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Ecological Balance Determined by Human Choice:

How does forestland change with consumer preferences for GM soybeans?

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Abstract

This paper modifies approaches for evaluating welfare impacts on consumer preferences of genetically modified (GM) foods from Yang (2015) and uses GTAP-Agro-Ecological Zones (GTAP-AEZ) model (Lee, 2005) to estimate the ecological impacts of consumer preferences of GM foods. The paper (i) accesses GTAP Land Use and Land Cover Data Base including six growing periods of three different climatic zones to evaluate the change in forestland; (ii) uses GM soybeans as an example to focus on the impact on change of natural forest in three largest suppliers of GM soybeans (i.e., the U.S., Brazil and Argentina) brought by change in soybean imports in China—the world's largest soybean importing country—that are reflected by consumer attitudes toward the consumption of GM soybeans; (iii) and compares with the estimated impact on forestland in China affected by change in Chinese domestic production that are reflected by negative consumer preferences of general GM foods. Lastly, this paper uses FAOSTAT data and ArcGIS and applies methodology drawn upon U.S. Forest Services and previous forest ecology studies to evaluate the estimated impact on forest ecosystem (i.e., carbon sequestration) due to change in consumer preferences.

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I. Introduction

The natural ecological balance is important for sustaining the environment, but people often overlook the extent to which ecological change may be driven by human preferences. The purpose of this paper, therefore, is to provide researchers and policy makers with an *intuitive* and *convenient* evaluation on ecological impacts attributed to change in consumer preferences. The methodology for the estimation and analysis is also handy for researchers outside the GTAP network. The analysis of ecological impacts builds upon considerations of heterogeneous climatic and soil characteristics on both farmland and forestland across AEZs in determining the impact of trade and consumer preferences on industry output and land supply.

Forests are important to humans and the ecological system in many different ways. The change in forestland, for instance, may affect the efficiency of abatement of greenhouse-gas emissions (GHG) by changing the amount of carbon storage in forests, and the GHG may, in turn have adverse effects on ecosystems and biodiversity. In forest ecosystems, forestation may allow carbon sequestration by removing CO2—one of the most abundant GHG— from atmosphere through the process of photosynthesis and incorporating carbon into biomass. Deforestation, on the other hand, subjects to removal of forest. The loss of forest may contribute about 30% of global greenhouse-gas emissions every year (Johnson 2009).

Consumer preferences likely affect the supply of GM foods, but may also affect the change in forestland. The production of GM crops generally requires less land than that of conventional crops thereby potentially curbing deforestation and thus increasing re-forestation, but reliance on GM supplies from countries like Brazil and Argentina can cause significant monoculture issues, draining the land of its own nutrients, damaging bio-diverse habitats and, therefore, destroying forests. This paper will investigate these mechanisms and their potential affects and will identify the conditions under which consumer preferences regarding GM foods may or may not affect the ecology of certain regions in the world.

This paper finds that consumer preferences potentially have a large impact on GHG emissions through the likely change in global forest cover. When China consumes more GM soybeans from Brazil and Argentina, and less from the U.S., there will likely be a large positive impact on reduction in CO2 emissions in the U.S. However, this shift will potentially have negative impacts on the environment in Brazil, Argentina and China. In Brazil and Argentina, these negative ecological impacts are led by potential deforestation owning to increases in domestic production and demand for soybeans in China, which is driven by change in consumer preferences.

In addition, it finds that the change in soybean acreage (i.e. land supply) is highly sensitive to the level of domestic soybean production in China. The safety concerns over GM foods slow down the approval process for commercialization of GM soybeans in China, which likely leads to lower soybean yields (i.e., FAOSTAT, 2013). In the absence of sufficient foreign soybean supply, Chinese farmers likely tend to seek more land in order to compensate the unmet domestic demand, which may cause ecologically destructive conversions of forestland to cropland, thereby potentially reducing carbon sequestration.

II. Previous work

Hertel *et al*. (2009) estimates the effects of market-mediated land use changes on climate due to expansions of biofuels production (i.e., U.S. maize ethanol). The analysis involves GTAP simulations to shock an increase in biofuel production and estimation of change in carbon stocks and sequestration due to conversions of land use. Hertel *et al*. (2009) combines GTAP-based model with a carbon accounting model that measures CO2 emission, which builds on and modifies earlier works from Searchinger, Heimlich *et al*. (2008). By measuring GHG discharges owing to maize ethanol production, Hertel *et al*. establishes useful steps to model indirect change in land use to carbon emissions.

Plevin *et al*. (2014) recently developed a new model—the Agro-Ecological Zone Emission Factor model (aka. AEZ-EF). The model draws upon both matrices of carbon fluxes (Mg CO2/hectare/year) and matrices of changes in land use separated by AEZs, which gives estimates for total CO2-equivalent based on changes in land use obtained from GTAP-AEZ modelling results. The U.S. Agency for International Development (USAID) developed another approach called *Agriculture, Forestry and Other Land Use* (AFOLU) program, which also provides estimates of the impact of land use on CO2 emissions using pre-determined information such as effective percent (i.e. effectiveness of forest management) and carbon accumulation rate. While USAID provides a basic guidance on estimating efficiency rate and may be useful for policy makers to conduct sensitivity analysis, the results estimated using these inputs are likely unmeasurable and may tend to be biased. At this stage, this paper adopts a simple method introduced by American Forests. The detailed calculations are based on previous estimates from U.S. Forest Services, which will be introduced again in section V (b) below.

Yang (2015) uses GTAP 9 Data Base for the year of 2011 and links the consumers' attitude towards consumption of GM foods to its potential economic impact on China and the U.S. The methodology includes three GTAP simulations and one comprehensive simulation that reflect the change in consumer preferences, which establishes a connection between change in consumer preferences of GM soybeans and the change in national welfare. The change in welfare is measured as the change in equivalent variation (EV). By decomposing EV, Yang (2015) finds that the reduction of EV is largely due to the loss in export sales for GM soybeans, which is caused by a negative shock to consumer preferences. In the comprehensive GTAP simulation, the result shows that shifts in consumer preferences away importing U.S. grown-GM soybeans will lower both export sales and production of GM soybeans in the U.S.

The United States Environmental Protection Agency (U.S. EPA) has funded researchers in GTAP Center, University of Wisconsin-Madison, and the Ohio State University to construct GTAP Land Use and Land Cover Data Base, which also build on global forestry data. The accessible forest area is calculated by AEZ and by country. This derivation is accomplished by weighting the aggregated forest area data by the share of accessible forests of total forest area by country and by each particular zone (Lee, 2005; GTAP, 2013). Through these procedures, the GTAP Land Use and Land Cover Data Base is adopted and used in the GTAP-AEZ framework to capture the inter-sectoral land transition in AEZs.

The standard GTAP model (Hertel, 1997) does not specify climatic and soil constraints of land and it assumes that land is completely mobile among uses of farming, livestock breeding, or forestation. The GTAP-AEZ modified the standard model by taking into account the FAO fashion of agro-ecological zoning (i.e., FAO, 2000; Fisher *et al*., 2002; Lee, 2005). In the GTAP-AEZ model, land endowments are heterogeneous across 18 AEZs, covering six growing yearly periods and three climate zones (i.e., temperate, tropical and boreal). Hence, land distributed in any of the 18 specific zones is homogeneous in the landform, as well as climatic and soil characteristics.

The incorporation of AEZs in the standard GTAP model gives availability of homogeneous lands to move within an individual AEZ, but constraints have been assigned to those lands so that they are not transformable across other AEZs. For example, suitability of soybean planting areas varies from one zone to another. In the U.S., soybeans are mainly grown in the Midwestern states, such as Illinois, and some are grown in northwestern region, such as Idaho, but the distribution of forests and cropland in the U.S. are largely different due to heterogeneous climatic and soil characteristics.[2] Therefore, GTAP-AEZ gives more reasonable estimates of the change in forestland corresponding to different shocks (shifts in consumer preferences of GM soybeans) in the simulation.

III. Research Design and Methods

The paper assesses the ecological impact of consumer preferences of GM soybean in 3 steps:

1) Determining the effects of consumer preferences of GM soybean on domestic production and domestic supply of land under three different scenarios.
2) Evaluating the changes in forestland owning to the change in production and soybean hectares harvested.
3) Mapping the ecological impacts of potential changes in forestland on carbon sequestration and GHG emissions under two different approaches.

A comparative static GTAP-AEZ model is used to evaluate the change in forestland associated with different shifts in consumer preferences of GM soybeans. The parameter for the commodity to be estimated in the model is oilseeds. Based on U.S. Department of Agriculture (USDA) estimates for the model year from 2014 to 2015, China imported approximately 72 millions tons of soybeans, covering over 95% of total oilseeds imports (USDA, 2014).[3] In the simulations, it is assumed that all soybeans imported to China are genetically modified. This assumption is based on the fact that the world's three largest soybean suppliers (the U.S., Brazil and Argentina) to China produced *almost exclusively* GM soybeans and they together accounted for 96.6% of total Chinese soybean imports in 2011. Thus, while it is still desirable to disaggregate the GTAP database by separating GM soybeans from non-GM soybeans, reducing imports of soybeans from these countries may largely represent actions in China to respond to the on-going fierce debate over GM food safety (Yang, 2015).

[2] The cropland data is provided by the Center for Sustainability and Global Environment (SAGE), University of Wisconsin-Madison.
[3] Economic Research Service, USDA (http://www.ers.usda.gov/data-products).

The first modeling procedure is to set up a framework for assessing the implications of changes in consumer preferences. There are three scenarios of the changes in consumer preferences, modified from Yang (2015). The first scenario, for sensitivity analysis purposes, assumes that Chinese consumers alter their preferences for GM soybeans imported from the U.S. to a lower level. The second scenario assumes that Chinese consumers favor more GM soybeans imported from the rest of the world, which in essence implies that more GM soybeans will be imported from Brazil and Argentina, but there are no negative effects on the preferences of GM soybeans consumptions from the U.S. The third scenario represents a policy shock that China responds to consumers by importing less GM soybeans from the rest of the world (see Figure 1 for modeling structure).

The second modeling procedure is to assume that Chinese consumers generally oppose all GM soybean imports, which in turn will also significant affect Chinese domestic soybean production and change in land use for soybean. According to SAGE, those AEZ zones for soybean hectares harvested largely overlap with the same region that grows large areas of forest cover (mostly from AEZ8 to AEZ12). Since China is the fourth leading soybean producer in the world, the change in Chinese domestic production of soybeans may potentially have a large impact on forestland in China.

The last modeling procedure is to account for heterogeneous characteristics in AEZs. GTAP 8 Land Use and Land Cover Data Base is used in the model. The inclusion of global land cover and forestry data in AEZs allows for robust competition between agriculture and use in forestland captured by changes in forestry sector. Each specific AEZ attributed by the land of temperature and moisture regime determines the suitability of growing both forest and soybean. The defined region consists of 18 or less (more likely) global AEZs that carry heterogeneous soil and climatic characteristics to cropland. For example, according to SAGE, the climate in the U.S. in general is considered relatively temperate, whereas Brazil is considered to have tropical climate. Each climatic characteristic is then assigned with six AEZs that measure the length of growing period (Figure 2).

Under Implications of <u>Forestation/Deforestation and their Impacts on Greenhouse-gas Emissions</u> in section V (b), two different approaches are used to evaluate the change in forestland and their impacts on GHG emissions: (i) this paper first interprets the change in soybean output resulted from the three shocked scenarios to possible changes in land use across all assessed countries in the GTAP-AEZ model, which potentially involves forestation (i.e., tree-planting projects) or deforestation. A few assumptions have to be made, such as constant sales price from producers as well as continuous demand for soybeans at a constant rate. Under this approach, the paper assesses FAOSTAT (2013) data to evaluate the likely change in soybean land by dividing the output change in quantity by average yield per harvested area (ton/hectares). The data for area harvested and production quantity for soybeans from 2003 to 2013 is used to compute an estimated average yield per harvested area for soybeans; (ii) the second approach is to evaluate the possible change in forestland based on SAGE, which categorizes land area (in hectares) by different use and by AEZ in each country. The potential change in forestland is evaluated using estimated modelling results for change of supply in sluggish endowment (i.e., land) for soybean production by AEZ and by country. This approach assumes that forest reversion or clearing do not involve the change in land use of other types. The results can be refined by taking into account the change of supply in land endowment used in other industries. However, this paper finds that the change of land use for other sectors is less influential.

The next, this paper focuses on carbon sequestration on forestland. This step is to determine how much carbon is sequestered or could be returned to atmosphere by estimating how much trees that can be planted on marginal cropland as well as how much trees can be cut down due to deforestation as a result of increases in soybean output. The methodology is adopted from American Forests based on previous studies conducted by USDA and the U.S. Forest Service. This paper equalizes the number of trees planted in potential tree-planting projects, which averages about 450 trees per acre if selected countries assessed in the GTAP-AEZ model establish forestation projects on unused farmland. This assumption implies that trees are planted with same spacing between rows and trees. This paper then adopts techniques from American Forests to calculate carbon sequestration of trees. The carbon stored by trees (50.8 metric tons per acre) is converted to carbon dioxide or its equivalent, which is 911 pounds of CO2 per tree. Further, this paper applies the estimates for carbon sequestration to the likely changes in soybean acreage resulted from the three shocked scenarios. Another key assumption is that the newly added trees, across all modeling countries, will have same growing species, same water balance without consideration of additional differentiated climate effects and other side factors on forest growth. Finally, this paper accesses the ecological footprints, CO2 emissions, and forest area under ArcGIS to evaluate the impact on CO2 emissions in terms of each country's share for total emissions, or the *share of contribution* per period.

IV. Assumption

The following results are anticipated. Negative shifts in consumer preferences of GM soybeans imported from the U.S. will likely increase the production of GM soybeans in Brazil and Argentina. An increase in GM soybean production in Brazil and Argentina will likely curb afforestation. It may also have harmful impacts on ecosystem (i.e. reduced level of carbon sequestration) where the areas of soybean production are largely covered by forestland (Figure 3). In the case in which Chinese consumers generally oppose all GM soybean imports, it is likely that the impact on potential change in forestland in the U.S. will be greater than in Brazil and Argentina (due to baseline size for forestland and soybean acreage). However, it is expected that there will be less damages to forests in the U.S. relative to China (due to China's high demand for soybean and soybean by-products). By comparing the results from the three scenarios of changes in consumer preferences, one may have a clearer sense and sound predictions of how the ecological balance of different parts of the world, measured principally as a change in land devoted to forests, may be influenced by food choices in humans.

Figure 4 is a simple imaginary chart to illustrate the size of land use that can be internally transformed in a homogenous zone x. This chart supposes that the zone x being commercially utilized only contains the land for crops growing, livestock and forestry productions, and supposes that the rest is completely covered by natural forest. It is assumed that the change of land in industrial sectors can affect the size of natural forest (Figure 4).

V. Model Decomposition and Results

a. Implications on Soybean Production and Land Use

Soybean is among the major crops in terms of total agricultural production and the share of land use for countries assessed in this paper. In the U.S., soybean acreage has increased rapidly since 50 years ago. USDA reports that soybean acreage was over 64 million acres in 2007, which is more than doubled than the area planted in 1963. The soybean acreage surpassed wheat in 1995 and became the second most-planted field in the U.S. after corn and followed by wheat.[4] For Brazil, the top three Brazilian agricultural productions are cattle, sugar cane and soybean, and major land uses for crops in Brazil are soybeans (37%), corn (23%) and sugar cane (15%) (Figure 5). Furthermore, soybean was the top agricultural production in terms of international dollar value in Argentina, followed by cattle, milk and corn (FAO, 2012).

1) Scenario 1 - Low Consumer Preferences for importing GM Soybeans from the U.S.

The simulation results show that when there is a 16% negative Chinese consumer preferences of GM soybean imported from the U.S., the market price of soybean in the U.S. will decrease by 0.69%, but will increase by 0.55% and 0.89% in Brazil and Argentina, respectively. The change in market prices (for imports) of other crops, such as rice and wheat, occurred in a similar trend. In forestry sector, the negative shift in consumer preferences will cause a 0.26% decrease in the market price of commercial forest in the U.S. but will lead to a 0.68% increase in Brazil and a 0.83% increase in Argentina. In livestock sector, the negative shock will decrease the market prices for cattle, cattle meat and other animal products in the U.S. but prices in Brazil and Argentina will rise. (Table 1).

As Soybean acreage has become the second most-planted field in the U.S., the change in soybean production therefore has considerable impacts on the total U.S. land area, as cropland covers 18% of U.S. total land area (408 million) (USDA, 2007). In the U.S., the shock caused a 2.98% decrease in soybean output, which will subsequently affect the land use in the U.S. The decrease in market price and a lower-level of soybean production give farmers incentive to cut the acreage used for soybean planting, reducing the total land use for crop and potentially leaving more room for conversion of U.S. cropland to forest. While the change in production of other agricultural sectors remains important, they are not numerically significant enough to be taken into account, given their shares of land use in the U.S. and the magnitude of percent changes compared to soybean production. One may see that the possible change in natural forestland caused by reduction in soybean production can be diminished by increases in production of other agricultural sectors, but it is clear that these changes, such as in wheat, cattle and forestry sectors, only happen to a certain extent and are much less than the change in soybean production.

Two major components that affect the production of soybean in the GTAP model are domestic and export sales:

$$qo\ (i,r) = SHRDM\ (i.r) * qds\ (i,r) + \sum_{s \in REG} [(SHRXMD\ (i,r,s) * qxs(i,r,s)] + tradsclack\ (i,r) \qquad (1)$$

where *qo* is industry output, *qds* is domestic sales, and *qxs* is export sales.

Equation 1 clears the market for the non-margins commodities in the model. In the U.S., the shock leads the domestic sales of soybean to increase by 0.16% but also causes the export sales to decrease by -25.4% which is largely due to the exogenous shock of negative preference:

[4] In USDA's *Major Uses of Land in the United States, 2007* (Figure 9) shows that soybeans acreage, represented by yellow dashed line, and wheat acreage, represented by blue dashed line, intersected somewhere in the middle between the year 1992 and 1997 (http://www.ers.usda.gov/media/188404/eib89_2_.pdf).

$$qxs\ (i,r,s) = -ams(i,r,s) + qim\ (i,s) - ESUBM(i) * [pms(i,r,s) - ams(i,r,s) - pim(i,s)] \tag{2}$$

where *ams* is preference (shock) variable, *qim* is aggregate imports, *pms* is domestic price, and *pim* is market price of composite import.

The shock decreases the demand for soybean by U.S. soybean farms but increases the demand by other agricultural sectors in the U.S. For instance, the demand for soybean (as cow feed) in the U.S. cattle sector increases sharply by 1.58% due to a lower price of soybean. Advantages of soybean forage include flexibility of harvest date and cheaper price to raise livestock, which is also favorable as other animal feed in the U.S. For instance, the demand for soybean by other animal products is increased by 1.84%. The result also shows that there is an increase in demand for soybean by U.S. vegetable oil (as soybean by-products) sectors. However, the upward trend in total domestic sales does not outweigh the decrease in export sales, which is dominated by the large reduction in imports from the U.S. to China. In the regard of export sales, the standard GTAP model estimates that the export sales from the U.S. to China decreases by over 40%, which tends to understate the change in soybean production (Yang, 2015). The GTAP-AEZ model brings the estimates much closer in line with reality as it captures the heterogeneity of land endowments across AEZs in the U.S.

Negative preferences of soybean imported from the U.S. to China lowers the demand for land used for soybean farming in the U.S. Therefore, the supply of land falls across all AEZs. Conversely, soybean field likely expands in Brazil, Argentina and China as output increases. In Brazil and Argentina, a higher level of soybean output, resulted from increases in exports, steadily raises the quantity of value added (i.e., composite quantity of primary factors used to harvest soybeans) in soybean farming (equation 4 below clears sector demand for composite primary factors). It should be noted that these changes in soybean hectares harvested are only reflected in certain AEZ zones, because a change in soybean acreage only takes place if there are soybeans planted. In the U.S., the supply of land for soybean farming decreases by a range from 2.25% to 2.67%. In China, domestic output has to increase to compensate the strong demand for soybean, which requires more land (about 2.58% in avg. across corresponding AEZs), because higher level of imports from Brazil and Argentina does not meet demand.

$$qva\ (j,r) = -ava\ (j,r) + qo(j,r) - ao(j,r) - ESUBT(j) * [pva(j,r) - ava(j,r) - ps(j,r) - ao(j,r)] \tag{3}$$

where *qva* is quantity index of land-labor-capital composite (value-added). The rest refers to appendix.

The forecasting of change in land use is visually consistent to the FAO Global Spatial Database of Agricultural Land-use Statistics (GSD-ALS) in 2015. The simulation results show an evident much larger effect of change in soybean outputs in Brazil, indicating that Brazil will likely have a larger effect in forestland relative to Argentina caused by a negative preference shock, which will potentially increase soybean production in both Argentina and Brazil. According to GSD-ALS, northern Brazil has roughly more than 75% of natural forest, grass and shrubs, which concurrently overlap with a large area for soybean farming. In Argentina, total forest areas in three regions (AEZ13-AEZ15), where almost no soybeans are grown, are estimated at 4.02 million hectares. In addition, AEZ11 has roughly about 1.8 million hectares of soybean harvest area but no natural forest.

2) *Scenario 2 - High Consumer Preference for importing GM Soybeans from the Rest of the World*

The term “Rest of world” used in this paper essentially does not deviate much away from just assuming Brazil and Argentina, since U.S., Brazil and Argentina together account for almost 97% of soybean imports in China. Table 2 shows similar results obtained from shocking higher consumer preference for importing GM soybeans from the rest of the world, except the effect on change in price is much smaller. For example, the positive shock to consumer preferences of GM soybeans imported from Brazil and Argentina will cause the price of soybean in the U.S. to decrease by 0.47% and to increase by 0.2% and 0.32% in Brazil and Argentina, respectively.

The shock in the second scenario with higher consumer preferences to the rest of the world decreases the U.S. commodity prices in the sectors of crops, livestock and forestry but the prices in Brazil and Argentina will increase. The soybean outputs in the U.S. will decrease by 1.98%, whereas the soybean outputs in Brazil and Argentina will increase by 1.24% and 0.87%, respectively. The results show some diminishing effects on industry outputs in other agricultural sectors, such as cattle, other animal products and vegetable oils, but these effects (i.e., increase in outputs) are much smaller relative to soybeans (i.e., decrease in outputs). For instance, the cattle output will increase by 0.02% while the output for raw milk will increase by only 0.01%, and etc., and therefore the decrease in soybean outputs dominate the reduction in total agricultural outputs in the U.S.

According to USDA, soybean is the second largest U.S. crop product in value of production (US$ 52.4 billions) in 2014 and the fifth largest major agricultural products in quantity (89 million tones) in 2013. With the large output of soybean production, scenario 2 also suggests that the aggregate decrease in output (and hence the area of planted field) in crop sectors may potentially contribute to forestation. However, compared with the first scenario, the magnitude of reduction in soybean production is much smaller. Thus, the first scenario may potentially benefit the ecological balance more in the U.S. than the second scenario by allowing fewer expansions in crop sectors, whereas the second scenario may behave more ideally for Brazil and Argentina by the same reasoning.

What becomes remarkable in scenario 2 is the change in Chinese industry output. In scenario 1, Chinese soybean production increases by 2.96% when China imports fewer soybeans from the U.S., whereas in scenario 2 Chinese soybeans output shrinks by 1.54% when China imports more soybeans from Brazil and Argentina. Refer to equation (1), the domestic sales of soybean in China decreases by 1.75%, which is caused by a fall in demand for soybeans by other agricultural sectors in China (i.e. those with high demand for soybean, livestock, vegetable oils):

$$qds\ (i,r) = \sum_{j \in PROD\_COMM} \big(SHRDFM(i,j,r) * qfd(i,j,r)\big) + SHRDPM\ (i,r) * qpd(i,r) + SHRDGM\ (i,r) * qgd\ (i,r) \tag{4}$$

where *qfd* is demand for domestic good by industry, *qpd* is private household demand, and *qgd* is demand by government.

The result shows that the demand for soybeans by all agricultural sectors (selected in the model) falls largely in China, which is led by decrease in market price for Chinese soybeans and subsequently decrease in industry prices for soybeans (expressed as *pf* in equation 5) in China, combining both imported and domestically produced. By further decomposing the demand for soybeans in China, one can see that both market price for soybean produced domestically and price of composite import for soybeans decreases. The latter one is directly led by the preference shock. In scenario 2, positive importing preferences from Brazil and Argentina contributed to decrease in market price of composite imports for soybeans, whereas negative importing preferences from the U.S. does exactly the opposite:

$$qfd\ (i,r,s) = qf(i,j,s) - ESUBD(i) * [pfd(i,j,s) - pf(i,j,s)] \tag{5}$$

where *qf* is demand for commodity for use by industry, *pfd* is price index for domestic purchases, and *pf* is firm's price for composite commodity for use by industry.

The main drivers of the two different impacts on change in Chinese soybean output are the large share of soybean imports from the U.S. (second largest soybean supplier in China) as well as the change in consumer preferences. In scenario 1, negative consumer preference of soybean imports with large share of soybean supplied from the U.S. drives up the market price of composite import for soybean in China, whereas positive consumer preference from the rest of the world (i.e., Brazil and Argentina) in scenario 2 increases the supply from the rest of the world, spurring a reduction in market price. As a result, scenario 1 expands soybean output in China while the output in scenario 2 falls by 1.54%, which may in turn reduce the land use for Chinese soybean farming.

The change in soybean acreage in China may have a large impact on forestland as soybeans are chiefly farmed in those AEZs where the natural forest lies. Northeast (Dongbei provinces) is the major source for Chinese soybean production, accounting for nearly 41% of the country's total soybean output (USDA, 2014).[5] In the meanwhile, natural forest in China is mainly concentrated in the country's northeast and southwest, with cold-temperate coniferous forests mainly distributed in hilly area of cold-temperate zone such as northeast China (SFA, 2014).[6] Another key source for Chinese soybean production is Inner-Mongolia (as shown in the dark purple area neighboring Mongolia in Figure 3D), which also largely overlaps with the Northeast Inner Mongolia forest area.

Compares the results of change in soybean harvested area in scenario 2 with FAO spatial database (GSD-ALS), both scenarios may potentially contribute to deforestation in Brazil and Argentina, whereas the shock in the second scenario may potentially promote conversion of cropland to forest in the U.S. and China (see section b).

3) Scenario 3 - Low Consumer Preferences for importing GM Soybeans from the World

In this scenario, negative consumer preferences for imports have been assigned to China's three largest soybean suppliers. This is a case in which Chinese consumers generally dislike GM food, and therefore reduce level of GM soybean imports from the rest of the world. In the absence of sufficient soybean imports, Chinese domestic soybean production is expected to rise.

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[5] FAO, *Northeast China: Prospects for U.S. Agricultural Exports*: http://www.fas.usda.gov/data/northeast-china-prospects-us-agricultural-exports.

[6] State Forestry Administration P.R. China (SFA), *Forest Resources in China*: http://english.forestry.gov.cn/index.php/information-services/forest-resources/2-forest-resources-in-china.

U.S., Brazil and Argentina together account for nearly all Chinese soybean imports. Soybean imports in China skyrocketed in the past 15 years, mainly because of Chinese economic growth and China's Grain Self-Sufficiency Policy, which does not include soybeans. Rapid economic growth with almost 20% of the world's human population spurs high demand for food consumption, and particularly raises both industrial and private demand for soybeans owning to large needs for livestock sectors and higher demand for cooking oil consumption (USITC, 2011). As a result, the unmet demand has to be compensated by increased domestic production and soybean imports.

The shock also leads to increases in soybean output in the U.S., Brazil and Argentina, but these changes are very small. Interestingly, soybean production in China increases by 2.01% and the shocked effect on soybean production is the largest among the world (Figure 3). The Chinese domestic soybean output increases partly due to large increases in industry demand in other agricultural sectors. For instance, the demand by Chinese cattle meat sector and vegetable oils sector increases by 9.36% and 3.57%, respectively.

The result shows positive and strong cross-country effects on market price and industry output which dominate the negative own effect in which case Chinese consumers dislike GM soybean imports from the U.S. Recall what happens to the soybean sectors in Brazil and Argentina in scenario 1, when negative consumer preference in China hit U.S. soybeans, there is a large positive effect on the market price of soybean. However, as negative consumer preferences in China hit all three exporting countries, there are little impacts on market prices of soybeans in US, Brazil and Brazil.

The increase in soybean output in China is followed by large expansions of soybean harvested area across all AEZs, which averages about 2.58% (Figure 3). The effects of demand for soybean acreage in China is much influential than the U.S., Brazil and Argentina. It is likely because that the change in Chinese soybean acreage (i.e. land supply) is highly sensitive to the level of domestic soybean production attributed to low soybean yields.

b. Implications on Afforestation/Deforestation and Greenhouse-Gas Emissions

Afforestation is the establishment of forest cover, which could be a result of conversion from cropland to forestland due to reduced demand and output for agriculture. Economic shocks to the world can lead to decreases in farm production and size at home, which reasonably leaves room for government to encourage forestation (i.e., tree-planting projects) on those unused farmland.

The change in forest cover is important as it may affect the efficiency of abatement of GHG emissions. In forest ecosystems, forestation may allow carbon sequestration by removing CO2— one of the most abundant GHG— from atmosphere through the process of photosynthesis and incorporating carbon into biomass. Deforestation, on the other hand, subjects to removal of forest, which includes converting forestland to cropland. The loss of forest may contribute about 30% of global GHG emissions every year (Johnson 2009).

This section discusses two different approaches in evaluating possible changes in forestland and their effects on GHG emissions. The first approach is to estimate the change in forestland owning to the change in production of soybeans (FAOSTAT data for soybean yield). The second approach is to estimate the change in forestland based on AEZ land endowments (SAGE).

(1) Estimates based on Change in Production

This approach finds possible implications on afforestation/deforestation and their effects on GHG emissions attributed to reduced/increased soybean production evaluated in the GTAP-AEZ model. The calculation of estimated room for land use changes requires a few assumptions. It assumes that changes in land use fully responds to changes in soybean production.

The first step in determining how much marginal cropland in soybean can be planted of trees is to calculate how much change in output in terms of quantity. The FAOSTAT publishes data for area harvested and the production quantity for soybeans from 1961 to 2013. The data from the year 2003 to 2013 is used to compute the average yield per area harvested (ton/hectares) in the U.S., Brazil, Argentina and China. The yield goes up and down but there are no evident outliers in those selected years. The next is to multiply the percent change measured in the GTAP-AEZ model (in dollar-value terms) by soybean production in 2013 to obtain the estimates for the output change in quantity terms by assuming that 1) the sale price from soybean producers is constant; and 2) demand for soybeans is continuous and at a constant rate. Finally, the possible change in cropland is calculated by dividing the output change in quantity by average yield per harvested area.

The second step is to determine how much carbon is sequestered or could be returned to atmosphere by estimating how many trees can be planted on marginal cropland as well as how many trees can be cut down due to deforestation as a result of increases in soybean output. Instead of using other approaches such as AEZ-EF (Plevin *et al*., 2014) model and AFOLU computing method (USAID), this paper adopts a simple method published by American Forests – a non-profit organization for conservation of natural resources. American Forests estimated that a tree-planting project averages about 450 trees in one acre. U.S. Forest Service's previously estimated that the average for carbon stored by trees with the age of 55 years is about 58.8 tons per acre. American Forests modified this number to 50.8 metric tons by taking out significant outliers. The next is to convert carbon to carbon dioxide (CO2) or its equivalent, which gives 186 metric tons of CO2 per acre of forest, or 410,060 pounds of CO2 sequestered per acre of trees, or 911 pounds of CO2 per tree. The estimates are based on assumption that 1) a tree-planting project averages the same quantity of trees per acre (i.e., same tree spacing) across all modeling countries; 2) for simplification purposes, same amount of carbon stored per tree across all modeling countries regardless of tree species (i.e., same growing species are planted, second-growth forest), same climate effect and water balance, etc.

(2) Estimates based on GTAP-AEZ Land Endowment

This approach assesses the change in forest cover based on GTAP Land Use Data Base released in 2009. Both forestry and crop harvested area data are divided by AEZ per country. In addition, this approach involves more economic mechanisms under GTAP framework and assumes that the change in land use is led by change in supply of land.

Modelling results for changes in supply of sluggish endowment (i.e., land) are used to compute the areas of possible changes in forest cover in each AEZ. Those AEZs that does not appear to have any soybean productions are not taking into account. The data for possible changes in forest area are aggregated at each country's level, and are estimated at different level of land conversions (i.e., 100%, 50%, 25%, 10%, and 5%) between forestland and soybean acreage (Table 4).

The method introduced by American Forests is used again to estimate potential CO2 sequestration or discharge resulted from the change in land use. The next is to estimate an average quantity of CO2 emissions using the data (1993-2011) provided by ArcGIS and the World Bank. The average CO2 emissions (metric ton/year) for each country are used to measure the evaluated share of contribution due to CO2 sequestration, or potential release of CO2 when forestland is converted to soybean field.

The results show that the estimates for overall share of contribution to CO2 emissions are lower than those estimated based on changes in production. The estimates based on the changes in production do not fully take into account the AEZs as well as changes in domestic and foreign demand resulted from the shock. The estimates for change in land area based on production tend to overstate the estimated effects on forest sequestration. However, for the situation in China, both estimates are largely close possibly because of the climatic and soil characteristics. It appears that the land where it is suitable for farming soybeans is also suitable for forest to grow in China. Furthermore, the change of area for soybean acreage in China is highly sensitive to the change in production, which is possibly because of the low yields due to public concerns and controversies surrounding GM foods in China (Bawa et al., 2013).

Conclusion

The purpose of this paper is to provide researchers and policy makers with an *intuitive* and *convenient* evaluation on ecological impacts attributed to change in consumer preferences. The methodology for the estimation and analysis is also handy for researchers outside the GTAP community. The analysis of ecological impacts builds upon considerations of heterogeneous climatic and soil characteristics on farmland across AEZs in determining the impact of trade and consumer preferences on industry output as well as the supply of land.

The paper helps us better understand the vital connection between consumer preferences and our ecological system. Hence, this paper interprets the relationship between change in consumer preferences of foods and their likely ecological footprints under the world's challenge of CO2 mitigation for the twenty-first century. Under this connection, it finds that the preferences of food consumption potentially have a large impact on GHG emissions through the likely change in global forest cover.

In the first scenario, when China consumes more GM soybeans from Brazil and Argentina and less from the United States, there will be a large positive impact on potential reduction in CO2 emissions in the U.S. However, this shift will potentially have negative impacts on the environment in Brazil, Argentina and China. In Brazil and Argentina, these negative ecological impacts are led by potential deforestation owning to increases in domestic production and soybean demand from China. In China, the increases in soybean exports from Brazil and Argentina do not fully compensate the increasingly high demand for soybean possibly due to Chinese rapid economic growth and a lack of efforts on soybean production under China's Grain Self-Sufficiency policy.

If China, instead, tends to prefer more GM soybeans imported from Brazil and Argentina, both United States and China may gain ecological benefits by reducing CO2 emissions through potential conversions from cropland to forestland. The main drivers of the change in Chinese soybean output are the positive consumer preferences of soybean imports from the rest of the world (i.e., Brazil and Argentina) with large share of soybean supplies to China. The shock does not affect the preferences of soybean imports from the United States who also have a large share of Chinese soybean imports. The shock drives down the market price of composite soybean imports in China, thereby spurring a reduction in output as well as the demand for cropland.

The results from the third scenario show positive and strong cross-country effects on market price and industry output, which dominate the negative own effect in which case Chinese consumers dislike GM soybean imports from the U.S. The third scenario also puts China in a bad situation as in the first scenario, when China generally oppose all GM soybeans imported from the world, the unmet industrial demand and demand for private consumption have to be compensated by increases in domestic production, and the increases in outputs may, in turn spurs expansions in cropland, which may potentially reduce the area of forest land.

Lastly, this paper finds that the change of cropland for Chinese soybean farming (i.e. land supply) is highly sensitive to the level of domestic soybean production. The safety concerns over GM foods slow down the approval process for commercialization of GM soybeans in China, which likely leads to lower soybean yields (i.e., FAOSTAT, 2013). In the absence of sufficient foreign soybean supply, Chinese farmers likely tend to seek more land in order to compensate the unmet domestic demand, which may cause ecologically destructive conversions of forestland to cropland, thereby potentially reducing carbon sequestration.

VI. References

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VII. Appendix

a. Selected Sets, Parameters and Variables in the GTAP model (GTAP).[7]

Sets
TRAD_COMM Traded Commodities (TC)
PROD_COMM Produced Commodities (PC)

Technology Parameters
$ESUBD_i$ substitution parameter between domestic and composite imported commodities in the Armington utility/production structure of agent/sector i in all regio
$ESUBM_i$ substitution parameter among imported commodities from different sources in the Armington utility/production structure of agent/sector i in all regions

Price variables
PIM_{ir} market price of aggregate imports of tradable commodity i in region r
PMS_{irs} market price by source of tradable commodity i imported from source r to destination s
PFD_{ijr} demand price for domestic tradable i by firms in sector j of region r
PF_{ijr} demand price for composite tradable i by firms in sector j of region r

Quantity Variables
QO_{ir} quantity of non-saving commodity i output or supplied in region r
QDS_{ir} quantity of domestic sales of tradable commodity i in region r
QXS_{irs} quantity of exports of tradable commodity i from source r to destination s
QIM_{ir} quantity of aggregate imports of tradable commodity i demanded by region r using market prices as weights
QGD_{ir} quantity of domestic tradable commodity i demanded by government household in region r
QF_{ijr} quantity of composite tradable commodity i demanded by sector j firm in region r
QFD_{ijr} quantity of domestic tradable i demanded by sector j firm in region r
QPD_{ir} quantity of domestic tradable i demanded by private household in region r
QVAjr quantity index of land-labor-capital composite (value-added) in sector j firm in region r

Technical Change Variables
AMS_{irs} import i from region r augmenting tech change in region s

Slack Variables
$tradslack_{ir}$ slack variable in the MKTCLTRD equation

Shares
$SHRXMD_{irs}$ share of export sales of i to s in r
$SHRDM_{ir}$ share of domestic sales of i in r
$SHRDFM_{ijr}$ share of domestic sales of tradable commodity i used by firms in sector j of regin r evaluated at market prices
$SHRDGM_i$ share of domestic sales of commodity i used by the government in region r evaluated at market prices

[7] For a complete list of sets, parameters and variables, visit: https://www.gtap.agecon.purdue.edu/models/setsVariables.asp.

b. Tables and Figures.

TABLE 1. SELECTED RESULTS FROM SCENARIO 1.

Scenario 1				
Soybean (%-change)	**U.S.**	**Brazil**	**Argentina**	**China**
Decomposition of Output Change				
Output	-2.98	3.36	2.31	2.96
Domestic Sales	0.16	-0.09	-2.35	3.46
Export Sales from U.S. to China	-25.16	32.44	31.21	
Market Price for Imports	-0.69	0.55	0.89	
Change in Harvested Area				
AEZ1	-2.6	2.5	2.2	2.6
AEZ2	-2.6	2.7	2.2	2.6
AEZ3	-2.6	2.9	2.2	2.6
AEZ4	-2.6	2.5	2.2	2.6
AEZ5	-2.6	2.3	2.2	2.6
AEZ6	-2.6	2.8	2.2	2.6
AEZ7	-2.7	2.9	2.3	2.6
AEZ8	-2.5	2.9	1.9	2.5
AEZ9	-2.5	2.9	1.7	2.5
AEZ10	-2.2	3.1	1.5	2.5
AEZ11	-2.4	3.0	1.4	2.5
AEZ12	-2.6	2.4	1.5	2.6
AEZ13	-2.7	2.9	2.3	2.6
AEZ14	-2.7	2.9	2.3	2.6
AEZ15	-2.7	2.9	2.3	2.6
AEZ16	-2.7	2.9	2.2	2.5
AEZ17	-2.6	2.9	2.2	2.4
AEZ18	-2.6	2.9	2.2	2.6

Source: Author's results obtained using RunGTAP CGE model; SAGE.

TABLE 2. SELECTED RESULTS FROM SCENARIO 2.

Scenario 2				
Soybean (%-change)	**U.S.**	**Brazil**	**Argentina**	**China**
Decomposition of Output Change				
Output	-1.98	1.24	0.87	-1.54
Domestic Sales	0.06	-0.07	-0.97	-1.75
Export Sales from U.S. to China	-15.89	12.87	12.41	
Market Price for Imports	-0.47	0.2	0.32	
Change in Harvested Area				
AEZ1	-1.7	0.9	0.8	-1.4
AEZ2	-1.7	1.0	0.8	-1.4
AEZ3	-1.7	1.1	0.8	-1.4
AEZ4	-1.7	0.9	0.8	-1.4
AEZ5	-1.7	0.9	0.8	-1.4
AEZ6	-1.7	1.0	0.8	-1.3
AEZ7	-1.8	1.1	0.9	-1.4
AEZ8	-1.7	1.1	0.7	-1.3
AEZ9	-1.6	1.1	0.6	-1.3
AEZ10	-1.5	1.2	0.6	-1.3
AEZ11	-1.6	1.1	0.5	-1.3
AEZ12	-1.7	0.9	0.6	-1.3
AEZ13	-1.8	1.1	0.9	-1.4
AEZ14	-1.8	1.1	0.9	-1.4
AEZ15	-1.8	1.1	0.9	-1.3
AEZ16	-1.8	1.1	0.8	-1.3
AEZ17	-1.7	1.1	0.8	-1.2
AEZ18	-1.7	1.1	0.8	-1.4

Source: Author's results obtained using RunGTAP CGE model; SAGE.

TABLE 3. SELECTED RESULTS FROM SCENARIO 3.

Scenario 3					
Soybean (%-change)		**U.S.**	**Brazil**	**Argentina**	**China**
Decomposition of Output Change					
	Output	0.33	0.29	0.19	2.01
	Domestic Sales	0.01	0.02	-0.14	2.32
	Export Sales from U.S. to China	2.12	2.23	2.13	
	Market Price for Imports	0.08	0.05	0.08	
Change in Harvested Area					
	AEZ1	0.29	0.21	0.18	1.77
	AEZ2	0.29	0.23	0.18	1.77
	AEZ3	0.29	0.25	0.18	1.77
	AEZ4	0.29	0.21	0.18	1.79
	AEZ5	0.29	0.20	0.18	1.78
	AEZ6	0.29	0.24	0.18	1.77
	AEZ7	0.29	0.25	0.19	1.79
	AEZ8	0.27	0.25	0.15	1.71
	AEZ9	0.27	0.25	0.14	1.72
	AEZ10	0.24	0.26	0.12	1.70
	AEZ11	0.25	0.26	0.11	1.72
	AEZ12	0.28	0.20	0.12	1.75
	AEZ13	0.29	0.25	0.19	1.80
	AEZ14	0.29	0.25	0.19	1.79
	AEZ15	0.29	0.25	0.19	1.75
	AEZ16	0.29	0.25	0.18	1.73
	AEZ17	0.29	0.25	0.18	1.63
	AEZ18	0.29	0.25	0.18	1.77

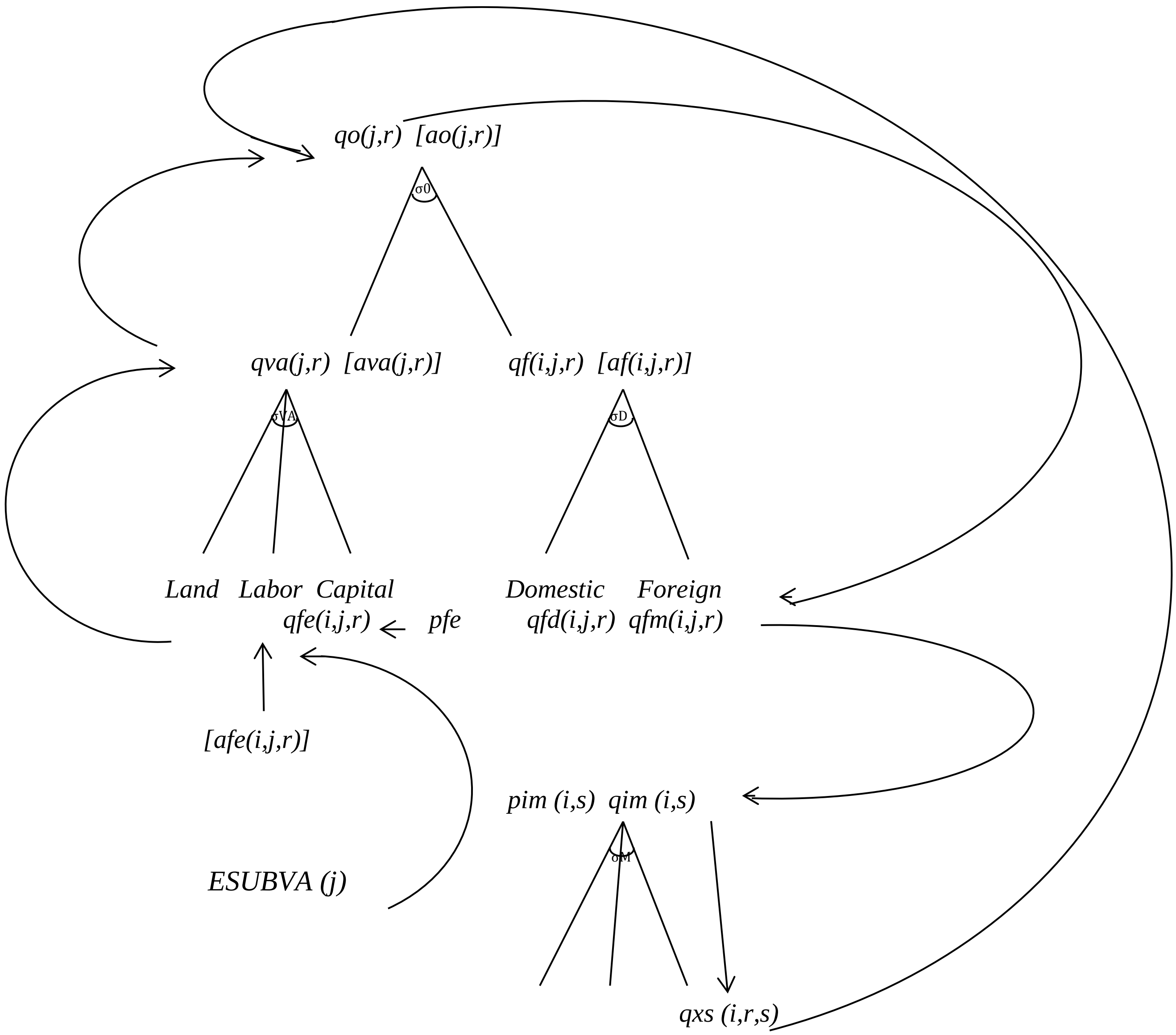
Source: Author's results obtained using RunGTAP CGE model; SAGE.

TABLE 4. LAND CONVERSIONS, CO2 EMISSIONS.

	Scenario 1				Scenario 2				Scenario 3			
Country	**U.S.**	**Brazil**	**Argentina**	**China**	**U.S.**	**Brazil**	**Argentina**	**China**	**U.S.**	**Brazil**	**Argentina**	**China**
Average CO2 Emissions (1993-2011) (metric ton/year)	5,524,532	334,686	151,394	4,898,952								
Case 1 (based on Production)												
Forestation (+)/Deforestation (-) (hectares)	956,946	(1,019,575)	(441,263)	(213,532)	635,823	(376,272)	(166,190)	111,094	(105,971)	(87,999)	(36,294)	(145,000)
CO2 Sequestration (metric ton/year)	7,994,713	(8,517,939)	(3,686,486)	(1,783,935)	5,311,923	(3,143,525)	(1,388,417)	928,128	(885,321)	(735,179)	(303,217)	(1,211,388)
Share of Contribution (%)												
At 100% of Land Conversion	145%	-2545%	-2435%	-36%	96%	-939%	-917%	19%	-16%	-220%	-200%	-25%
At 50% of Land Conversion	72%	-1273%	-1218%	-18%	48%	-470%	-459%	9%	-8%	-110%	-100%	-12%
At 25% of Land Conversion	36%	-636%	-609%	-9%	24%	-235%	-229%	5%	-4%	-55%	-50%	-6%
At 10% of Land Conversion	14%	-255%	-244%	-4%	10%	-94%	-92%	2%	-2%	-22%	-20%	-2%
At 5% of Land Conversion	7%	-127%	-122%	-2%	5%	-47%	-46%	1%	-1%	-11%	-10%	-1%
Case 2 (based on Land Endowment)												
Forestation (+)/Deforestation (-) (hectares)	709,784	(330,292)	(137,531)	(228,174)	469,474	(122,793)	(52,308)	118,008	(76,340)	(28,217)	(10,965)	(154,633)
CO2 Sequestration (metric ton/year)	5,929,820	(2,759,391)	(1,148,991)	(1,906,254)	3,922,178	(1,025,864)	(436,998)	985,890	(637,778)	(235,740)	(91,608)	(1,291,870)
Share of Contribution (%)												
At 100% of Land Conversion	107%	-824%	-759%	-39%	71%	-307%	-289%	20%	-12%	-70%	-61%	-26%
At 50% of Land Conversion	54%	-412%	-379%	-19%	35%	-153%	-144%	10%	-6%	-35%	-30%	-13%
At 25% of Land Conversion	27%	-206%	-190%	-10%	18%	-77%	-72%	5%	-3%	-18%	-15%	-7%
At 10% of Land Conversion	11%	-82%	-76%	-4%	7%	-31%	-29%	2%	-1%	-7%	-6%	-3%
At 5% of Land Conversion	5%	-41%	-38%	-2%	4%	-15%	-14%	1%	-1%	-4%	-3%	-1%

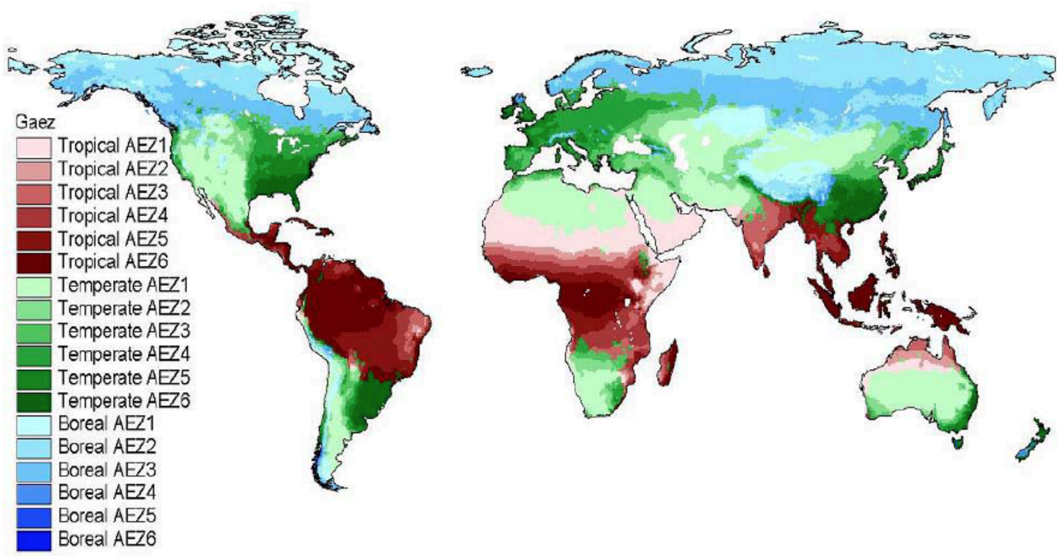
Source: Author's calculations based on SAGE, ArcGIS, the World Bank, American Forests, USDA, and the U.S. Forest Service.

FIGURE 1. A GRAPHICAL REPRESENTATION FOR THE MODELING STRUCTURE



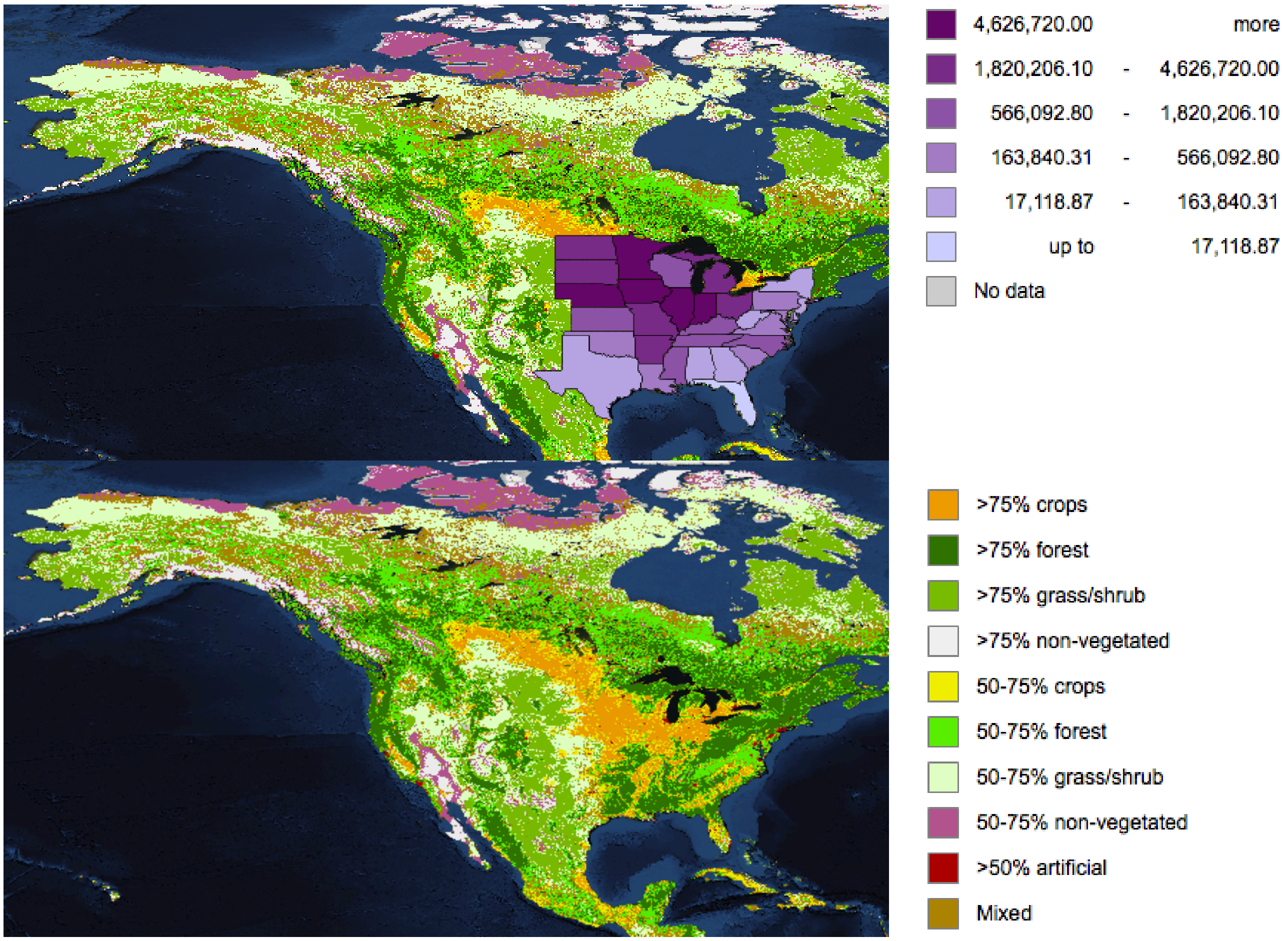
Source: Figure 2.6 in Hertel and Tsigas (1997) and author's modifications; Yang (2015).

FIGURE 2. THE SAGE GLOBAL MAP OF THE 18 AEZS



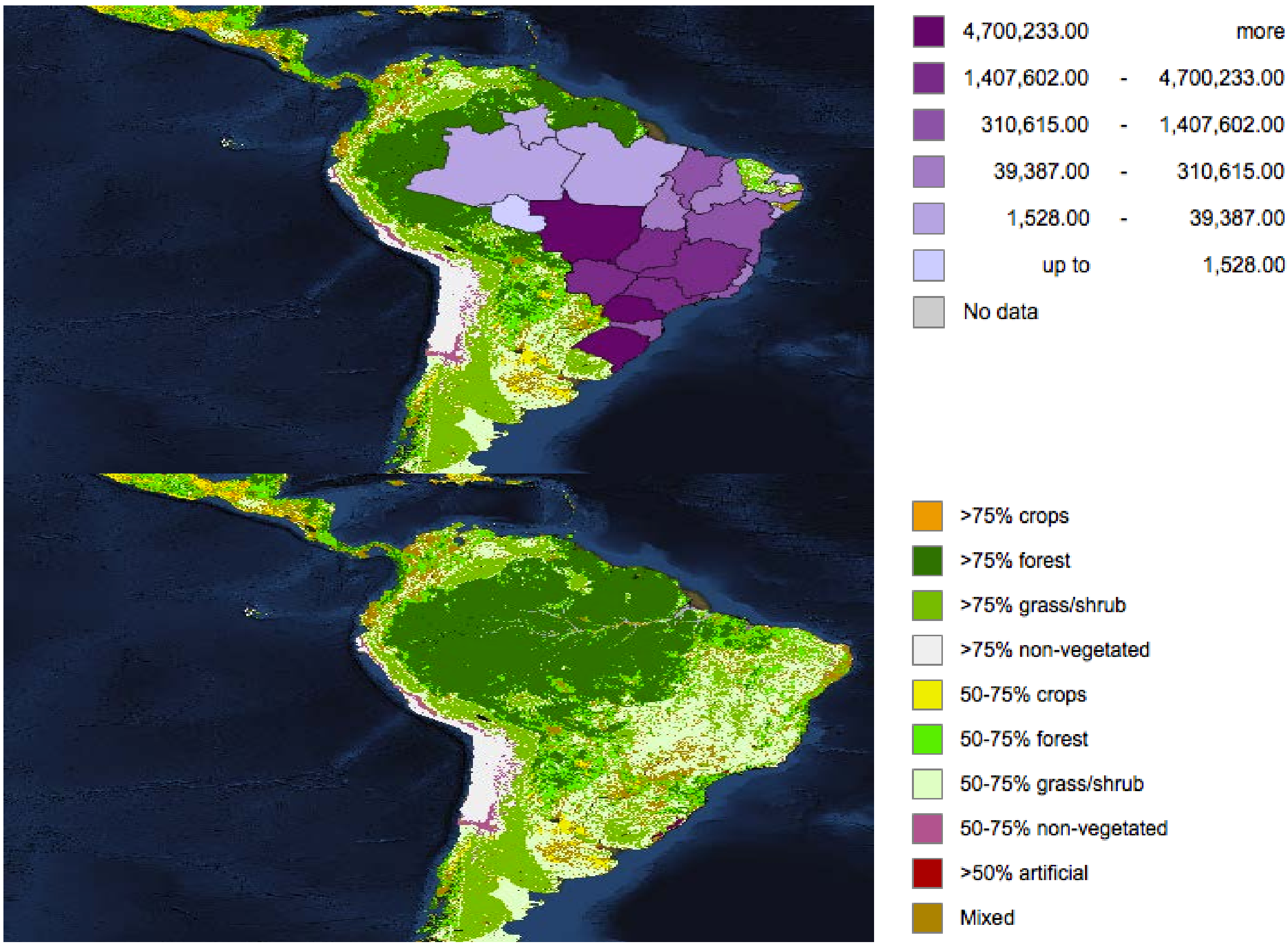
Source: GTAP and SAGE (retrieved in 2015).

FIGURE 3A. THE MOST RECENT AREA OF SOYBEAN PRODUCTION (IN MILLION TONS) VERSUS LAND COVER AND USE IN THE UNITED STATES



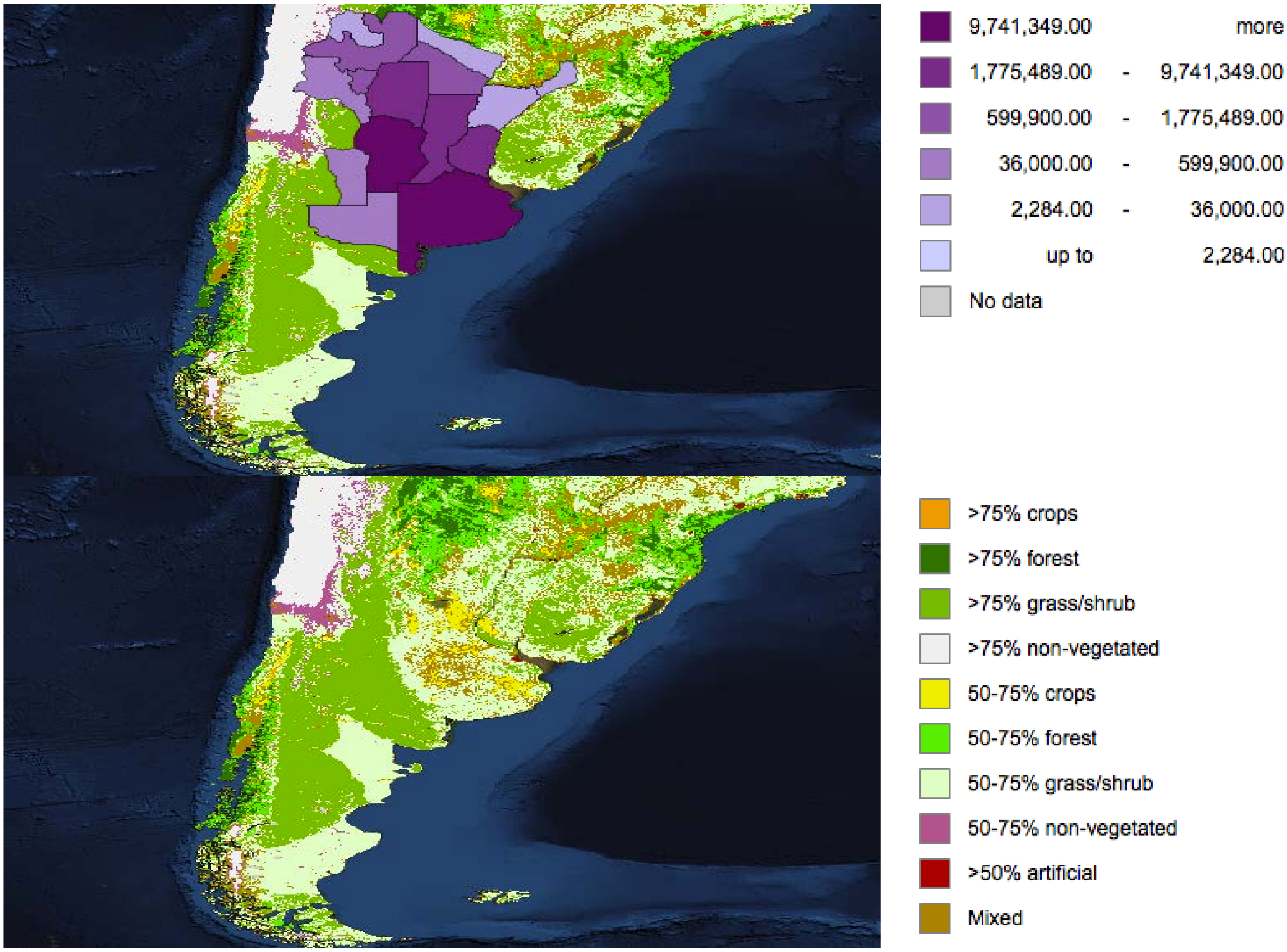
Source: FAO Global Spatial Database of Agricultural Land-use Statistics (2015).

FIGURE 3B. THE MOST RECENT AREA OF SOYBEAN PRODUCTION (IN MILLION TONS) VERSUS LAND COVER AND USE IN BRAZIL



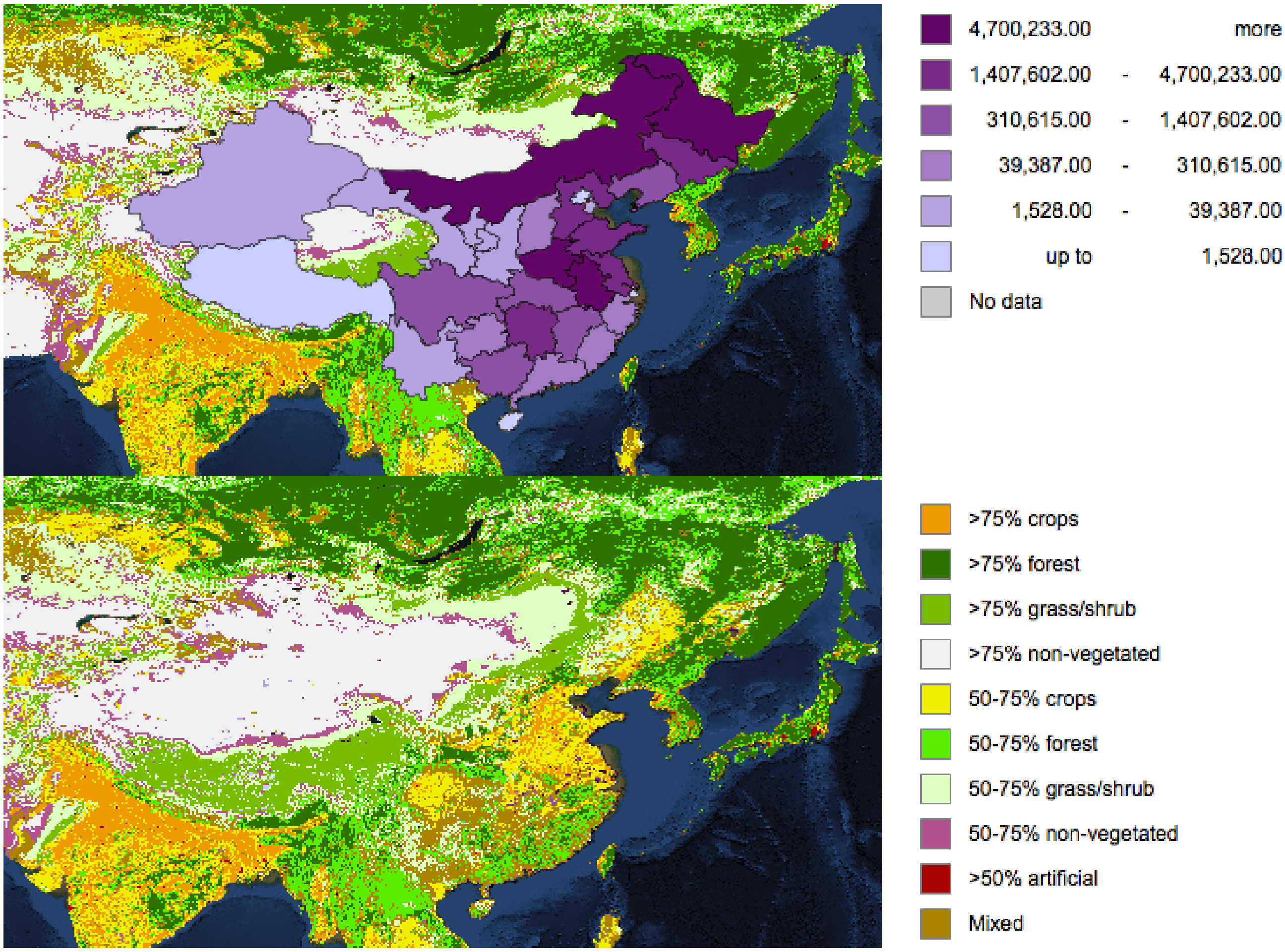
Source: FAO Global Spatial Database of Agricultural Land-use Statistics (2015).

FIGURE 3C. THE MOST RECENT AREA OF SOYBEAN PRODUCTION (IN MILLION TONS) VERSUS LAND COVER AND USE IN ARGENTINA



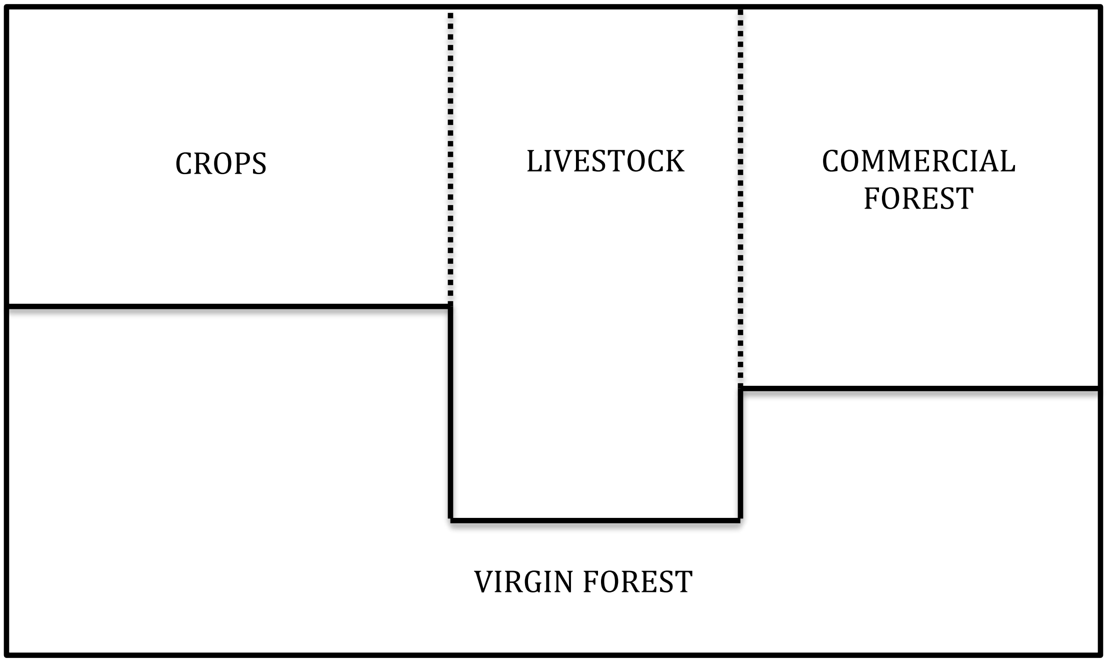
Source: FAO Global Spatial Database of Agricultural Land-use Statistics (2015).

FIGURE 3D. THE MOST RECENT AREA OF SOYBEAN PRODUCTION (IN MILLION TONS) VERSUS LAND COVER AND USE IN CHINA



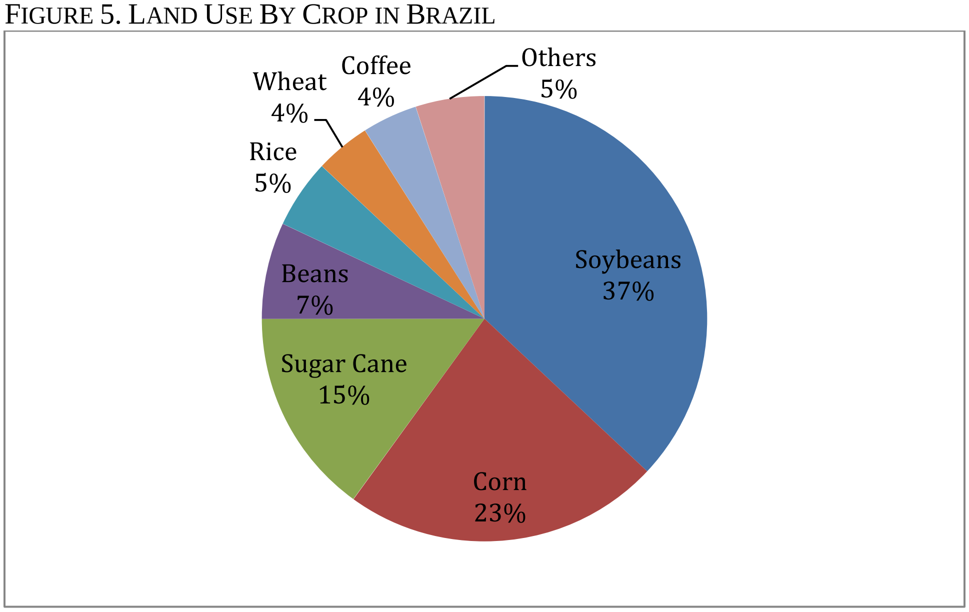
Source: FAO Global Spatial Database of Agricultural Land-use Statistics (2015).

FIGURE 4. LAND USE BY CATEGORY IN A HOMOGENEOUS ZONE X.



Source: Author's own drawing based on selected industry variables in the GTAP model.

FIGURE 5. LAND USE BY CROP IN BRAZIL



Source: FAO, 2009.