasizing the treatment of land markets, as well as pointing out some caveats of our modeling approach. Section 2 discusses the results of the three simulations of interest. Section 3 closes with a brief discussion for further research.

1 Modeling framework[1]

We use the GTAP-AEZ model, a modified version of the standard Global Trade Analysis Project (GTAP) Model that incorporates different types of land. The GTAP Model is a multi-commodity, multi-regional computable general equilibrium model. (Detailed discussion on theory and derivation of the behavioral equations involved in the model can be found in the volume by Hertel (1997).) In GTAP, the world economy is divided in regions. Depending on the availability of national input-output data, these regions can be countries (e.g., Brazil) or aggregations of countries (e.g., "Rest of North Africa")[2]. As summarized in Hertel, Burke, and Lobell (2010), in each region, a representative "regional household (e.g., the EU) collects all the income in its region and spends it over three expenditure types — private household (consumer), government, and savings, as governed by a Cobb-Douglas utility function. A representative firm maximizes profits subject to a nested Constant Elasticity of Substitution (CES) production function which combines primary factors and intermediates inputs to produce a final good. Firms pay wages/rental rates to the regional household in return for the employment of land, labor, capital, and natural resources. Firms sell their output to other firms (intermediate inputs), to private households, government, and investment. Since this is a global model, firms also export the tradable commodities and import the intermediate inputs from other regions. These goods are assumed to be differentiated by region, following the Armington assumption, and so the model can track bilateral trade flows."

The model used in this paper incorporates different types of lands in the GTAP standard model.

[1]This section relies heavily on Hertel, Rose, and Tol (2009, p. 14-20) and Hertel et al. (2009, p.125-129).

[2]See table A-1 for a complete list of the regions included in the version 7 of the GTAP Database. Further details for aggregated regions are at https://www.gtap.agecon.purdue.edu/databases/regions.asp?Version=7.211. The GTAP database is fully documented in Narayanan and Walmsley (2008).

The foundation of these data are the global datasets for agricultural productivity from Monfreda, Ramankutty, and Hertel (2009) and forests from Sohngen et al. (2009). Lee et al. (2005) used these data to develop a land use and land cover database that offers a consistent global characterization of land in crops, livestock, and forestry, taking into account biophysical growing conditions. We use the most recent version of this database, which defines 18 global AEZs and identifies crop and forest extent and production for each region by AEZ for specific crop and forest types in year 2004 (Avetisyan, Baldos, and Hertel, 2010). The AEZs represent six different lengths of growing periods (6 x 60 day intervals) spread over three different climatic zones (tropical, temperate, and boreal). Following the work of IIASA/FAO (2010), the length of the growing period depends on temperature, precipitation, soil characteristics, and topography.

The GTAP-AEZ framework used for this work introduces land competition directly into land supply via a two-tiered structure such as that used by Keeney and Hertel (2009). In the upper tier, crops compete with each other for land within a given Agro-Ecological Zone (AEZ). In the lower tier, crops as a whole compete with grazing and forestry for land within a given AEZ. In addition, different AEZs can be substituted in the production of any single agricultural or forest product.

1.1 Derived demand for land

The basic production function in the GTAP-AEZ framework is given in figure 1, where it can be seen that output is a function of all intermediate inputs and a value-added composite. These factors of production substitute for one another with the ease of substitution governed by the parameter σ_T. As with the standard GTAP model, value-added is a composite of skilled and unskilled labor, capital, land, and natural resources (in the case of the extraction sectors). The ease with which these factors substitute for each other is governed by σ_{VA}. The substitutability of the value added components in the production of crops implies that producers can substitute capital and labor for land to increase output. So it is possible to increase production using the same amount of land by employing more of the non-land factors or, in other words, the yields are endogenous.

The land input is an aggregation of the diverse AEZs. For this we assume that the same products produced in the same region must share a common price since they are perfect substitutes in use. If, as we assume, production functions for each crop and within a given region are similar across AEZs, and the firms face the same prices for non-land factors, then land rents in comparable activities must move together (even if they do not share the same initial level). In this case, from the point of view of land markets, the returns to land on different AEZs employed in the production of the same product must move together. This suggests a very high elasticity of substitution, σ_{AEZ}, between AEZs in the crop-specific national production function specification.

1.2 Land supply

Agricultural land is imperfectly mobile across uses. Land supply across alternative uses (sectors), within a given region and AEZ, is constrained via a Constant Elasticity of Transformation (CET) frontier. This is the approach taken in the standard GTAP model, and it is an effective means of restricting land mobility. In this specification, the absolute value of the CET parameter represents the upper bound (the case of an infinitesimal rental share for that use) of the elasticity of supply for a given use of land in response to a change in its rental rate. The lower bound of this supply elasticity is zero (the case of a unitary rental share whereby all land is already devoted to that activity). Furthermore, we follow the nested CET approach of Hertel et al. (2009). In this framework (see figure 2), land owners first decide on the optimal mix among crops. Based on the composite return to land in crop production relative to the the average return on land allocated to productive activities, the land owner then decides on the allocation of land among farming, livestock production, and forests.

Calibration of the constant elasticity of transformation of land supply functions in the model is based on the available econometric evidence. Recent evidence for the United States (U.S.) from Choi (2004) indicates that the elasticity of land supply to forestry averages about 0.25[3]. Accordingly, we set the CET parameter at the bottom of this supply tree (Ω_1) equal to -0.25. This places the maximum forest land supply elasticity at 0.25. In AEZs where the forest land share is dominant, the supply elasticity will be much smaller, as would be expected. At the top of the supply tree where land is supplied to individual crops, we employ the elasticity from the standard GTAP model.

[3]I.e., A 1% increase in the rental price of forestlands relative to the land rents of competing uses increases land supply to forests by 0.25%, provided that forests have an infinitesimal share of total rents.

The GTAP model uses a CET value of -1.0, based on econometric evidence for land supplies to US crop sectors, which suggests an upper bound of 1 on this elasticity. Accordingly, we set $\Omega_2 = -1.0$.

1.3 Caveats

The introduction of land heterogeneity in CGE models is a relatively new enterprise. As such, most of the modeling assumptions need to be validated against observed data. From our description of the modeling framework, two of such assumptions seem critical. On the demand side, it is worth asking: To what extent is it reasonable to assume that there is only one national production function for each crop? On the supply side, a natural question is: What are the compromises implied by using the CET functional form to determine the transformation of land across different uses? Furthermore, there is the question about how to access new lands for which we do not have economic values amenable to use in the modeling framework described above.

The assumption of a unique crop-specific national production function requires further assumptions: a) the products are identical across AEZs, b) common non-land input prices prevail across AEZs, and c) the non-land input-output ratios are the same across AEZs. Under cost minimization and zero profits, these assumptions mean that land rents must vary in direct proportion to yields. The existence of a national production function is used in a number of other modeling approaches such as Eickhout et al. (2008), and the implied inverse relationship between land rents and yields is the building block of their land supply schedules. In their review of the challenges faced by modeling global land markets using CGE models, Hertel, Rose, and Tol (2009) emphasize the need for testing the existence of a national production function using observed data. Of particular interest is the extent to which non-land input-output ratios vary systematically with AEZ either due to different techniques across AEZs or due to differing input prices.

A special challenge for modeling land use is the issue of the homogeneity of land and its potential mobility across uses. As noted by Hertel, Rose, and Tol (2009), "if the unit of observation is small enough so that for all practical purposes the land is perfectly homogeneous, then we would expect rental rates on all land within that unit to be equalized. In the absence of risk and uncertainty, and in the absence of technological interdependence amongst the crops (e.g., benefits from crop rotation or the sharing of common inputs), we would expect farms to specialize in the crop with the highest return, net of non-land input costs. However, farms are often diversified, and certainly most of the larger units of observation (e.g., grid cells or AEZs) exhibit diversification of production. An approach to deal with this diversification is to appeal to risk considerations".

According to the same authors, "when we move to the level of regions, or indeed countries, the appeal of a risk-based approach to model calibration is somewhat lessened. For such large areas, it would seem that diversification likely reflects heterogeneity of the underlying land and climatic endowments, as well as the heterogeneity of local markets. For example, it may be attractive to (e.g.) grow certain crops in the valley and others on the hillside. So physical heterogeneity is a reason why we might observe diversification in crops within a given AEZ."

As mentioned above, the GTAP model deals with land heterogeneity by using a simple CET function by which an aggregate endowment of land is transformed across alternative uses, subject to some transformation parameter that governs the responsiveness of land supply to changes in relative yields. Hertel, Rose, and Tol (2009) note that: "The problem with the CET approach is that the transformation of land from one use to another destroys the ability to track the allocation of hectares across agricultural activities. Instead of constraining the sum of hectares across uses to equal the total availability of hectares in a given AEZ or country, the CET function constrains the land rental share-weighted sum of hectares to equal the total endowment of land. In this framework, differential land rents reflect differences in the effective productivity of a given hectare of land across uses and it is these effective hectares that are constrained in the aggregate. Also, given the lack of an explicit link to yields and the underlying heterogeneity of land, this model is difficult to validate against the observed data. In short, while it is an extremely versatile approach to limiting factor mobility across uses, the CET function covers a multitude of sins. A more explicit approach to handling land heterogeneity would be desirable." Nevertheless, this approach is used in several studies, such as Eickhout et al. (2008).

Another issue where more empirical support desirable, is the pattern of nesting the supply functions. For instance, Hertel et al. (2009) and Taheripour, Hertel, and Tyner (2010) used three different nests: first, there is allocation among crops. Then, depending on relative prices, cropland

and pastures are allocated. Finally, the decision between forests and overall agricultural land is performed. Another pattern of nesting is provided by Eickhout et al. (2008), who single out some crops for special treatment in their nesting structure. The patterns of nesting do have implications for the results obtained: however, there is little empirical evidence to discriminate among them.

A last caveat is that we do not model access to new lands in this study. By new lands, we mean lands that are not economically accessible given current market conditions. A simple approach to dealing with accessibility of new lands in the context of a static CGE model is offered by Eickhout et al. (2008) using the LEITAP modeling framework. They construct a total agricultural land supply curve which specifies the relationship between land supply and land rental rates. For building the supply curves, they need information on total available land, price elasticity of land supply, and land rents. Information on total land comes out of the IMAGE model, a biophysical model with emphasis on the environment. They do not observe land rents and thus assume that marginal land prices are the inverse of aggregated yields (i.e., they imposed the assumption of a unique national production function discussed above) which were also calculated from the IMAGE database. With these two pieces of information and econometric estimates of price elasticities for the EU, they estimate long-run land supply elasticities for non-EU regions. The land elasticities are then used to link LEITAP and IMPACT and determine future land needs. Eickhout et al. (2008)'s approach does not consider the use of land in forestry in their CGE model. More importantly, their approach is mute as to where the new lands come from. The problem with this is that much of the new land that can be brought into commercial production is currently covered with forests (Hertel, Rose, and Tol, 2009, p. 19). Golub, Hertel, and Sohngen (2009) explored the issue of inaccessibility in considerable detail using a dynamic recursive version of the GTAP model. By formulating land use decisions in an investment framework, they model access costs explicitly, and thus, the access to new lands requires real resources. Given the difficulties of modeling the long-run accessibility of new lands in a static model, we maintain the CET formulation discussed above in which the total land endowment is fixed and composed of accessible forests, pastures, and cropland[4].

With these limitations in mind, we now discuss the experimental design and results of the

[4]Details of the underlying agricultural, forestry, and land rents databases can be found in Monfreda, Ramankutty, and Hertel (2009), Sohngen et al. (2009), and Lee et al. (2005).

different counterfactuals.

2 Simulations

2.1 Re-analysis of Evenson and Rosegrant

Evenson and Rosegrant (2003) (E&R) measured the impact of crop genetic improvement (CGI) contributions attributable to national agricultural research systems (NARS) and international agricultural research centers (IARCS) using two counterfactual scenarios. The first scenario, labeled *1965 CGI*, simulated how agricultural prices, production, consumption, and trade would have differed in the year 2000 if the developing world had been constrained to have no CGI after 1965. This first scenario assumed historically observed total factor productivity growth (TFP) via CGI in the developed world and thus aimed to isolate the combined effects of developing countries' NARS and IARCs on the world food system. The second scenario, labeled *No IARC*, covered only the effects of the IARCs.

E&R used two sets of TFP shocks for each scenario. These sets were intended to represent lower and upper ends of the CGI contributions. Table 22.9 (p. 466) of Evenson (2003) provides the basis for these shocks. For convenience, the first three columns of table 1 reproduce the figures of Evenson's table 22.9 relevant for this study[5]. In table 1, the column "CGI" is the annual TFP growth contributions averaged over 1960-1998. Thus, on average for 1960-1998, CGI contributions to TFP growth in "All crops" and "All regions" from both NARS and IARCS grew by 0.72%. The next two columns, IARC25 and IARC50, are estimates of CGI contributions of the IARCS only. These estimates are based on the assumption that in the absence of IARCs, NARS would have been more active, thus contributing some of the TFP growth that came out of the IARCS. So back in table 1, column IARC25 is the 1960-98 average CGI contributions to TFP assuming that if the IARCS had not been created, the NARS would have produced 25% more varieties that would have been adopted by farmers with the same yield impact as the IARC crosses would have had. The column IARC50 presents estimates assuming a substitution rate of 50%.

[5] We try to use the same regional aggregations of Evenson and E&R. The mapping between the aggregated IMPACT regions, the GTAP regions, and the regions used in this study is in table A-1.

In the context of a static model such as GTAP, the first step to obtain the lower and upper bounds of each counterfactual is to calculate the size of the shocks to apply to the initial equilibrium. It is important to understand that these are one-time shocks; that is, the assumption is that the economy moves from an initial equilibrium (characterized in the baseline year of 2004) to a counterfactual equilibrium in one step. This contrasts with the solution of the IMPACT model that recursively applies annual shocks for as many periods as needed. Another difference between E&R and this work are the baseline years. As mentioned, E&R used the year 2000, while we use the year 2004. In practical terms, this means that we will be using slightly larger shocks (equivalent to the difference in TFP growth between 2000 and 2004). However, to the extent that the TFP growth between 2000 and 2004 is properly reflected in our baseline, this difference is of limited importance.

To adapt the data from Evenson to our needs, the annual shocks are composed over the period, 1965-2004. This is shown in table 1, column "CGICONT."[6] Following Evenson and E&R, the total CGI contribution in column "CGICONT" is a conservative estimate of the combined effects of NARS and IARCS because it ignores the potential complementarity between CGI and non-CGI factors in TFP growth. Hence, the lower end set of shocks for the *1965 CGI* scenario is just the negative of the total TFP contributions (as shown in column "CGIL," the total contribution of CGI to TFP growth in All crops and All regions during 1965-2004 years was 32%). To obtain the upper end of the NARS-IARC contributions, the lower end is multiplied by 1.3 (E&R, p. 483). These upper ends are in the column labeled "CGIU." For the *No IARC* scenario, E&R used the 1/2 substitution (column IARC50) as the lower end and the 1/4 substitution as the upper end. As before, we compound those shocks for the period 1965-2004. The results are shown in columns IARCL[7] and IARCU[8].

Another small issue is that the commodity aggregations of the IMPACT and GTAP model are different[9]. In particular, barley, maize, millets, and sorghum are all embedded within the coarse grains ("Cereal grains nec") sector, while cassava, lentils, beans, and potatoes are aggregated within

[6] $CGICONT = (((1 + CGI/100)^{2004-1965}) - 1) * 100$ with CGI in the first column of table 1.

[7] $IARCL = ((1 + IARC50/100)^{2004-1965} - 1) * 100$ with IARC50 in table 1.

[8] $IARCU = ((1 + IARC25/100)^{2004-1965} - 1) * 100$ with IARC25 in table 1.

[9] Our sectoral aggregation consists of rice, wheat, coarse grains, oil-seeds, vegetables & fruits, rest of agricultural products, forests, pasture-supported animal production (bovine cattle, sheep and goats, horses, raw milk and wool), other animal products, agriculture and food processing, vegetable oils and fats, manufacturing and services.

the vegetable and fruits ("Vegetable, fruit, nuts") sectors[10].

To translate Evenson's shocks to the GTAP model, we weight the shocks using production value shares derived from FAO data[11]. The value-share weighted shocks are shown in table 2. As can be seen, the shocks in the vegetable & fruits sectors are quite low because cassava, lentils, and potatoes have both low CGI gains (see table 1) and low value shares. On the other hand, the coarse grains sector shows large shocks due to the significant CGI gains in maize, millets, and sorghum, and the large value shares of these products in the coarse grains aggregate. The values for sub-Saharan place Africa relatively low due to the low CGI gains for this region.

The shocks in tables 1 and 2 are implemented by using the factor neutral (i.e., TFP), technical change variable attached to the production functions of each crop and region (see Gohin and Hertel, 2003, for derivations). This is an analogous procedure to that of E&R who applied their shocks to a "non-price total factor productivity term" embedded in the IMPACT's yield functions (Evenson and Rosegrant, 2003, p. 478). We employ the standard GTAP model closure which imposes equilibrium in all the markets, where firms earn zero-profits, the regional household is on its budget constraint, and global investment equals global savings.

2.1.1 Simulation results

Our objective is to understand the changes in global land use associated with the productivity gains in plant crop genetic improvement. To initiate this investigation, we begin with a focus on developing countries, where the initial impact of productivity shocks arises. The first row in the upper panel of table 3 show the impacts on agricultural output[12] for the lower and upper ends of the 1965 CGI counterfactuals in developing countries. Unless otherwise indicated, the results are the percentage differences between the base year (2004) and the counterfactual[13]. Thus, in the absence of CGI, wheat production in the developing world in 2004 would have been 43 to 60%

[10] "Cereal grains nec" and "Vegetable, fruit, nuts" are standard labels of the GTAP commodity classification, which have a somehow widespread use in the general equilibrium and agricultural trade literatures (Josling et al., 2010). In what follows, we use the more convenient labels "coarse grains" and "vegetable and fruits".

[11] The value shares are in tables A-2 and A-3 in the appendix.

[12] Variable *qo*, percentage change in output weighted by physical output.

[13] To move between different levels of aggregation we use value, production, or area share weighted averages depending on the variable.

lower than it actually was. The decrease in production can be observed in wheat, rice, grains, and vegetables & fruits. These are the crops affected by the productivity shocks, so this decline across the board is not surprising. Table 3 shows two additional commodity categories — oilseeds and other agricultural products — that, although not directly affected by the shocks are important for the aggregated changes in land use discussed below. As can be seen in table 3 these crops also show declines in production as a result of the reallocation of production factors (such as land) to those crops which prices have increased.

The contribution of each crop to total agricultural output varies by region. Thus, we weight the percentage changes by production values to get a sense of the overall output results. The column "ER crops" shows the weighted average only for the crops subjected to productivity shocks. Thus, on average, the combined output of these crops in the developing world was 10-15% lower than actually observed. When all the crops are included (column "All Crops") production-value-weighted output declined by 8-12% in the developing countries. The reductions in TFP for the No IARC CGI counterfactuals are much smaller than those in the 1965 CGI scenarios and thus, the production effects are smaller. For wheat, rice, coarse grains, and vegetables & fruits, the column, "ER crops," indicates that agricultural output fell on average 3%, while the output of the entire agricultural sector ("All Crops") declined by 2%. The much more limited output effects of the No IARC scenario provide evidence of the important role of the NARS (Evenson & Rosegrant).

The output reductions in the developing world are ultimately reflected in increased world prices. The first two rows of table 4 report equilibrium prices[14] for the 1965 CGI and No IARC scenarios. In the case of the 1965 CGI counterfactual equilibrium, wheat prices would have been 29-59% higher than they actually were in 2004. For rice, 2004 prices would have been 68-134% higher. As noticed by E&R, price increases from CGI reductions in developing countries depend on both actual CGI gains, which vary by crop, and on the proportion of the crop produced in developing countries. Because rice is mostly produced in developing countries, price effects in the rice sector are more pronounced than in other crops. The coarse grains also show significant price increases (20,41%), while prices in the vegetable & fruit categories are more moderate (6-10%), reflecting

[14] Variable pm, percentage change in regional market prices weighted by export values.

both lower CGI gains in cassava and the fact that potatoes and cassava represent relatively low shares of the production value of vegetables & fruits. In line with the output effects, price effects in the No IARC CGI counterfactuals are much smaller than those in the 1965 CGI scenarios. For the crops subjected to shocks, "ER crops" shows that prices in the 1965 CGI counterfactual would have been 13-26% higher. In the No IARC counterfactuals, we found price increases of 4-5%.

The crops not subjected to shocks (oilseeds and rest of the agricultural sector) also experience price increases as a consequence of the decline in production associated with the migration of production factors to the sectors with direct productivity loses (three last columns in table 4). Thus, for all crops (column "All crops"), price increases would have been 10-19% and 3% in the 1965 CGI and No IARC counterfactual, respectively; this figures are slightly lower to those for the affected crops as oilseeds and other agricultural products represent large shares of global exports.

For ease of comparison, the lower panel of table 4 shows the main results obtained by E&R. Their price increases are remarkably similar to ours. For the 1965 CGI counterfactual, they found that wheat prices increased by 29-61%, rice by 80-124%, maize by 23-45%, and other grains, 21-50%. Although not shown in table 4, E&R also reported price increases for potatoes (13-31%) and other root crops (28-52%). In GTAP, these products are in the vegetable & fruit categories, which shows a moderate range of price increase (6-10%), reflecting both lower CGI gains in cassava and the fact that potatoes and root crops have relatively low production values. Similarities are also found in the No IARC scenarios. For all the crops, E&R estimated an increase of 35-66%, twice as high as our estimates, probably reflecting differences in trade assumptions and weighting schemes. The trade assumptions are important because they determine the international patterns of agricultural production. While IMPACT assumes that there is an integrated world market with one global market clearing equation for agricultural commodities GTAP uses the Armington assumption that assumes that products are differentiated by virtue of their national origin. In the first case there is a prevailing world price while in the latter there are as many prices as trading partners. In general, the integrated world market tend to give a higher supply response in larger countries thus reducing trade relative to the Armington assumption [15]. This reduced level of trade may explain lower price

[15] For an econometric analysis of these assumptions the reader is referred to Villoria and Hertel (2010).

effects in IMPACT, although without a formal comparison of the models this is just speculation. Another potential difference is that we use export values to weight-average the prices over crops while E&R used production values.

Price effects are the consequence of reduced productivity, but at the same time, higher prices make production more profitable, thus attracting production factors (land, labor, capital) that are withdrawn from other activities. In the case of land, the increase in supply prices translates into higher land rents, thus attracting more land into the sectors where productivity was negatively affected. As mentioned above, these higher land rents in the affected sectors are responsible for the output contraction and price increases of the non-affected crops, oilseeds and rest of the agricultural sector. Back in table 3, it can be seen that the harvested area[16] of rice and coarse grains increase considerably under the 1965 CGI counterfactual (19-25% and 15-25% respectively) and more moderately under the No IARC counterfactuals (5-6% and 4-5%). The expansion of lands in these sectors is partly sustained by reductions of land in wheat, vegetable & fruit, oilseed, and other agricultural sectors, which also experience a reduction of their outputs. Overall, harvested areas in the developing world increased by 1% in the 1965 CGI counterfactual but kept constant in the No IARC counterfactual.

The third and sixth rows of table 3 show yields[17] for both scenarios. In general, yields declined as a consequence of the productivity shocks applied. Together, the figures on production, area, and yields indicate that the expansion of areas experienced by the developing countries could not offset the decline in yields, leading to a decline in overall production. The decline in overall production is reflected in reduced exports from developing countries (fourth and eighth rows of the upper panel in table 3[18]) under both scenarios. The exception is rice, a crop for which exports increased under the 1965 CGI counterfactual by 19-240%. The wide range of these changes in exports is consistent with the wide range of rice price increases shown in table 4. Under the more conservative No IARC scenario, rice exports also declined (28-30%). To get a more realistic measure of export decline, we weight the changes in exports by their export values. These weighted averages show overall export

[16] Variable harvstcom(j,r), using harvested area to weight the regional values.
[17] Variable p_YIELD, percentage change in yield weighted by production in tonnes.
[18] The variable shown is qxw, percentage change in exports weighted using export values.

reductions of 7-11% in the 1965 NO CGI counterfactual and 0-5% in the No IARC scenarios. To compensate for the losses in domestic production, developing countries imported more of their food from abroad.(The fifth and tenth rows of the upper panel in table 3 show that for the affected crops, imports[19] increased by 54-99% in the 1965 CGIAR counterfactual and 11-14% in the No IARC. For the agricultural sector as a whole, imports increased by 6-8%.)

The price increases caused by declining production in developing countries stimulate expansion of the crop sector in developed countries. In table 3, in the first row of the lower panel (for developed countries), it can be seen that for all the crops subject to shocks (column "ER All"), the increase in the 1965 CGI counterfactual was 16-27% and 4-5% in the No IARC. When oilseeds and other agricultural sectors are included, the increase is 12-20% (column "All Crops") and 3-4% for the 1965 CGI and No IARC counterfactuals, respectively. The output expansion in the developed countries is explained by modest increases in area (1-2% in the 1965 CGI counterfactual and and none in the NO IARC scenarios) and sizable increases in yields of 11-19% (1965 CGI) and 3% (No IARC)[20]. Finally, exports from the developed to the developing countries increased by 25-43% (1965 CGI) and 6-8% (No IARC), which is consistent with the trade changes for developing countries discussed above.

Table 4 combines the changes in developing and developed countries showing that production in the affected crops declined by around 1% in the 1965 CGI counterfactual and kept constant under the No CGIAR scenarios. When all crops are included, production declines were slightly higher (2% and 1% for the 1965 CGI and No IARC counterfactuals, respectively). This finding is in line with those of Evenson and Rosegrant (2003), who found that the impacts of CGI were sizable and important for prices but much more reduced in terms of production and area than what can be expected at first sight by seeing the important contributions of CGI to agricultural growth.

In terms of the area devoted to the crops subjected to the shocks, we find increases of 6-8% and 2% for the 1965 CGI and No IARC counterfactuals, respectively. As with prices, these results are quite close to those of E&R, who found aggregate area changes of 2.8-4.6% and 1.5-2.7% for

[19]Variable *qiw*, percentage changes in imports, weighted by import values when necessary.

[20]Evenson2003a get yield increases in developed countries of 2.32-4.77% (1965 CGI) and 1.35-2.45% (NO IARC). For developing countries, they find yield decreases of 19.45-23.50% and 8.07-8.91%.

the 1965 CGI and No IARC counterfactuals (see table 23.3 in E&R and lower panel of table 4 in this report). However, when the area contraction in the rest of the agricultural sector (oilseeds and others) is considered, the expansion reduces to 1-2% for the 1965 CGI counterfactuals and around 1% of the No CGIAR scenarios (see the last two rows, column "All Crops" in table 4). In addition to the differences between the trade assumptions in IMPACT ant GTAP, a probable cause of the divergence in E&R and the GTAP results is that GTAP includes factor markets that are linked to product markets. In the case of land, the endowment is fixed, and thus expansion possibilities are constrained. This causes that much of the expansion in the affected crops comes from reductions in the area of other crops, forest, and pastures. We emphasize however, that given the fundamental differences between the two modeling approaches, a direct comparison of the results is likely to be unfruitful and incomplete. Moreover, as discussed below, our total area estimates are consistent with those of E&R.

The natural question at this point is where the land for agriculture comes from. Table 5 shows productivity (rental) weighted changes in land use in the developed and developing countries. As discussed, in the 1965 CGI counterfactual, cropland expanded by around 1% in the developing countries. Table 5 shows that much of this expansion comes from forests and some from pastures. In the developed countries, land expansion also comes from forest and pastures but the contribution of each sector is more even. The No IARC results are in generally more reduced due to the lower shocks.

As noted in the previous section, the CET functional form optimizes land allocations based on their productivity. As a consequence, land allocation in the CET is constrained by the productivity-weighted value of the land endowment rather than by total area. Because not all the hectares are equally productive, CET effective area and physical area generally differ considerably. More theory is needed to get the area estimates from the GTAP model to be consistent with observed data on physical hectares. In absence of this theory, an ad-hoc mechanism to translate the CET changes to physical changes is to adjust the CET outcomes by a productivity differential[21]. This productivity

[21] A naive approach would be to simply use the percentage changes in table 5 and the hectares of each cover to get an estimate of physical has. According to the GTAP database there are 841.41 million ha of forestlands in the developing world and 836.74 in the developed world. Using the percentage changes for the lower end of the 1965 CGI counterfactuals, this would imply a reduction of 4.45 and 2.42 million ha in the developing an developed world,

adjustment equalizes the productivity-weighted sum of changes in effective hectares of different crops (such as those reported in table 3) or land covers (shown in table 5) with the area-weighted sum of changes in physical hectares. A problem with this approach is that the land rents of the different covers vary widely. While the CET handles such differences trough a constant elasticity of transformation, it is likely the case that difference in land rents reflect high conversion costs that at the moment are not explicitly taken into account. The differences in land rents among land covers (pasture, forests, and croplands) are much larger than differences in land rents among crops. In the particular context of the experiments performed here, the productivity adjustments yield implausible results.

The differences in land rents among crops are much smaller, and the productivity adjustments tend to work well giving plausible results. Table 6 translates the changes in crop CET area to changes in hectares by world region and crop using the productivity adjustments explained above. The intersection of the last two rows and the last column in table 6 show that globally, the 1965 CGI counterfactual would imply an expansion in cropland of between 17.95 and 26.75 million ha of which 11.97-17.68 million ha are in the developing regions. The No IARC scenario table 6, shows an expansion of 5.75-6.58 million ha with 3.55-4.02 in the developing regions. Again, notwithstanding fundamental differences in modeling approaches and underlying databases, the 1965 CGI results are close to those obtained by E&R who estimated an expansion of 24-32 million ha (15-20 in developing countries) under the 1965 CGI counterfactual. For the NO IARC scenarios their area estimates a lower (16-19 million ha with 11-13 million in developing countries).

Table 6 also shows that the contributions of regions such as sub-Saharan Africa and the Middle East and North Africa are quite modest because the CGI contributions in these regions were low. The bulk of the area comes from the developed countries and the Rest of Asia (which includes large countries such as China and India). In table 7, we show the hectares at the level of aggregation used in the simulations. It can be seen that China and India are the largest contributors to area

respectively. The GTAP database indicates that there are 1819 million ha of pastures in the developing world and 926 million ha in the developed world. For the lower end of th 1965 CGI counterfactual this would imply a reduction of 7.10 and -1.94 million ha in the developing and developed world, respectively. It is important to reiterate that these estimates assume that productivity, and as a consequence, land rents, do not vary across physical hectares, an assumption that is clearly untenable.

expansion in the Rest of Asia.

2.1.2 Focus on South-East Asia

The productivity shock in Southeast Asia caused a significant contraction in the production of rice (1965 CGI:-22, -35; No IARC:-6, -7) and coarse grains (1965 CGI: -23, -33; No IARC: -7, -8). This is reflected in the considerable increase in the price of rice (1965 CGI: 125, 220; No IARC: 25, 29) and of coarse grains (1965 CGI: 137, 258; No IARC:30, 35) and in expansion of the area devoted to rice (1965 CGI: 16, 20; No IARC: 5, 6) and to some extent to coarse grains (1965 CGI: 19, 30; No IARC: 7, 7). Some of the land expansion comes from other crops as the higher prices in the rice and coarse grains sector stiffens competition for resources, for a total cropland expansion of 0.58-.75% in the 1965 CGI and 0.and 17-0.2% in the No IARC scenarios. This translates into 0.69-0.89 million ha in the 1965 CGI counterfactual and 0.2-0.23 in the No IARC (third and fourth rows in table 6). Note that the largest expansion is in rice (1965 CGI: 7,9 million ha; No IARC: 2.1,2.4 million ha), followed by coarse grains, with sharp reductions of the area devoted to oilseeds, vegetables and fruits, and other agricultural sectors.

2.2 Reduction in soybean productivity in Brazil

Data provided by the CGIAR-SPIA Secretariat shows that soybean yields in Brazil have grown around 3% per year during the last two decades. For the period 1990-2004, this represents total yield growth of approximately 57%[22]. We assume that this growth in yields comes from increases in total factor productivity. In the GTAP database, soybeans are part of the category, oilseeds. A look at FAO production and price data for 2004 reveals that 96% of the Brazilian oilseed sector is soybeans, so we adjust the TFP growth estimate by this value share, obtaining a shock of 55%. As in the previous shocks, the reductions in TFP are applied to the year 2004. Thus, we are answering the question: How different would have been prices, production, and land use in the year 2004 if productivity in Brazilian soybeans had stagnated at 1990 levels.

Table 8 summarizes the result of this exercise for oilseeds and for the rest of the crops used in the

[22] Using continuous compounding of the average change in yields (i.e.) $e^{3\% \times 15 years} \times 100 = 56.69\%$.

aggregation described above. The upper panel presents percentage changes in prices, production, and other variables of interest for Brazil. The lower panel presents the same information for the rest of the world. The first column in the upper panel of table 8 shows that the decrease in productivity reduces soybean output by 67% while substantially increasing prices by 135%. This decline in output can be decomposed in a reduction of domestic consumption (which falls by 48% — not shown in the table) and demand for exports (which, as shown in table 8, declines by 95%). This is a considerable loss of competitiveness. However, in contrast to the simulations above, this is a localized shock. Thus, although Brazil is an important world producer and exporter of soybeans (see figures 3 and 4), price disruptions overseas are moderate, around 2% as shown in the first row of the lower panel of table 8. This limited price impact in the face of such large declines in output is explained by a highly elastic import demand curve. The general equilibrium elasticity of export demand is -2.50. Thus a 1% increase in the Brazilian price causes a more than proportional reduction in import demand of 2.5%. This elasticity is based on econometric estimates which show that trade demands are generally more elastic than domestic demands, reflecting, in this case, the fact that there are many other oilseed producers that can fill the gaps left by Brazil. Thus, table 9 shows how Canada, China, the EU, and the United States increase both output and exports to respond to the 2% price rise increase originating in the Brazilian oilseeds sector.

In Brazil, the lower demand for soybeans translates into lower demand for land and non-land inputs. The rental price of land for soybean production decline by 37%, thus encouraging the expansion of other agricultural activities such as rice and coarse grains (see columns 2 to 6 in table 8). Much of this expansion is simply taking place in land formerly used for growing soybeans; thus, the net result is a contraction of the overall cropland. This can be seen in table 10, which shows rental share weighted percentage changes in land covers by agro-ecological zones or AEZ. Note that in AEZs 4 to 6 and AEZ 12, there are small contractions in cropland. These AEZs are where the agricultural production in Brazil is concentrated. This can be seen in table 11, which shows land rents in each AEZ for each cover: cropland, forest, and pastures. As most of the production is concentrated in AEZs 4 to 6, as well as 12, and cropland is declining in those AEZs, the model predicts a modest expansion of forested areas and pasture. Averaging over AEZs using as weights land rents, Brazilian cropland contracts by -0.24%, making way for forest expansion (0.10%) and growth in pastures (0.13%). As shown in the first column of the lower panel of table 8, the area devoted to soybeans in the rest of the world increases by 6%. Globally, this translates into some cropland expansion (0.05%) at the expense of forests (which decline by -0.03%) and pastures (-0.02%)[23].

Finally, table 12 translates the changes in croplands into terms of new hectares for oilseeds, all the competing crops, and the entire cropland (column "All crops"). The last column shows that Brazilian cropland decreases by 300.000 ha. Combined, the rest of the world would put 1.2 million ha into soybean production to compensate for Brazil's loss of competitiveness.

2.3 Palm oil in Malaysia and Indonesia

Productivity gains in the palm oil sectors of Indonesia and Malaysia during the last ten years have been meager (see report by Derek Byerlee). So, in contrast to the two other experiments, here we do not evaluate the impact of past growth in TFP attributable to CGI or other improvements. Instead, we work with a prospective scenario that evaluates what would be the productive effects of an increase in the productivity of the oil palm sector in Malaysia and Indonesia similar to the increase experienced by Brazilian soybeans (57% growth in TFP during 1990-2004). Due to the similarities in agro-ecological endowments, we apply the shocks to a region that combines Indonesia and Malaysia. In the GTAP database, oil palm and palm oil are in separated categories. Oil palm is included in the category oilseeds, while palm oil is included in the category vegetable oils and fats. The productivity shock is applied to the oilseeds sector. Because oilseeds are tightly coupled to the palm oil processing sector (the GTAP database indicates that 99% of the region's production of oilseeds is for domestic production of palm oil), below we discuss the implications for both the primary and the processing sectors. According to FAO data, oil palm accounts for 68% of the total oilseed sector in Malaysia and 81% in Indonesia. Thus, we adjust the shock of 57% using Indonesia's

[23]We refrain from reporting these changes in terms of physical hectares due to the reasons discussed. A naive conversion of these estimates to physical hectares yields an expansion of 150 thousand ha of Brazilian forests (0.10% $\times$ 156.07 million ha of forests) and 220 thousand ha of pastures (0.13% $\times$ 175.04 million ha of forests). In the rest of the world, the naive estimates suggest a reduction of 456 thousand ha of forests (0.03% $\times$ 1522.08 million ha of forests) and of 514 thousand ha of pastures (0.02% $\times$ 2570.21 million ha of pastures).

share of oil palm in oilseeds and increase the productivity of the oilseeds sector in Indonesia and Malaysia by 46.17%.

The increase in TFP in the oilseed sector causes output to expand by 68%, as shown in the first row and column of table 13. As a consequence, producer prices decline (by 26%). The expansion of the oilseed sector is explained by an important increase in yields (58%), a natural result as the shock increased the productivity of all land and non-land inputs, and by a increase in harvested area of 10%[24]. The reason of the expansion in area is and increase in the rental price of land (+7%) that in turn is caused by an increase in palm oil exports, as discussed below. This mirrors the Brazilian case in which a decline in productivity resulted in a decline in the amount of land used for growing soybeans. Indeed, the import-demand elasticity of palm oil to changes in the price of oil palm is -2.63[25], a high value that implies that a 1% reduction in the price of oil palm fruits increases the demand for imports by 2.63%.

Palm oil firms benefit from the lower price palm seeds[26]. The decline in oil palm prices translates into a reduction of 17% in the price of palm oil (see first row, second column of table 13). This cost advantage inherited from the productivity increases in oil palm production induces an expansion of the palm oil industry (by 74%) and exports (by 98%). For the rest of the world, the shock has a moderate impact on oil palm prices (as shown in the first column of the lower panel in table 13). However, the growth in Indonesia-Malaysian palm oil exports comes at the expense of other exporters; thus, production and exports in the rest of the world decline by 9 and 18% respectively, as shown in the second column, lower panel of table 13.

Table 14 shows changes in harvested areas (in million ha) for Indonesia-Malaysia and other oilseed producers. In Indonesia-Malaysia, there is an expansion of 1.1 million for oil palm production. This land expansion is the consequence of an increase in the rental price of land for oil palm production (which increased by 7%), that in turn takes land away from other crops; thus, the land

[24]Table 13 also reports a large increase in exports. However, although the region is an important producer of oilseeds (see figure 3), it is a marginal exporter (figure 4); thus, the increase in exports is of little importance.

[25]This is a general equilibrium elasticity based on the econometric partial-equilibrium estimates of price and income elasticities that underlie the GTAP parameters.

[26]According to the GTAP database (Narayanan and Walmsley, 2008), oilseeds represent around 15% of total palm oil costs; however, evidence from FAOSTAT and cost structures for Indonesia indicate that oil palm represents more than 80% of the value of palm oil production. To remedy this, we adjusted the cost structure of the vegetable oils and fats for Indonesia-Malaysia so oil palm represents 80% of the palm oil production costs.

to all the other crops decline by 1 million ha. As a result, Indonesia-Malaysia needs approximately 100,000 ha of additional cropland to grow oilseeds, all of which are coming from deforestation (as displayed in table 15, which shows percentage changes in land covers in Indonesia-Malaysia and the rest of the world). Recall that the expansion of oil palm production in Indonesia-Malaysia reduces production and exports elsewhere, thus, the shock implies a global reduction of around 500.000 ha of cropland (last row and column in table 14), which in turn increase by similar proportions the areas devoted to forests and pastures (as shown in table 15).

3 Recommendations for possible future research

The incorporation of land use in global policy models is an area of active research. In this section, we highlight two activities that would improve current practices and complement existing efforts.

As mentioned in the modeling section, a disadvantage of the CES functional form currently used to model land supply is its inability to relate changes in effective (productivity-weighted) area with physical measures such as hectares. This inability is the result of a compromise between conceptual consistency and empirical tractability. The main challenge is to devise a framework that recognizes the heterogeneity of the land endowment, even within the same AEZ. Empirically, this heterogeneity manifests itself in large differences in land rents among different activities, especially among the land cover categories: cropland, pastures, and forests. It is likely that many of these differences reflect transformation costs that are not taken into account by the CET functional form. While transformation costs among covers can explain some of the differences in land rents, it is reasonable to expect that some of these differences relate to the diversification of production due to the heterogeneity of the land endowment. To tackle this heterogeneity, there is the need to calibrate functional forms that can handle joint production, such as the CRETH (constant ratio of elasticities of transformation, homothetic) form employed by Vincent, Dixon, and Powell (1980). Thus, fruitful areas of research would encompass a combined strategy in which transformation costs are explicitly modeled and production diversification due to land heterogeneity is properly recognized through an appropriate functional form.

A related issue, for which empirical knowledge is lacking, is the productivity of marginal lands.

In principle, it is reasonable to expect that the most productive lands are already in production; thus, land expansion will come from lands that are less productive given the same level of inputs. Work in this area is almost non existent, although some modeling groups are employing eco-terrestrial models in the investigation of productive potential given biophysical attributes[27]. An alternative to the use of eco-terrestrial models is to use statistical techniques (Lobell and Burke, 2010) and the recent global gridded datasets such as Monfreda, Ramankutty, and Hertel (2009) to predict productive behavior, given biophysical and socioeconomic covariates.

[27] Farzad Taheripour, personal communication.

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Table 1: CGI and IARC contributions to yield growth 1965-2004 (percentages)

Crop	Regions	CGI	IARC25	IARC50	CGICONT	CGIL	CGIU	IARCL	IARCU
All crops	All regions	0.72	0.33	0.29	32.18	-32.18	-41.84	-12.00	-13.62
	Asia	0.88	0.39	0.35	40.95	-40.95	-53.24	-14.73	-16.53
	Latin America	0.66	0.28	0.24	29.15	-29.15	-37.89	-10.01	-11.48
	MENA	0.69	0.39	0.33	30.66	-30.66	-39.85	-13.80	-16.44
	SS Africa	0.28	0.13	0.11	11.52	-11.52	-14.98	-4.30	-5.12
Barley	MENA	0.49	0.28	0.23	21.00	-21.00	-27.30	-9.59	-11.43
Beans	All regions	0.21	0.13	0.10	8.44	-8.44	-10.97	-3.89	-5.24
	Latin America	0.22	0.13	0.09	9.03	-9.03	-11.74	-3.65	-5.07
	SS Africa	0.18	0.12	0.09	7.27	-7.27	-9.45	-3.73	-4.87
Cassava	All regions	0.22	0.14	0.11	9.03	-9.03	-11.74	-4.34	-5.69
	Asia	0.17	0.12	0.09	7.02	-7.02	-9.12	-3.61	-4.71
	Latin America	0.10	0.00	0.00	3.98	-3.98	-5.17	-0.12	-0.20
	SS Africa	0.25	0.17	0.13	10.18	-10.18	-13.24	-5.16	-6.81
Lentils	MENA	0.28	0.14	0.11	11.65	-11.65	-15.15	-4.46	-5.77
Maize	All regions	0.66	0.29	0.26	29.50	-29.50	-38.35	-10.87	-12.00
	Asia	0.96	0.45	0.40	45.10	-45.10	-58.63	-17.07	-19.32
	Latin America	0.62	0.20	0.19	27.51	-27.51	-35.76	-7.77	-8.23
	SS Africa	0.22	0.13	0.12	9.12	-9.12	-11.85	-4.91	-5.16
Millets	All regions	0.56	0.29	0.26	24.57	-24.57	-31.95	-10.74	-11.78
	Asia	1.04	0.55	0.51	49.88	-49.88	-64.84	-21.94	-23.95
	SS Africa	0.18	0.07	0.07	7.43	-7.43	-9.66	-2.61	-2.97
Potatoes	All regions	0.81	0.12	0.10	36.82	-36.82	-47.86	-4.06	-4.67
	Asia	0.82	0.09	0.08	37.77	-37.77	-49.10	-3.05	-3.41
	Latin America	0.75	0.10	0.09	33.93	-33.93	-44.12	-3.65	-4.14
	SS Africa	0.74	0.38	0.29	33.26	-33.26	-43.24	-12.13	-15.90
Rice	All regions	0.79	0.35	0.31	36.13	-36.13	-46.97	-12.92	-14.69
	Asia	0.87	0.37	0.33	40.08	-40.08	-52.11	-13.58	-15.49
	Latin America	0.82	0.37	0.33	37.40	-37.40	-48.62	-13.75	-15.67
	SS Africa	0.54	0.17	0.15	23.61	-23.61	-30.69	-6.14	-7.02
Sorghum	All regions	0.50	0.15	0.13	21.66	-21.66	-28.16	-5.07	-6.06
	Asia	0.85	0.20	0.19	38.95	-38.95	-50.63	-7.52	-7.89
	SS Africa	0.30	0.13	0.12	12.57	-12.57	-16.34	-4.87	-5.32
Wheat	All regions	0.96	0.46	0.41	45.15	-45.15	-58.70	-17.39	-19.79
	Asia	1.01	0.46	0.43	47.75	-47.75	-62.08	-18.08	-19.83
	Latin America	1.06	0.62	0.52	50.81	-50.81	-66.05	-22.32	-27.26
	MENA	0.83	0.48	0.41	37.99	-37.99	-49.38	-17.12	-20.39
	SS Africa	0.53	0.28	0.25	22.94	-22.94	-29.82	-10.40	-11.74

The three first columns are annual contributions of crop genetic improvement to total factor productivity growth. These contributions are taken fron Evenson (2003), table 22.9, p 466.-467. The rest of the columns compound these estimates over the period 1965-2004. See the main text of this report for details in the calculations of the lower and upper ends.

Table 2: E&R shocks aggregated to GTAP categories (percentages)

Category	DSUPERREG	CGI_L	CGI_U	NOIARC_L	NOIARC_U
Veg. & Fruits	Asia	-2.30	-2.99	-0.26	-0.31
	Latin America	-2.74	-3.56	-0.45	-0.57
	Middle East & N. Africa	-0.13	-0.17	-0.05	-0.07
	Sub-saharan Africa	-3.01	-3.91	-1.35	-1.77
Coarse grains	Asia	-43.34	-56.34	-16.33	-18.42
	Latin America	-23.44	-30.48	-6.62	-7.01
	Middle East & N. Africa	-11.41	-14.83	-5.21	-6.21
	Sub-saharan Africa	-9.23	-12.01	-4.11	-4.42

The shocks come from adjusting the shocks for cassava, potatoes, and lentils from the previous table by their value shares (reported in appendix) in the aggregated GTAP category vegetables & fruits. Likewise, sorghum, barley, and maize are adjusted by their value shares on the GTAP category coarse grains.

Table 3: Decomposition of production changes in yield and area changes — developing and developed countries

Region	Scenario	Variable	Wheat	Rice	C. Grains	Veg & Fruits	ER All	Oilseeds	Other Ag.	All Crops
Developing	1965 CGI	Production	-43, -60	-14, -22	-6, -6	-4, -7	-10, -15	-7, -11	-3, -5	-8, -12
		Harv.Area	-5, -11	19, 25	15, 25	-11, -15	5, 7	-12, -16	-11, -14	1, 1
		Yield	-38, -49	-33, -48	-21, -31	7, 8	-15, -22	4, 5	8, 10	-9, -13
		Exports	-85, -93	19, 240	-34, -38	-2, -1	-11, -7	3, 6	1, 6	-5, 0
		Imports	111, 191	228, 560	23, 50	6, 11	54, 99	-1, -2	6, 13	30, 56
	No IARC	Production	-12, -15	-3, -4	-2, -2	-1, -1	-3, -3	-2, -2	-1, -1	-2, -2
		Harv.Area	2, 1	5, 6	4, 5	-4, -4	2, 2	-4, -4	-4, -4	0, 0
		Yield	-14, -16	-9, -10	-6, -7	3, 3	-4, -5	2, 2	3, 3	-2, -3
		Exports	-50, -57	-28, -30	-12, -13	0, -1	-6, -7	1, 1	0, 0	-3, -3
		Imports	25, 32	22, 27	5, 6	1, 1	11, 14	0, 0	1, 1	6, 8
Developed	1965 CGI	Production	46, 76	53, 90	9, 15	1, 1	16, 27	-1, -2	1, 1	12, 20
		Harv.Area	21, 30	24, 40	-6, -8	-12, -18	5, 8	-12, -18	-13, -20	1, 2
		Yield	25, 46	29, 50	14, 23	13, 20	11, 19	11, 16	14, 21	11, 19
		Exports	104, 177	297, 572	27, 49	4, 6	38, 65	-4, -7	4, 5	25, 43
		Imports	-2, 0	-6, -3	-1, -1	0, 0	0, 0	0, 0	0, 1	0, 1
	No IARC	Production	13, 16	11, 13	2, 2	0, 0	4, 5	0, -1	0, 0	3, 4
		Harv.Area	9, 10	7, 7	-3, -3	-5, -6	2, 2	-5, -5	-5, -6	0, 0
		Yield	4, 5	4, 5	5, 6	5, 6	2, 3	4, 5	5, 6	3, 3
		Exports	28, 35	55, 65	7, 7	1, 1	10, 12	-1, -2	1, 1	6, 8
		Imports	-1, -1	-5, -5	-1, -1	0, 0	0, 0	0, 0	0, 0	0, 0

Results are percentage changes relative to the baseline year (2004) in prices (pm), harvested area ($harvcom$), production (qo), yields (p_YIELD), exports (qxw), and imports (qiw). The values are weighted averages using as weights: hectares (HA for areas), physical output ($TONS$ for production), export values (VXW for exports) and import values (VIM for imports). For each scenario, the values for the lower and upper ends are separated by a comma.

Table 4: Price, production, area, and trade effects. Alternative counterfactual scenarios

Variable	Scenario	Wheat	Rice	C. Grains	Veg & Fruits	ER All	Oilseeds	Other Ag.	All Crops
Price	1965 CGI	28.93, 59.3	68.27, 135.12	20.24, 41.67	5.7, 9.8	13.43, 26.31	4.85, 8.53	5.22, 9.3	10.03, 19.27
Price	No IARC	12, 13.7	14.87, 17.19	4.29, 4.89	1.33, 1.55	4.06, 4.65	1.2, 1.39	1.29, 1.49	2.92, 3.35
Production	1965 CGI	6, 15.07	-10.64, -17.33	2.84, 6.61	-2.99, -5	-1.38, -1.07	-4.68, -7.23	-2.46, -3.82	-1.93, -2.29
Production	No IARC	1.41, 1.92	-2.59, -3	0.4, 0.45	-0.69, -0.81	-0.39, -0.42	-1.18, -1.38	-0.53, -0.6	-0.5, -0.55
Harv.Area	1965 CGI	9.44, 12.16	20.12, 26.8	7.99, 13.58	-10.58, -15.24	5.74, 8.27	-11.2, -16.07	-10.93, -14.99	1.49, 2.21
Harv.Area	No IARC	5.84, 6.42	5.57, 6.49	1.59, 1.81	-3.8, -4.24	1.93, 2.19	-3.84, -4.33	-3.83, -4.31	0.48, 0.54
Prices in E&R	1965 CGI	29, 61	80, 124	23, 45		35, 66			
	No IARC	19, 22	30, 35	13, 15		18, 21			
Production in E&R	1965 CGI	-9, -14	-11, -14	-9, -12		-8, -12			
	No IARC	-5, -6	-4, -5	-4,-5		-4, -5			
Area in E&R	1965 CGI	3.5, 5.6	7.5, 9.4	1.1, 1.9		2.8,4.6			
	No IARC	2.1, 2.1	2.9, 3.3	0.5, 0.6		1.5, 2.7			

Results are percentage changes relative to the baseline year (2004) in prices (*pm*), production (*qo*), and harvested area (*harvcom*) aggregated using as weights: output values (VOW for prices), and physical output ($TONS$ for production and area). For each scenario, the values for the lower and upper ends are separated by a comma. The lower part of the table shows some of the results obtained by Evenson and Rosegrant (2003, table 23.3, p. 484). Ommited are changes for other grains, potatoes, and other root crops. Their results for maize are under the colummn coarse grains. For each scenario, the values for the lower and upper ends are separated by a comma.

Table 5: Change in land covers — developing and developed countries

Region	Scenario	Cropland	Forests	Pasture
Developing	1965 CGI	0.92, 1.52	-0.53, -0.86	-0.39, -0.66
	No IARC	0.22, 0.25	-0.13, -0.14	-0.09, -0.11
Developed	1965 CGI	0.50, 0.87	-0.29, -0.51	-0.21, -0.36
	No IARC	0.17, 0.20	-0.09, -0.11	-0.08, -0.09

Note: productivity (rental share) weighted changes in land covers. The figures are weighted averages of all regions within the developing and developed countries categories using as weights land rents. For each scenario, the values for the lower and upper ends are separated by a comma.

Table 6: New hectares by crop and region (million ha)

Region	Scenario	Wheat	Rice	C. Grains	Veg & Fruits	ER All	Oilseeds	Other Ag.	All Crops
Latin America	1965 CGI	-4.65, -6.93	1.62, 2.3	4.83, 7.02	-0.52, -0.71	1.29, 1.68	0.48, 0.91	-0.59, -0.79	1.18, 1.8
	No IARC	-1.35, -1.8	0.62, 0.72	1.19, 1.35	-0.15, -0.12	0.31, 0.16	0.15, 0.32	-0.15, -0.13	0.31, 0.34
S.E. Asia	1965 CGI	-0.05, -0.06	6.98, 8.51	1.63, 2.52	-2.26, -2.84	6.3, 8.14	-3.32, -4.33	-1.86, -2.41	1.11, 1.4
	No IARC	-0.01, -0.02	2.1, 2.43	0.58, 0.65	-0.74, -0.85	1.92, 2.21	-1.03, -1.18	-0.56, -0.65	0.34, 0.39
Rest Asia	1965 CGI	5.26, 5.05	19.02, 24.91	19.64, 33.85	-17.01, -24.84	26.9, 38.96	-12.85, -18.65	-6.33, -8.97	7.72, 11.35
	No IARC	3.35, 3.56	4.88, 5.72	5.12, 5.92	-5.45, -6.19	7.89, 9.01	-3.83, -4.36	-2.02, -2.29	2.04, 2.35
Subsaharan Africa	1965 CGI	-0.42, -0.44	1.31, 1.77	2.5, 3.09	-0.96, -1.21	2.43, 3.2	-0.67, -0.87	0.08, 0.39	1.85, 2.72
	No IARC	0.07, 0.06	0.48, 0.54	1.06, 1.12	-0.47, -0.44	1.14, 1.27	-0.33, -0.36	-0.09, -0.09	0.72, 0.82
Mid. East-N. Africa	1965 CGI	-4.59, -7.97	0.42, 1.31	2.38, 3.84	1, 1.65	-0.79, -1.16	0.55, 0.98	0.35, 0.59	0.11, 0.41
	No IARC	-0.09, -0.42	0.04, 0.06	0.3, 0.47	-0.09, -0.01	0.16, 0.1	-0.03, 0.01	0, 0.03	0.13, 0.13
Developed Ctries.	1965 CGI	24.91, 36.71	0.96, 1.56	-6.14, -8.1	-4.03, -6.31	15.7, 23.87	-7.56, -11.57	-2.16, -3.22	5.98, 9.07
	No IARC	10.7, 12.52	0.27, 0.3	-3.3, -3.9	-1.64, -1.91	6.02, 7.01	-2.95, -3.44	-0.87, -1.01	2.2, 2.56
All Regions	1965 CGI	20.46, 26.36	30.31, 40.37	24.84, 42.22	-23.78, -34.25	51.83, 74.69	-23.37, -33.53	-10.51, -14.41	17.95, 26.75
	No IARC	12.66, 13.91	8.39, 9.77	4.94, 5.61	-8.55, -9.54	17.45, 19.76	-8.02, -9.03	-3.68, -4.15	5.75, 6.58

Note: for each scenario, the values for the lower and upper ends are separated by a comma.

Table 7: New hectares by country (million ha)

Region	Scenario	Wheat	Rice	C. Grains	Veg & Fruits	ER All	Oilseeds	Other Ag.	All Crops
BRA	1965 CGI	-1.35, -1.74	1.46, 2.08	1.61, 2.21	-0.35, -0.54	1.37, 2.01	-0.35, -0.51	-0.33, -0.46	0.69, 1.04
BRA	No IARC	-0.59, -0.74	0.47, 0.55	0.47, 0.53	-0.09, -0.09	0.26, 0.25	-0.01, 0.02	-0.06, -0.06	0.18, 0.21
xla	1965 CGI	-3.3, -5.19	0.16, 0.22	3.22, 4.81	-0.16, -0.17	-0.09, -0.33	0.83, 1.42	-0.26, -0.33	0.49, 0.76
xla	No IARC	-0.76, -1.06	0.16, 0.18	0.72, 0.82	-0.07, -0.04	0.05, -0.09	0.16, 0.29	-0.08, -0.07	0.13, 0.13
IDN	1965 CGI	0, 0	3.1, 3.81	0.89, 1.37	-0.61, -0.8	3.38, 4.39	-1.67, -2.18	-1.09, -1.43	0.62, 0.77
IDN	No IARC	0, 0	0.92, 1.07	0.29, 0.33	-0.2, -0.23	1.01, 1.16	-0.51, -0.58	-0.32, -0.37	0.18, 0.21
xse	1965 CGI	-0.05, -0.06	3.88, 4.7	0.74, 1.15	-1.65, -2.04	2.92, 3.75	-1.65, -2.15	-0.77, -0.97	0.5, 0.63
xse	No IARC	-0.01, -0.02	1.18, 1.36	0.29, 0.32	-0.54, -0.62	0.91, 1.05	-0.52, -0.6	-0.24, -0.27	0.15, 0.18
CHN	1965 CGI	-3, -7.95	8.41, 11.38	12.3, 22.94	-7.16, -10.62	10.55, 15.75	-5.45, -8.05	-1.82, -2.69	3.28, 5.01
CHN	No IARC	0.7, 0.69	2.14, 2.49	2.78, 3.24	-2.47, -2.81	3.15, 3.61	-1.71, -1.95	-0.58, -0.66	0.86, 1
IND	1965 CGI	10.93, 17.62	6.18, 6.99	5.81, 8.53	-9.31, -13.61	13.62, 19.53	-6.98, -10.07	-4.12, -5.91	2.51, 3.55
IND	No IARC	2.59, 2.87	1.77, 2.09	2.03, 2.33	-2.65, -3.02	3.73, 4.26	-1.95, -2.22	-1.16, -1.32	0.62, 0.71
xea	1965 CGI	-0.03, -0.04	0.18, 0.2	0.04, 0.06	-0.07, -0.08	0.12, 0.14	-0.06, -0.07	-0.01, -0.01	0.05, 0.06
xea	No IARC	0, 0	0.09, 0.11	0, 0	-0.04, -0.05	0.05, 0.06	-0.03, -0.03	0, -0.01	0.02, 0.02
xsa	1965 CGI	-2.65, -4.59	4.25, 6.35	1.48, 2.32	-0.47, -0.53	2.61, 3.54	-0.35, -0.46	-0.37, -0.35	1.89, 2.73
xsa	No IARC	0.05, 0.01	0.87, 1.03	0.3, 0.35	-0.28, -0.31	0.95, 1.08	-0.14, -0.16	-0.28, -0.31	0.54, 0.62
USA	1965 CGI	6.03, 7.53	1.06, 1.7	-0.48, 0.43	-0.51, -0.71	6.1, 8.96	-3.55, -5.26	-0.97, -1.33	1.58, 2.36
USA	No IARC	2.77, 3.27	0.23, 0.27	-0.61, -0.75	-0.22, -0.25	2.17, 2.54	-1.28, -1.5	-0.39, -0.45	0.5, 0.59
CAN	1965 CGI	3.87, 4.89	0, 0	-0.27, 0	-0.47, -0.61	3.13, 4.28	-1.12, -1.52	-0.01, -0.01	2, 2.74
CAN	No IARC	1.69, 1.97	0, 0	-0.24, -0.29	-0.22, -0.25	1.23, 1.44	-0.48, -0.56	0, -0.01	0.75, 0.87
EU27	1965 CGI	4.88, 9.45	0.11, 0.16	-2.05, -4.07	-1.14, -2.13	1.8, 3.42	-0.97, -1.86	-0.27, -0.51	0.56, 1.05
EU27	No IARC	2.04, 2.39	0.07, 0.08	-0.9, -1.06	-0.48, -0.55	0.73, 0.85	-0.43, -0.5	-0.11, -0.13	0.19, 0.22
xrw	1965 CGI	10.12, 14.84	-0.22, -0.3	-3.33, -4.46	-1.9, -2.86	4.67, 7.22	-1.92, -2.93	-0.91, -1.37	1.84, 2.91
xrw	No IARC	4.19, 4.88	-0.03, -0.05	-1.54, -1.8	-0.73, -0.85	1.88, 2.19	-0.77, -0.89	-0.36, -0.42	0.76, 0.87
MENA	1965 CGI	-4.59, -7.97	0.42, 1.31	2.38, 3.84	1, 1.65	-0.79, -1.16	0.55, 0.98	0.35, 0.59	0.11, 0.41
MENA	No IARC	-0.09, -0.42	0.04, 0.06	0.3, 0.47	-0.09, -0.01	0.16, 0.1	-0.03, 0.01	0, 0.03	0.13, 0.13
SSAFRICA	1965 CGI	-0.42, -0.44	1.31, 1.77	2.5, 3.09	-0.96, -1.21	2.43, 3.2	-0.67, -0.87	0.08, 0.39	1.85, 2.72
SSAFRICA	No IARC	0.07, 0.06	0.48, 0.54	1.06, 1.12	-0.47, -0.44	1.14, 1.27	-0.33, -0.36	-0.09, -0.09	0.72, 0.82
All Regions	1965 CGI	20.46, 26.36	30.31, 40.37	24.84, 42.22	-23.78, -34.25	51.83, 74.69	-23.37, -33.53	-10.51, -14.41	17.95, 26.75
All Regions	No IARC	12.66, 13.91	8.39, 9.77	4.94, 5.61	-8.55, -9.54	17.45, 19.76	-8.02, -9.03	-3.68, -4.15	5.75, 6.58

Note: for each scenario, the values for the lower and upper ends are separated by a comma.

Table 8: Effects of declining productivity in Brazil's soybeans sector on production, yields, and area (percentage changes)

Region	Variable	Oilseeds	Wheat	Rice	C. Grains	Veg & Fruits	Other Ag.
Brazil	Price	135	-2	-4	-3	-3	-3
	Harv.Area	-18	19	6	8	8	9
	Production	-67	13	-1	1	1	3
	Yield	-50	-7	-8	-7	-7	-6
	Exports	-95	18	50	8	10	20
Rest of the world	Price	2	0	0	1	0	0
	Harv.Area	6	-1	-1	-2	-1	-1
	Production	10	-0	-0	-0	-0	-0
	Yield	3	1	1	2	1	1
	Exports	33	-1	-2	-0	-0	-1

Note: the table shows percentage change in prices (*pm*), harvested area (*harvcom*), production (*qo*), yields (p_YIELD), and exports (*qxw*). The values for the rest of the world are weighted averages using as weights: output values (VOW for prices), physical output ($TONS$ for area and yields) and export values (VXW for exports).

Table 9: Effects of declining productivity in Brazil's soybeans sector on production and exports (all model regions and crops)

Region	Variable	Oilseeds	Wheat	Rice	C. Grains	Veg & Fruits	Other Ag.
Brazil	Production	-67	13	-1	1	1	3
	Exports	-95	18	50	8	10	20
Canada	Production	18	-2	-4	0	-0	-1
	Exports	25	-2	-10	-0	-1	-3
China	Production	8	0	-0	-0	-0	0
	Exports	29	2	1	0	0	-0
EU27	Production	21	0	0	-0	0	-0
	Exports	50	1	1	-0	0	-1
USA	Production	14	-1	-1	-0	-0	-1
	Exports	31	-2	-2	-1	-1	-4
ROW	Production	6	0	-0	-0	0	-0
	Exports	34	-0	-2	-0	0	-1

Note: all figures are percentage changes (variables *qo* and *qxw*). Regional aggregates production and export value weighted averages.

Table 10: Changes in land cover in each AEZ in Brazil (percentages)

AEZ	Cropland	Forests	Pasture
AEZ 1	-0.00	0.00	0.00
AEZ 2	-0.00	0.00	0.00
AEZ 3	-0.00	0.00	0.00
AEZ 4	-0.01	0.01	0.01
AEZ 5	-0.13	0.03	0.09
AEZ 6	-0.05	0.04	0.01
AEZ 10	0.00	0.00	-0.00
AEZ 11	-0.00	0.00	0.00
AEZ 12	-0.05	0.02	0.03

Note: the table shows rental share weighted percentage changes in land cover by AEZ (variables $qocropland$, $qoforland$, and $qograzeland$).

Table 11: Land rents per cover type and for oilseeds in each AEZ in Brazil (million US$)

AEZ	Oilseeds	Cropland	Forests	Pasture
AEZ 1	0	0	0	0
AEZ 2	3	21	0	6
AEZ 3	4	78	0	21
AEZ 4	71	301	26	62
AEZ 5	489	1484	123	555
AEZ 6	146	1321	272	204
AEZ 10	0	8	0	1
AEZ 11	0	0	0	0
AEZ 12	445	1727	67	153

Table 12: New hectares by country after decline in productivity of Brazilian soybeans (million ha)

Region	Oilseeds	All other crops	All crops
Brazil	-3.9	3.6	-0.3
Canada	0.9	-0.5	0.4
China	1.4	-1.3	0.1
EU27	2.0	-1.8	0.1
Indonesia	0.3	-0.3	0.0
USA	2.6	-2.3	0.3
ROW	5.3	-4.7	0.6
All Regions	8.6	-7.4	1.2

Table 13: Effects of increasing productivity in the oil palm sectors of Indonesia and Malaysia on production, yields, and area

Region	Variable	Oilseeds	Vegetable oils & fats
Indonesia-Malaysia	Price	-26	-17
	Harv.Area	10	
	Production	68	74
	Yield	58	
	Exports	197	98
Rest of the world	Price	-1	-1
	Harv.Area	-2	
	Production	-3	-9
	Yield	-1	
	Exports	-3	-18

Note: the table shows percentage change in prices (pm), harvested area ($harvcom$), production (qo), yields (p_YIELD), and exports (qxw). The values for the rest of the world are weighted averages using as weights: output values (VOW for prices), physical output ($TONS$ for area and yields) and export values (VXW for exports).

Table 14: New hectares by country after increase in the productivity of Indonesia-Malaysia oilseeds (million ha)

Region	Oilseeds	All other crops	All crops
Brazil	-0.7	0.6	-0.1
Canada	-0.2	0.1	-0.1
China	-0.3	0.3	0.0
EU27	-0.2	0.2	-0.0
Indonesia	1.1	-1.0	0.1
USA	-0.6	0.5	-0.1
ROW	-2.9	2.6	-0.4
All Regions	-3.8	3.3	-0.5

Table 15: Change in land covers in Indonesia-Malaysia and the rest of the world (percentage changes)

Region	Cropland	Forests	Pasture
Indonesia-Malaysia	0.24	-0.24	0.00
Rest of the world	-0.02	0.01	0.01

Note: productivity (rental share) weighted changes in land covers. The figures for the rest of the world are land rent weighted averages of all regions except Indonesia-Malaysia.

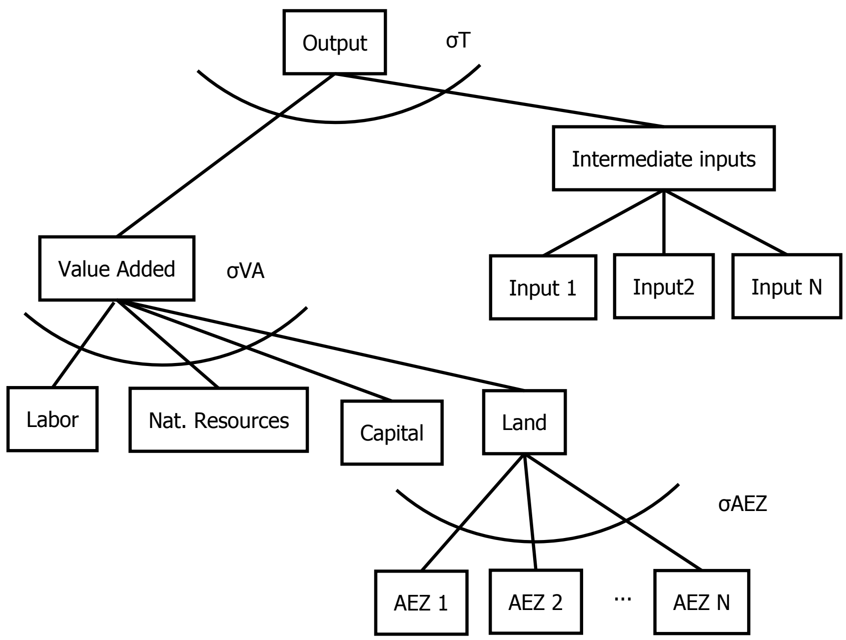

Figure 1: Land demand in the GTAP-AEZ model.

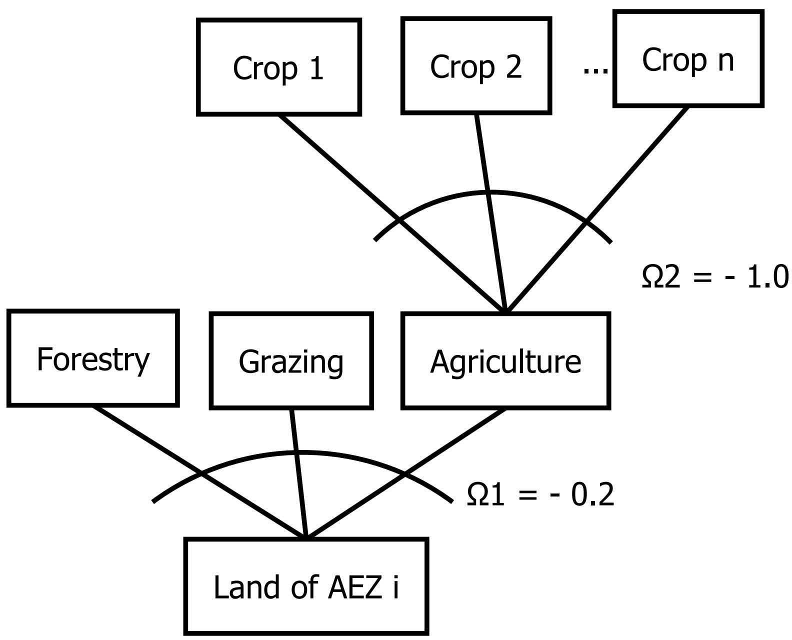

Figure 2: Land supply in the GTAP-AEZ model.

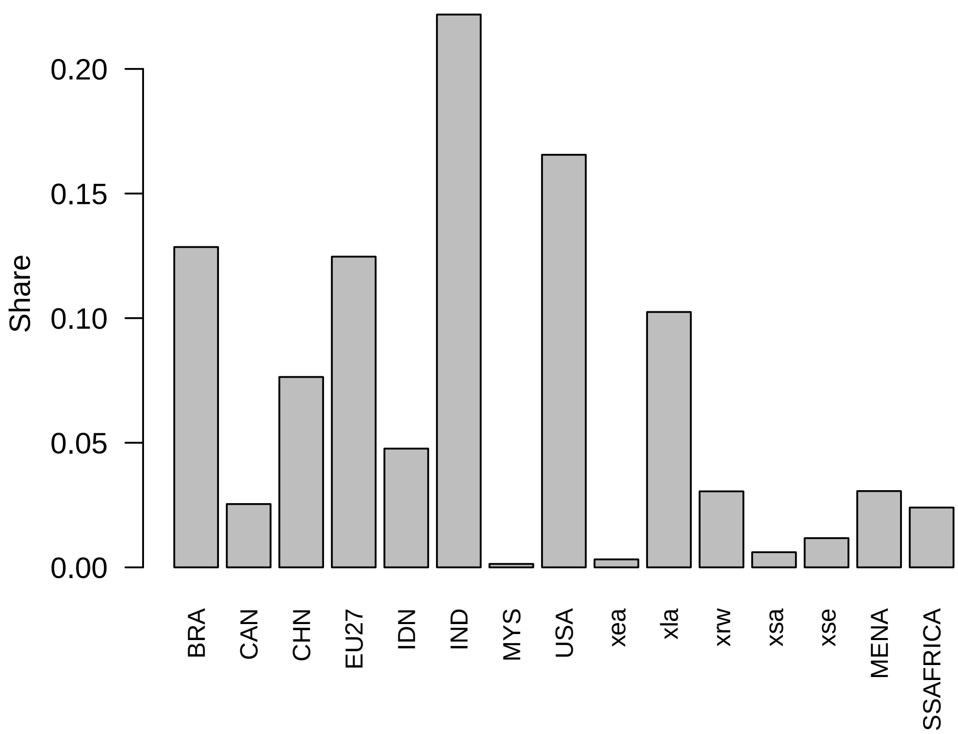

Figure 3: Value shares of global oilseeds production by region. Note: The shares are based on GTAP data (variable VOW) for 2004.

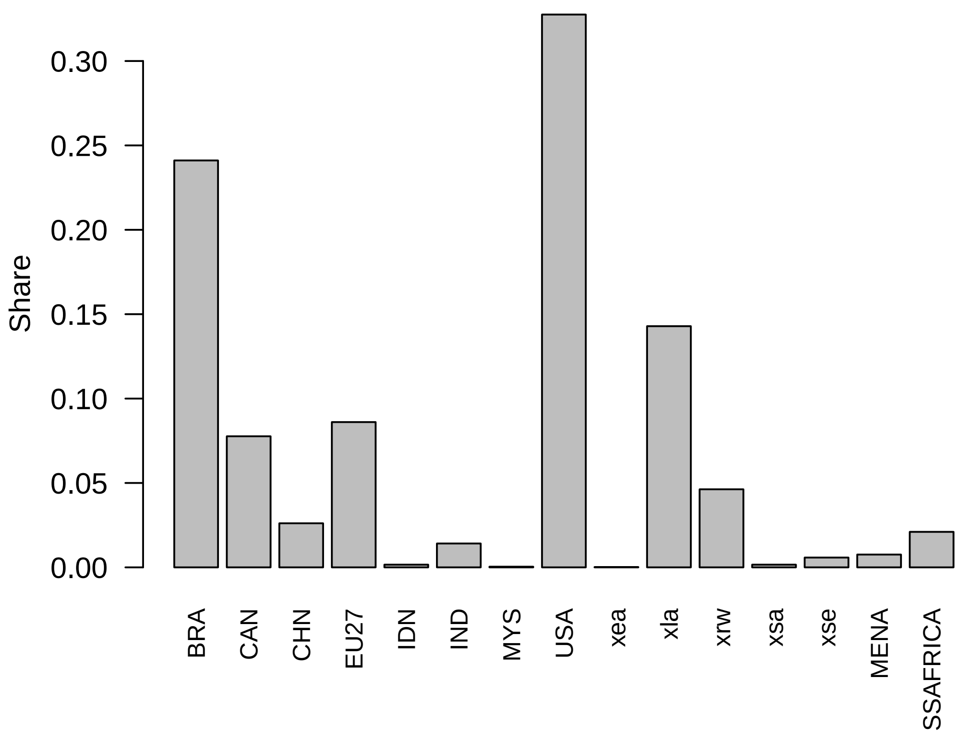

Figure 4: Value shares of global oilseeds exports by region. Note: The shares are based on GTAP data (variable VOW) for 2004.

Annex

Land Equations added to the GTAP-AEZ model

Regional mappings

Table A-1: Regional map between GTAP, IMPACT, and the aggregation of this study (SPIA.agg).

GTAP	GTAP.Description	SPIA_agg	SPIA_agg.Description	IMPACT.Regions
aus	Australia	xrw	Rest of developed world	Developed countries
nzl	New Zealand	xrw	Rest of developed world	Developed countries
xoc	Rest of Oceania	xrw	Rest of developed world	Developed countries
chn	China	CHN	China, Hong King, Taiwan	East Asia
hkg	Hong Kong	CHN	China, Hong King, Taiwan	East Asia
jpn	Japan	xrw	Rest of developed world	Developed countries
kor	Korea	xea	Rest of East Asia	East Asia
twn	Taiwan	CHN	China, Hong King, Taiwan	East Asia
xea	Rest of East Asia	xea	Rest of East Asia	East Asia
khm	Cambodia	xse	Rest of South-East Asia	South East Aia
idn	Indonesia	IDN	Indonesia and Malaysia	South East Aia
lao	Lao People's Democratic Republic	xse	Rest of South-East Asia	South East Aia
mmr	Myanmar	xse	Rest of South-East Asia	South East Aia
mys	Malaysia	IDN	Indonesia and Malaysia	South East Aia
phl	Philippines	xse	Rest of South-East Asia	South East Aia
sgp	Singapore	xse	Rest of South-East Asia	South East Aia
tha	Thailand	xse	Rest of South-East Asia	South East Aia
vnm	Viet Nam	xse	Rest of South-East Asia	South East Aia
xse	Rest of Southeast Asia	xse	Rest of South-East Asia	South East Aia
bgd	Bangladesh	xsa	Rest of South Asia	South Asia
ind	India	IND	India	South Asia
pak	Pakistan	xsa	Rest of South Asia	South Asia
lka	Sri Lanka	xsa	Rest of South Asia	South Asia
xsa	Rest of South Asia	xsa	Rest of South Asia	South Asia
can	Canada	CAN	Canada	Developed countries
usa	United States of America	USA	United States of America	Developed countries
mex	Mexico	xla	Rest of Latin America	Latin America
xna	Rest of North America	xla	Rest of Latin America	Latin America
arg	Argentina	xla	Rest of Latin America	Latin America
bol	Bolivia	xla	Rest of Latin America	Latin America
bra	Brazil	BRA	Brazil	Latin America
chl	Chile	xla	Rest of Latin America	Latin America
col	Colombia	xla	Rest of Latin America	Latin America
ecu	Ecuador	xla	Rest of Latin America	Latin America
pry	Paraguay	xla	Rest of Latin America	Latin America
per	Peru	xla	Rest of Latin America	Latin America
ury	Uruguay	xla	Rest of Latin America	Latin America
ven	Venezuela	xla	Rest of Latin America	Latin America
xsm	Rest of South America	xla	Rest of Latin America	Latin America
cri	Costa Rica	xla	Rest of Latin America	Latin America
gtm	Guatemala	xla	Rest of Latin America	Latin America
nic	Nicaragua	xla	Rest of Latin America	Latin America
pan	Panama	xla	Rest of Latin America	Latin America
xca	Rest of Central America	xla	Rest of Latin America	Latin America
xcb	Caribbean	xla	Rest of Latin America	Latin America
aut	Austria	EU27	European Union 27	Developed countries
bel	Belgium	EU27	European Union 27	Developed countries
cyp	Cyprus	EU27	European Union 27	Developed countries
cze	Czech Republic	EU27	European Union 27	Developed countries
dnk	Denmark	EU27	European Union 27	Developed countries

est	Estonia	EU27	European Union 27	Developed countries
fin	Finland	EU27	European Union 27	Developed countries
fra	France	EU27	European Union 27	Developed countries
deu	Germany	EU27	European Union 27	Developed countries
grc	Greece	EU27	European Union 27	Developed countries
hun	Hungary	EU27	European Union 27	Developed countries
irl	Ireland	EU27	European Union 27	Developed countries
ita	Italy	EU27	European Union 27	Developed countries
lva	Latvia	EU27	European Union 27	Developed countries
ltu	Lithuania	EU27	European Union 27	Developed countries
lux	Luxembourg	EU27	European Union 27	Developed countries
mlt	Malta	EU27	European Union 27	Developed countries
nld	Netherlands	EU27	European Union 27	Developed countries
pol	Poland	EU27	European Union 27	Developed countries
prt	Portugal	EU27	European Union 27	Developed countries
svk	Slovakia	EU27	European Union 27	Developed countries
svn	Slovenia	EU27	European Union 27	Developed countries
esp	Spain	EU27	European Union 27	Developed countries
swe	Sweden	EU27	European Union 27	Developed countries
gbr	United Kingdom	EU27	European Union 27	Developed countries
che	Switzerland	xrw	Rest of developed world	Developed countries
nor	Norway	xrw	Rest of developed world	Developed countries
xef	Rest of EFTA	xrw	Rest of developed world	Developed countries
alb	Albania	xrw	Rest of developed world	Developed countries
bgr	Bulgaria	EU27	European Union 27	Developed countries
blr	Belarus	xrw	Rest of developed world	Developed countries
hrv	Croatia	xrw	Rest of developed world	Developed countries
rou	Romania	EU27	European Union 27	Developed countries
rus	Russian Federation	xrw	Rest of developed world	Developed countries
ukr	Ukraine	xrw	Rest of developed world	Developed countries
xee	Rest of Eastern Europe	xrw	Rest of developed world	Developed countries
xer	Rest of Europe	xrw	Rest of developed world	Developed countries
kaz	Kazakhstan	xrw	Rest of developed world	Developed countries
kgz	Kyrgyztan	xrw	Rest of developed world	Developed countries
xsu	Rest of Former Soviet Union	xrw	Rest of developed world	Developed countries
arm	Armenia	xrw	Rest of developed world	Developed countries
aze	Azerbaijan	xrw	Rest of developed world	Developed countries
geo	Georgia	xrw	Rest of developed world	Developed countries
irn	Iran Islamic Republic of	MENA	Middle East & N. Africa	Middle East & N. Africa
tur	Turkey	MENA	Middle East & N. Africa	Middle East & N. Africa
xws	Rest of Western Asia	MENA	Middle East & N. Africa	Middle East & N. Africa
egy	Egypt	MENA	Middle East & N. Africa	Middle East & N. Africa
mar	Morocco	MENA	Middle East & N. Africa	Middle East & N. Africa
tun	Tunisia	MENA	Middle East & N. Africa	Middle East & N. Africa
xnf	Rest of North Africa	MENA	Middle East & N. Africa	Middle East & N. Africa
nga	Nigeria	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
sen	Senegal	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
xwf	Rest of Western Africa	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
xcf	Central Africa	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
xac	South Central Africa	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
eth	Ethiopia	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
mdg	Madagascar	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
mwi	Malawi	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
mus	Mauritius	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
moz	Mozambique	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
tza	Tanzania	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
uga	Uganda	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
zmb	Zambia	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
zwe	Zimbabwe	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
xec	Rest of Eastern Africa	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
bwa	Botswana	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
zaf	South Africa	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa
xsc	Rest of South African Customs Union	SSAFRICA	Sub-Saharan Africa	Sub-Saharan Africa

Shares used to map E&R shocks into GTAP categories

Table A-2: Value shares of indicated products in the GTAP category coarse grains

SUPERREG	barley	maize	millet	sorghum
ASIA	0.02	0.88	0.05	0.03
DEVD	0.23	0.62	0.00	0.02
LATAM	0.03	0.85	0.00	0.09
MENA	0.54	0.37	0.00	0.06
SSAFRICA	0.02	0.43	0.21	0.30

Table A-3: Value shares of indicated products in the GTAP category vegetables & fruits

SUPERREG	beansdry	cassava	lentils	potatoes
ASIA	0.01	0.03	0.00	0.06
DEVD	0.01		0.00	0.14
LATAM	0.06	0.06	0.00	0.06
MENA	0.01		0.01	0.09
SSAFRICA	0.01	0.16	0.00	0.04