Soybean Trade between the United States, Brazil and China: Interactions between Global Trade Flow and Gridded Agricultural and Environmental impacts

Zhan Wang, Department of Agricultural Economics, Purdue University, USA.
zhanwang@purdue.edu

Thomas W. Hertel, Department of Agricultural Economics, Purdue University, USA
hertel@purdue.edu

Selected Paper prepared for presentation at the 2024 Agricultural & Applied Economics Association Annual Meeting, New Orleans, LA; July 28-30, 2024

Soybean Trade between the United States, Brazil and China: Interactions between Global Trade Flow and Gridded Agricultural and Environmental impacts

Zhan Wang[1], Thomas Hertel[1]

1: Department of Agricultural Economics, Purdue University, USA

Abstract

The relationship between global trade impact and local agricultural and environmental responses has been an increasingly important research question, in particular its spillover effects both at national and subnational levels. Taking the soybean trade between the US, Brazil and China as an example, China's retaliatory tariffs on the US's soybean export stimulates the soybean production in Brazil, which further influences local crop production, land use and the corresponding environmental impacts. However, the local responses with spatial heterogeneity are seldom incorporated into global trade studies. In this study, we developed an innovative general-equilibrium economic model, GTAP-SIMPLEG. This model extends the current GTAP framework by embedding a gridded multiple-crop supply and multiple-land use system in the focused region (here is Brazil), in order to capture the relationship between global drivers and local responses. We apply GTAP-SIMPLEG to simulate the impact of China's 25% tariff on US soybean on Brazil's crop production and land conversion, both at national scale and fine spatial scale. We find the soybean tariff results in the expansion of soybean but shrinkage in sugar cane, while maize production decreases moderately. Furthermore, the tariff drives both the shrinkage of total pasture area and the shifting from center Brazil to its southeast region, as well as the forest plantation – cropland conversion in the south Brazil, which causes negative cross-sector spillover effects from farming to livestock and forestry. Findings of this study emphasize the importance of incorporating

spatial response into international trade analysis for future studies and policy assessment.

1. Introduction

The Global-to-Local-to-Global (GLG) approach of analyzing the nexus of agricultural and environmental systems has received increasing attention. Taking the US – China trade war as an example, when China imposed the retaliatory tariffs on soybean produced from the US (Li, Balistreri and Zhang 2019), it does not only reduce the demand of soybean from the US, but also stimulates soybean export from Brazil. As a result, the recent soybean production in Brazil has reached record high (Colussi et al. 2024). However, the impact of soybean demand from China will not be uniform across Brazil but cause spatially heterogeneous effects on the production of soybean and other crops, and also influence the land use patterns between cropland, forest and pasture and causes environmental implications.

To understand how drivers from global trade influence Brazilian agriculture and the environment, a multi-scale framework that incorporates both global and local scales is necessary, which allows researchers to capture spillover effects across countries and sub-national regions, as well as across crops and economic sectors. While existing studies have researched the impacts of the US- China trade war, many of these studies mainly focus on response in the US and China (Li et al. 2019; Itakura 2020), while the spillover effects to other countries are not included. In view of that, there has been an increasingly trend of studies on the spillover effects of the trade war globally (Carvalho, Azevedo and Massuquetti 2019) or on certain economies of the world, for example the European Union (Goulard 2020), India (Misra and Choudhry 2020), Indonesia (Purwono et al. 2022), Mexico (Gachúz Maya 2022) and Brazil (Dhoubhadel, Ridley and Devadoss 2023). Those studies contribute to the existing literature by capturing the spillover effects from the international market. However, they tend to evaluate those effects on the aggregated national level, while the spatial pattern of impacts remains outside of their research scope. Given that both crop production and land use vary at the local level, a gap still exists between the findings and implications from studies at the national level and the understanding of their spatial distribution for better impact assessment and decision making. In their analysis of trade war’s damage to soybean producers, Adjemian and colleagues (2021) disaggregated the value loss due to US’s soybean price reduction to county level. They find that the impact of trade war is centralized in the Midwest region, together with spatial variances across counties. This study indicates the importance of evaluating trade impacts at finer spatial resolution. Still, neither economic mechanism that governs farmers’ crop and land use choices in response to soybean tariff nor the spatial impacts in Brazil has been incorporated into this study. So far, there is a need for integrated analyses that couple both drivers and responses across scales, but such studies are still in a very early stage.

The present study aims to address this knowledge gap between global trade and local response. In this study, we develop an innovative general-equilibrium economic model, the GTAP-SIMPLEG model, and apply it to research the impact of China’s tariff from soybean export from the US on Brazil’s agriculture and environment. As its name suggests, the GTAP-SIMPLE-G model integrates two widely used models for economic and sustainability analyses: the Global Trade Analysis Project (GTAP) model (Corong et al. 2017) and the Simplified International Model of agricultural Prices, Land use and the Environment: Gridded version (SIMPLE-G) (Baldos et al. 2020) and its regional focused version for Brazil (SIMPLE-G-Brazil) (Wang et al. 2024). Inherited the complete supply chain, demand system and bilateral trade features from GTAP and the gridded crop production, land use and inputs demand features from SIMPLE-G, GTAP-SIMPLEG performs the capacity to simulate impacts from global trade drivers (shocks) from multiple levels (global, regional, sub-regional, local), as well as capture the connections between aggregated outcomes with spatial heterogeneity and spillover effects.

This paper is organized as follows. In section 2, we first propose a simplified economic framework to explain how soybean demand increase from global market influence local crop production patterns. We then introduce the computable general equilibrium model we developed for simulating the trade war's impact in Brazil, as well as the data we used to develop this model and the design of simulation scenario. In section 3, we report and interpret the results of China's soybean tariff for both national and gridded levels. Section 5 discusses implications of our findings, remaining limitations and future directions. Finally, section 6 concludes this paper.

2. Methodology

2.1 Economic framework

To understand the mechanism that how the increase of soybean from international demand influence crop production choice at gridded level, in this section we provide a simplified economic framework of multiple crop production in a certain local region, which is visualized as figure 1. Consider farmers from this region would like to decide how much soybean (denoted as "S") and non-soybean crops (denoted as "C") to be produced given the current prices of non-soybean crop and soybean, whose price ratio equals to the absolute value of the slope of line L_1. For the same number of aggregated inputs (the composition of land, labor, capital, water and other intermediate inputs), the possible mixture of soybean and non-soybean crops that can be produced in this region is depicted by the curve C_1. Since farmers in that region are not identical, some are more capable in producing soybean while others are more capable in producing non-soy crops, forcing all farmers to only produce a single type of crops (when C_1 intersects with the horizontal or vertical axis) will reduces the average productivity, which explains the concave shape of C_1. We assume that farmers' optimal choice of production is achieved by maximizing the profit from farming, or where L_1 is tangent to C_1. And the optimal output of soybean and non-soybean crops at baseline are shown as Q_1^s and Q_1^C in figure 1, respectively.

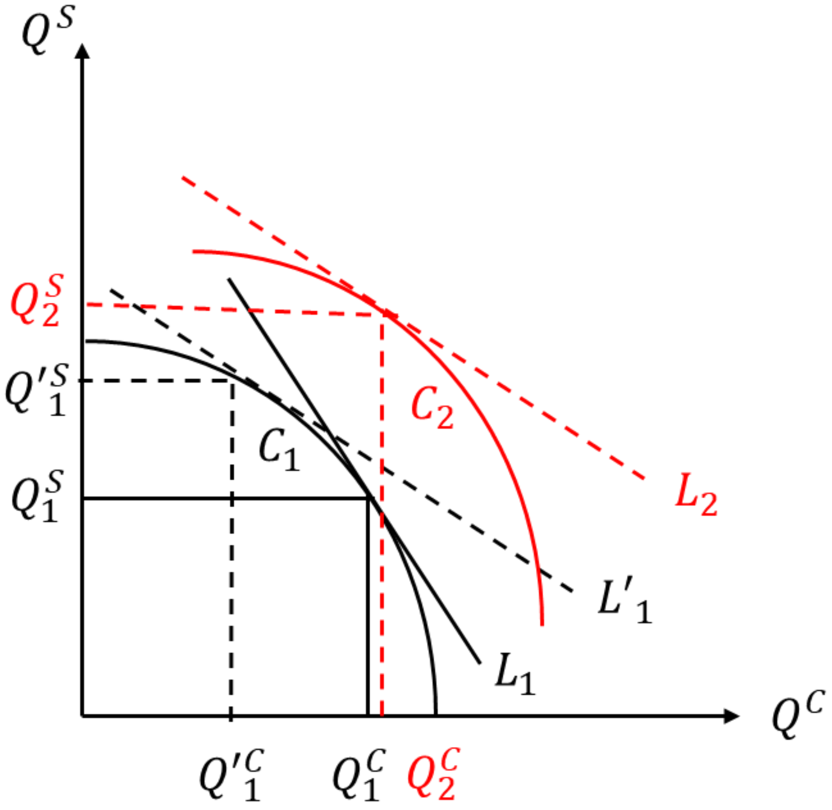

Figure 1. The economic framework of the global trade driver's impact on local agricultural production.

Then we consider there is an increase of soybean demand from the international market, which raise the soybean price with respect to non-soybean price and change the slope of L_1 to L'_1. Assuming the number of inputs available in this region does not change, now the optimal output of soybean (Q'^s_1) and non-soybean crops (Q'^C_1) are determined where L'_1 is tangent to C_1. As is shown by dashed lines in figure 1, the increase of soybean price drives farmers to produce more soybean ($Q'^s_1 > Q^s_1$) and less non-soybean crops ($Q'^C_1 < Q^C_1$) due to the substitution effect.

However, the actual response of crop production depends not only on the substitution effects, but also on a series of other factors. First, while the analysis above assumes the aggregated input does not change, the rise of soybean price would make region more suitable for soybean production to also more attractive to mobile inputs such as labor and capital, which consequently shifts the curve C_1 rightward to C_2, and results in the optimal production as Q^s_2 and Q^C_2, which is denoted as the scale (of output) effect. While both the substitution effect and the positive scale effect (increase in aggregated input) indicates $Q^s_2 > Q^s_1$, the relationship between Q^C_2 and Q^C_1 depends on both the slope change from L_1 to L_2 and the shift from C_1 to C_2, or the relative strengths of substitution and scale effects. In the same manner, regions that are less suitable for soybean production may experience a negative scale effect in spite of national soybean price increase, because it becomes less attractive in farming, which consequently influence the optimal crop production, Second, while in figure 1 we plot the possible output mixture curve C_1 for one certain region, the shape of that curve also varies across regions, which would further influence the response of crop output. Finally, in this simplified framework we only consider the economic sector of farming, while other sectors would also compete with farming sectors on input (land, labor, capital, etc.), and the demand of soybean and non-soybean crops are also determined by the supply-demand equilibrium at national and global market. In summary, this framework provides the general and qualitative economic intuition of the driving forces from international soybean demand to local production choice, which will be brought together with more rigorous modeling and real-world data for quantitative simulations.

2.2 GTAP-SIMPLEG model

To bring real-world data to the economic theory, we developed a computable general equilibrium (CGE) model, GTAP-SIMPLEG, with the focus of how bilateral trade flow influence the gridded multiple crop production and land use in Brazil. Figure 2 provides an overview of the GTAP-SIMPLE's model structure. For the demand system and bilateral trade flow system for all regions, as well the supply system of commodities that are not located in the focused region (here is Brazil) or do not use land as direct input, we keep the corresponding model structure and data from the standard GTAP model (Figure 2A). For land-using sectors (farming, forestry and livestock) in the focused region, we disaggregate the supply system from national level to grid cells with the resolution of five arcminutes[1] (Figure 2B). On each grid cell, we model the land use conversion between forest plantation (used by forestry), pasture (used by livestock production) and cropland (used by farming) with the constant elasticity of transformation (CET) functions in response to land rent change. CET function is a commonly used functional form that allows researchers to represent the allocation of commodities into multiple categories, with the flexibility in representing different level of convenience between substituting one category with another. For other land use types that are not directly used by sectors in GTAP model, for example natural forest or commercial and residential land, we represent them as exogenous variables in gridded land use allocation, which can be changed to represent conservation policies. After allocated at grid cell level, the pasture and forest planation area are further aggregated

---

[1] In Brazil, a grid cell with five-arcminute resolution contains roughly 7000 – 8000 hectares of land.

to national level and used as the input of livestock and forestry production from the GTAP framework.

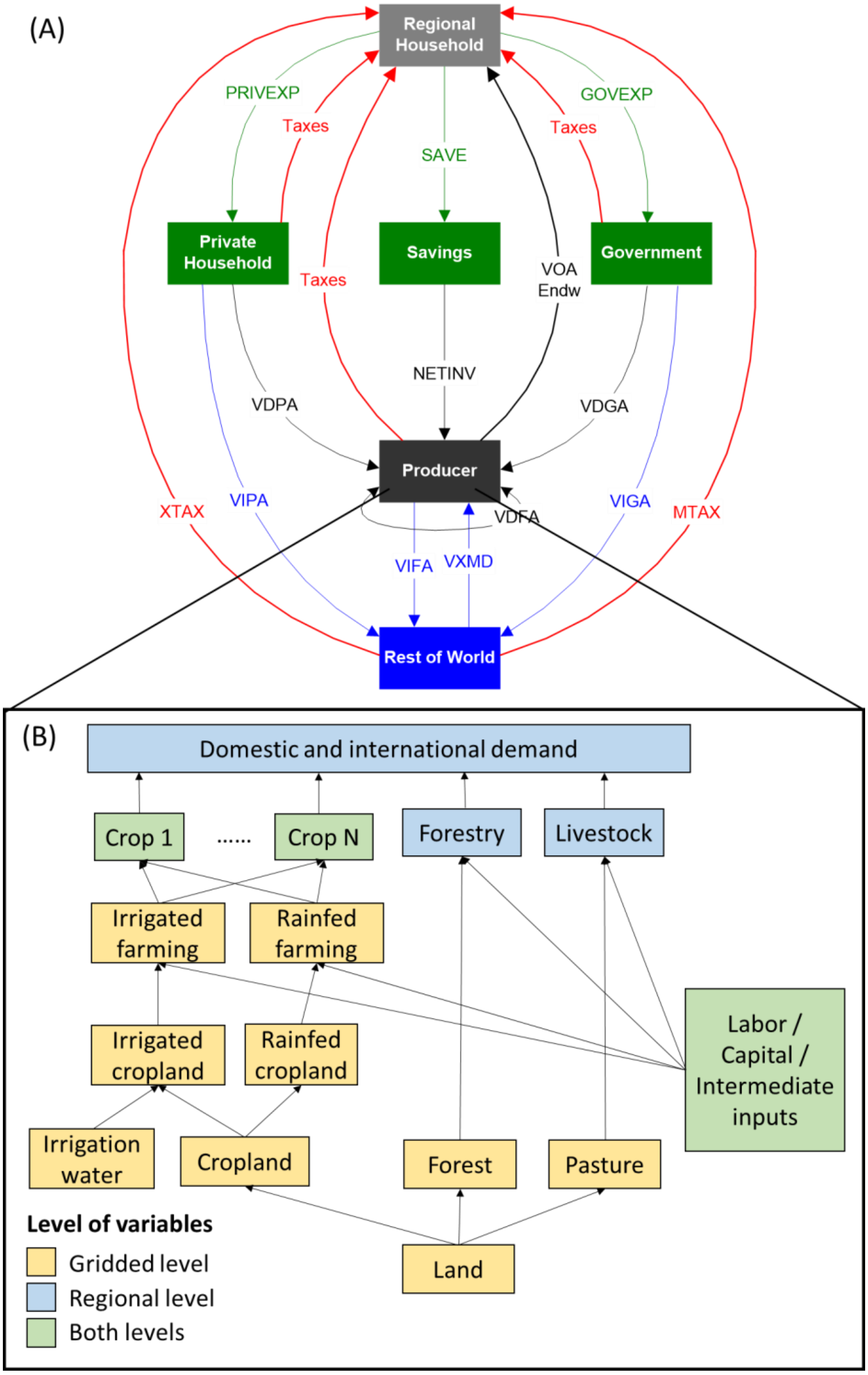

Figure 2. The structure of GTAP-SIMPLEG model. (A) The multi-region GTAP framework adapted from Brockmeier (2001). (B) The gridded multi-crop, multi-land use system within the focused region.

For the farming sector, we further model the gridded use of multiple inputs and output use by irrigation types following the SIMPLE-G framework. The total cropland in each grid cell is further allocated for irrigated and rainfed farming with the CET function. For each irrigation type of farming, we develop a nested constant elasticity of substitution (CES) structure of agricultural inputs including cropland, labor, capital, intermediate inputs, irrigation water and equipment (for irrigated farming only). The CES function is mathematically equivalent to CET functions, but it is used in representing the substitution between inputs in the production of a single output. With this nested structure, we aggregate multiple inputs to form a composite agricultural productivity, which is further allocated to produce eight GTAP crops with CET structure again. This model approach is consistent with our economic framework in the previous section, and also allows researchers to solve the change of crop output and input use quantitatively, in response to relevant price changes. Also, this structure helps researchers to overcome the challenges of collecting crop-specific input data at gridded level. In GTAP, all inputs except irrigation water and equipment also exist at the regional level. So to connect the gridded supply system of crops with the rest of model, we model the supply of irrigation and water with the supply elasticity that connects the change of price and response in quantity, and aggregate other inputs to regional level as the factor endowment and the intermediate inputs, as well as aggregate the gridded output of multiple crops to regional level to match the trade and demand systems.

Table 1 compares the GTAP-SIMPLEG model with the SIMPLE-G-Brazil model, which is a partial equilibrium model that also focuses on the gridded agricultural production and land use. While SIMPLE-G-Brazil focus on the expansion of cropland and the production of a single aggregated crop (all crops are aggregated together with price-based weight) and only includes grids with crop production, in GTAP-SIMPLEG we expands this grid-resolving framework to also include pasture and forest plantation, as well as incorporate the production of eight crop categories included in the GTAP model and database, which greatly enhance the model capacity for simulating more complex scenarios and response.

Table 1. The comparison of features between SIMPLE-G-Brazil and GTAP-SIMPLEG

Feature	SIMPLE-G-Brazil	GTAP-SIMPLEG
Grid cells	50,598 (Brazilian cropland only)	103,751 (Brazil, all land uses)
Land use type(s)*	1 (cropland)	3 (cropland, pasture, forest planation)
Crop type(s)	1 (corn-equivalent)	8 (rice, wheat, oil seeds, other grains, sugar crops, vegetable & fruits, plant fibers, other crops)
Input types	6 (fertilizer, land, labor, capital, irrigation water, irrigation equipment)	6 (intermediate input, land, labor, capital, irrigation water, irrigation equipment)
Equations	304,867	3,109,779

Note *: Here we list the land use types that are solved endogenously. In GTAP-SIMPLEG-Brazil, land use for natural forest is modeled as an exogenous variable.

GTAP-SIMPLEG is benchmarked with the baseline year of 2017. In the development of GTAP-SIMPLEG, we obtained the data and parameters on national supply, trade and demand from the GTAP database version 11 (baseline year 2017) (Aguiar et al. 2022). The land use data for cropland, pasture, forest plantation and natural forest in Brazil are obtained from Mapbiomas (2020), while the output data of multiple crops at gridded level are obtained from SPAM 2010 database (Yu et al. 2020) and updated to 2017 with the aggregated national output data from FAOSTAT (Food and Agriculture

Organization of the United Nations 2023). We further convert crop outputs to crop value with the price data from FAOSTAT, and aggregate them to GTAP crop categories according to Chepeliev (2020) (the mapping between FAO and GTAP crop categories are available in supplementary material S1). With the crop value available, we further disaggregate the total value into the value of farming inputs, using the cost share data from SIMPLE-G-Brazil (Wang et al. 2024). Finally, all gridded data are further adjusted so their national sum matches with the GTAP database for Brazil.

2.3 Research design

In this study, we apply the exogenous shock of China’s 25% tariffs on the US’s soybean export, which is equivalent with China’s retaliatory tariff in August, 2018 in response to the US’s tariff from China’s industrial commodities (Li et al. 2019). Although not directly influencing Brazil, this shock results in the increased demand of Brazilian soybean exports as the spillover effect from global market, which would further change the domestic supply of crops, as well as the land use competition between cropland, pasture and forest plantation both nationally and locally.

Historically, there are other external drivers that influence the soybean tariff’s impacts, for example the outbreak of swine fever that reduces the soybean demand in China, and the US’s subsidy to mitigate impacts on domestic soybean producers (Adjemian et al. 2021), In this study, we focusing on the tariff impact since our objective is not to replicate the historical pattern, but to identify the impact of trade driver only. Still, other domestic and international drivers can be included in future simulations with GTAP-SIMPLEG.

3. Results[2]

---

[2] Currently, the model is under further calibration, so results shown in this paper are not finalized and

Table 2 reports simulation results on the percentage change of commodities production from farming, livestock and forestry sectors for the US, Brazil and China. When China increases the tariff on soybean export, the oil seeds sector in the US experiences the reduction in output by 9.43%. The reduction of soybean demand drives farmers to switch from soybean to other crops, resulting in the increase of output for all non-soybean crops except sugar crops. It also causes landowners to favor farming less but grazing more in land use allocation, which consequently causes the net increase in ruminant production. In sharp contrast, Brazil expands oil seeds production by 3.54% in responses to the demand from China, while the production of almost all non-soybean crops (expect wheat) to decrease, in particular sugar crops (mainly sugar canes) which reduces by 1.73% decreases except for wheat. It also drives the cropland to be more profitable in land use allocation, which causes the reduction in production in ruminant and forestry sector. Finally, China's tariff on the US's soybean also rises challenges to satisfy its own soybean demand, which stimulates higher domestic production (5.26%) to strengthen soybean self-sufficiency. Combining the percentage change with the output data, the tariff's impact in table 1 is equivalent to the increase of 4.94 million metric tons (t) in oil seeds production, the decrease of 15.22 million t in sugar crops production, while the category "other grains" experiences the reduction in output by 0.45 million t.

Table 2. Percentage changes (%) of national output by sectors

Output by sectors	USA	Brazil	China
Rice	0.52	-0.37	-0.01
Wheat	0.66	0.25	-0.07
Other grains	0.17	-0.41	-0.05

---

subject to further update.

Vegetable and fruits	0.41	-0.52	-0.01
Oil seeds	-9.43	3.54	5.26
Sugar Crops	-0.36	-1.73	-0.02
Plant fibers	0.49	-1.30	0.09
Other crops	0.73	-1.33	0.06
Ruminants	0.38	-0.34	-0.01
Forestry	-0.66	-0.74	0.03

Results from table 2 reveal the aggregated impact on national level, but their impacts on local level are equally, if not more, important in the evaluation of tariff's impact. Figure 3 shows the change of net output by the three major crop categories in Brazil: the oilseed, sugar crops and other grains, which are dominated by soybean, sugar cane and maize in Brazil according to their value share in each category. As is shown in figure 3(A), the rise of international soybean demand causes the soybean production to increase in entire Brazil, in particular the major soybean producing regions in the central Brazil. On the other hand, the expansion of soybean productions negatively affects the competitivity of sugar cane (figure 3B), resulting in the output reduction in southeast Brazil, the major sugar cane production region. As to the production of maize, although its national output decreases, maize production still shows expanding pattern in the central Brazil, similar with the pattern of soybean (figure 3C). The gridded pattern of maize is consistent with the pattern when the scale effect overwhelms the substitution effects in the simplified economic framework.

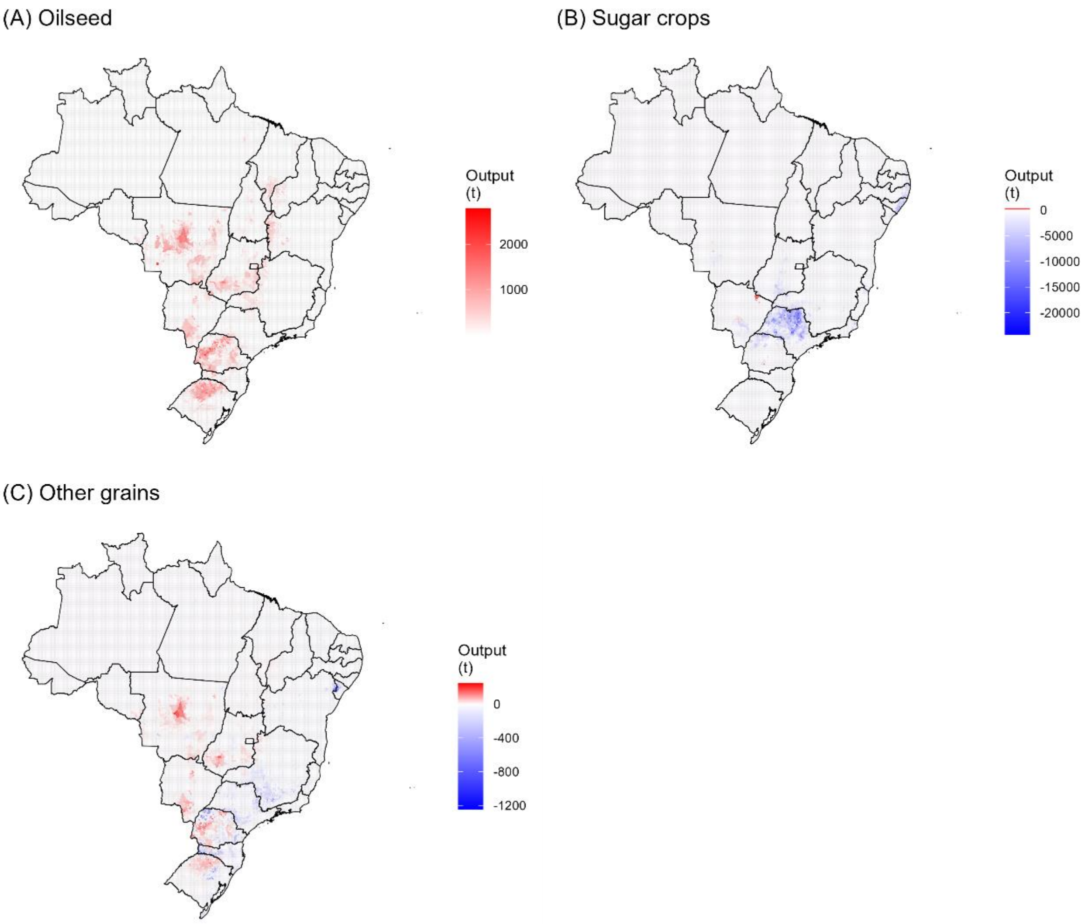

Figure 3. Impact on gridded crop production changes. Unit: metric ton (t) per grid cell

Furthermore, we also examined the simulation results on land use conversion. At the national level, the tariff causes the expansion of cropland by 0.33 million hectares (ha), together with the shrinkage of pasture by 0.31 million and the shrinkage of forest plantation by 0.02 million ha. At gridded level, figures 4(A) indicates that the national pattern of cropland is mainly driven by the expansion of soybean and the shrinkage of sugar cane production (figure 3 A and B). While pasture area decreases at national level, it also shows the pattern of shifting from the central Brazil to the southeast region. Finally, the reduction of forest plantation is milder than pasture, and mainly concentrated in the south region.

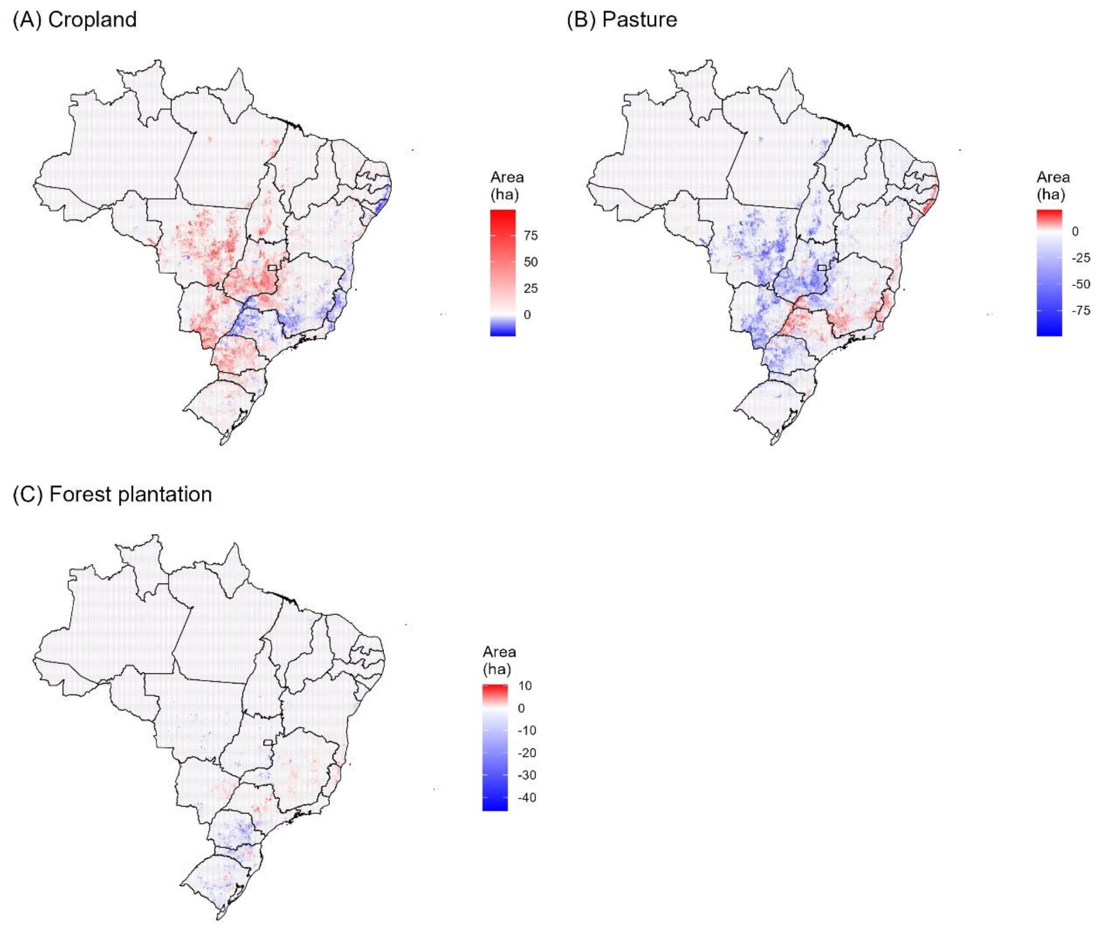

Figure 4. Impacts on gridded land use. Unit: hectare (ha) per grid cell.

4. Discussion

In this study, we research how China's tariff on the soybean export from the US influence the agricultural commodities production in Brazil, in particular on the spillover effects over other crops and non-farming sectors, as well as the spatial pattern of impacts on the gridded level. While our results on national level are consistent with existing studies (Carvalho et al. 2019; Dhoubhadel et al. 2023), the gridded simulation results further help us the explore the in-depth mechanism between global drivers and gridded responses.

Our results identify that the increase of soybean demand not only causes the expansion of soybean but also the shrinkage of other crops, especially for sugar cane production. Comparing the responses of crop output and land use pattern, we further find that the spatial pattern of soybean expansion overlaps with pasture shrinkage, while the pattern of pasture expansion further overlaps with sugar cane shrinkage. This finding indicates the existence of spillover effects both across geographic regions and across sectors: the demand of soybean export cause cropland expansion in the soybean producing regions of central Brazil. However, as the major exporter of both soybean and ruminant, Brazil still needs to satisfy the demand of pasture for its livestock sector, which further drives the pasture pattern to shifts towards southeast Brazil, to the producing regions of sugar cane. As a result, on the national level we find the tariff causes strong increase in soybean production, mild decrease in ruminant production and strong decrease in sugar cane production. The transmission of spillover effects across sectors and geographic regions would facilitate our understanding of global drivers' local impacts.

Besides, we also find although maize production experiences mild reduction on national level, it still expands the central Brazil with a similar pattern of soybean. This finding indicates that the driving force of maize production will be the scale effect from soybean expansion. In Brazil, a special feature of agricultural production is the rotation between corn and soybean. When the expansion of soybean happens in response to higher international demand, it attracts agricultural inputs to central Brazil, which also makes maize production in the same region to be also more profitable. As a result, both soybean and maize production increases due to the soybean tariff. This finding indicates that extending the research scope to multiple crop production at fine spatial resolution helps us to explore the economic mechanisms that are usually absorbed by aggregated national data, but still very important for policy makers and stakeholders in agriculture.

As this paper is currently under development, we recognize that several limitations still exist and should be addressed in upcoming versions or future studies. First, in this paper we focus on the impact from international trade aspect, while the impacts from other domestic drivers (soybean demand decrease due to swine fever in China, or soybean production subsidy from the US) and their interactions between the tariff drivers also worth further analyses. Second, in the current version the land use for natural forest is set exogenously since there is no economic demand of natural forest in the model yet. It is possible to further expand the model by including the market value of natural forest (together with the access cost) and the non-market value of the ecosystem services it provides, in order to simulate natural forest's response to economic drivers in an endogenous approach. Third, while in this study only Brazil is selected as the region to be disaggregated to gridded level, the GTAP-SIMPLEG model allows researchers to disaggregate any number of regions to any resolution of grids, so a possible extension is to include the US at gridded level and research the local level impacts as well. Last but not the least, while the current study focusing on interactions between framing, livestock and forestry sections, it is also important to further explore the impact between industrial and agricultural sectors, for example the demand of soybean or sugar cane for biofuel production, which further associated with the energy sector and associated carbon emissions, in order to achieve more comprehensive understanding of environmental implications.

5. Conclusion

In this study, we research the impact of China's tariff on the US's soybean export on Brazilian agriculture and land use, in particular its spillover effects across sectors at fine spatial level. We simulate the imposition of a 25% soybean tariff with GTAP-SIMPLEG, a multi-scale general-equilibrium economic model that captures both bilateral trade and comprehensive economic sectors at national level, and also gridded multiple crop output, land use allocation and inputs use for Brazil. Simulation results indicates that with the soybean tariff, China turns to Brazil for soybean export, which boosts the production of soybean but also causes the reduction in other crops, especially for sugar cane. Consequently, Brazil experiences further land use conversion from pasture and forest plantation to cropland. At gridded level, we further identify that the expansion of soybean production mainly happens in central Brazil, which drivers the demand of pasture to shifts to southeast Brazil and occupy land in sugar cane's major producing region. While maize production expands together with soybean in central Brazil from the corn-soy rotation. We conclude that GTAP-SIMPLEG model has shown the capacity of capturing the spillover effects from global trade to local level, as well as across crop types and economic sectors, which will all contribute to future studies and policies assessments.

References

Adjemian, M.K., A. Smith, and W. He. 2021. "Estimating the market effect of a trade war: The case of soybean tariffs." *Food Policy* 105:102152.

Aguiar, A., M. Chepeliev, E. Corong, and D. van der Mensbrugghe. 2022. "The global trade analysis project (GTAP) data base: Version 11." *Journal of Global Economic Analysis* 7(2).

Baldos, U.L.C., I. Haqiqi, T.W. Hertel, M. Horridge, and J. Liu. 2020. "SIMPLE-G: A multiscale framework for integration of economic and biophysical determinants of sustainability." *Environmental Modelling & Software* 133:104805.

Brockmeier, M. 2001. "A graphical exposition of the GTAP model." GTAP Technical Paper No. 8, Available at: https://doi.org/10.21642/GTAP.TP08.

Carvalho, M., A. Azevedo, and A. Massuquetti. 2019. "Emerging Countries and the Effects of the Trade War between US and China." *Economies* 7(2):45.

Chepeliev, M. 2020. "The GTAP 10A Data Base with Agricultural Production Targeting Based on the Food and Agricultural Organization (FAO) Data." GTAP Research Memoranda Series GTAP Research Memoranda. Available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=6180 [Accessed February 29, 2024].

Colussi, J., G. Schnitkey, J. Janzen, and N. Paulson. 2024. “The United States, Brazil, and China Soybean Triangle: A 20-Year Analysis.” *Farmdoc daily* (14):35.

Corong, E.L., T.W. Hertel, R. McDougall, M.E. Tsigas, and D. Van Der Mensbrugghe. 2017. “The standard GTAP model, version 7.” *Journal of Global Economic Analysis* 2(1):1–119.

Dhoubhadel, S.P., W. Ridley, and S. Devadoss. 2023. “Brazilian soybean expansion, US–China trade war, and US soybean exports.” *Journal of the Agricultural and Applied Economics Association* 2(3):446–460.

Food and Agriculture Organization of the United Nations. 2023. “FAOSTAT.” Available at: https://www.fao.org/faostat/en/#home.

Gachúz Maya, J.C. 2022. “Mexico’s Trade Relationship with China in the Context of the United States–China Trade war.” *Journal of Current Chinese Affairs* 51(1):83–107.

Goulard, S. 2020. “The Impact of the US–China Trade War on the European Union.” *Global Journal of Emerging Market Economies* 12(1):56–68.

Itakura, K. 2020. “Evaluating the Impact of the US–China Trade War.” *Asian Economic Policy Review* 15(1):77–93.

Li, M., E. Balistreri, and W. Zhang. 2019. “The US-China trade war: Tariff data and general equilibrium analysis.” Center for Agricultural and Rural Development (CARD) at Iowa State University.

MapBiomas. 2020. “Project MapBiomas—collection v7 of Brazilian land cover & use map series.” Available at: http://mapbiomas.org [Accessed May 11, 2021].

Misra, R., and S. Choudhry. 2020. “Trade War: Likely Impact on India.” *Foreign Trade Review* 55(1):93–118.

Purwono, R., U. Heriqbaldi, M.A. Esquivias, and M.K. Mubin. 2022. “The American–China Trade War and Spillover Effects on Value-Added Exports from Indonesia.” *Sustainability* 14(5):3093.

Wang, Z., G.B. Martha, J. Liu, C.Z. Lima, and T.W. Hertel. 2024. “Planned expansion of transportation infrastructure in Brazil has implications for the pattern of agricultural production and carbon emissions.” *Science of The Total Environment* 928:172434.

Yu, Q., L. You, U. Wood-Sichra, Y. Ru, A.K.B. Joglekar, S. Fritz, W. Xiong, M. Lu, W. Wu, and P. Yang. 2020. “A cultivated planet in 2010 – Part 2: The global gridded agricultural-production maps.” *Earth System Science Data* 12(4):3545–3572.

Supplementary material

S1. The aggregation from FAO crop to GTAP crop classification

To match the commodity trade data from GTAP with the crop production and price data from FAO, we aggregate FAO crop categories to eight GTAP crop categories following the mapping criteria from Chepeliev (2020), listed in Table S1.

Table S1. The mapping between crop classifications in FAO and GTAP

GTAP	FAO
Rice	Rice
Wheat	Wheat
Other grains	Maize (corn), Sorghum, Barley, Rye, Oats, Millet, Triticale, Buckwheat, Fonio, Quinoa, Canary seed, Mixed grain, Cereals n.e.c,
Vegetable and fruits	Asparagus, Cabbages, Cauliflowers and broccoli, Lettuce and chicory, Spinach, Artichokes, Cassava leaves, Watermelons, Cantaloupes and other melons, Chillies and peppers, green (Capsicum spp. and Pimenta spp.), Cucumbers and gherkins, Eggplants (aubergines), Tomatoes, Pumpkins, squash and gourds, Okra, String beans, Other beans, green, Peas, green, Broad beans and horse beans, green, Carrots and turnips, Green garlic, Onions and shallots, green, Onions and shallots, dry, Leeks and other alliaceous vegetables, Mushrooms and truffles, Green corn (maize), Other vegetables, fresh, n.e.c, Avocados, Bananas, Plantains and cooking bananas, Dates, Figs, Mangoes, guavas and mangosteens, Papayas, Pineapples, Other tropical and subtropical fruits, n.e.c., Pomelos and grapefruits, Lemons and limes, Oranges, Tangerines, mandarins, clementines, Other citrus fruit, n.e.c., Grapes, Apples, Pears, Quinces, Apricots, Sour cherries, Cherries, Peaches and nectarines, Plums and sloes, Other pome fruits, Other stone fruits, Currants, Gooseberries, Kiwi fruit, Raspberries, Strawberries, Blueberries, Cranberries, Other berries and fruits of the genus, Locust beans (carobs), Persimmons, Cashewapple, Other fruits, n.e.c., Almonds, in shell, Cashew nuts, in shell, Chestnuts, in shell, Hazelnuts, in shell, Pistachios, in shell, Walnuts, in shell, Brazil nuts, in shell, Areca nuts, Kola nuts, Other nuts, Potatoes, Cassava, Cassava, fresh, Sweet potatoes, Yams, Taro , Yautia, Edible roots and tubers with high starch, Beans, dry, Broad beans and horse beans, dry, Chick peas, dry, Lentils, dry, Peas, dry, Cow peas, dry, Pigeon peas, dry, Bambara beans, dry, Vetches, Lupins, Other pulses n.e.c.
Oil seeds	Soya beans, Groundnuts, excluding shelled, Cottonseed, Linseed, Mustard seed, Rapeseed or colza seed, Sesame seed, Sunflower seed, Safflower seed, Castor oil seeds, Poppy seed, Melonseed, Hempseed, Other oil seeds, n.e.c., Olives, Coconuts, in shell, Oil palm fruit, Palm kernels, Karite nuts (sheanuts), Tung nuts, Jojoba seeds, Tallowtree seeds, Kapok fruit, Kapokseed in shell.
Sugar Crops	Sugar beet, Sugar cane, Other sugar crops n.e.c.
Plant fibers	Seed cotton, unginned, Cotton lint, ginned, Jute, raw or retted, Kenaf, and other textile bast fibres, Flax, raw or retted, True hemp, raw or

	retted, Kapok fibre, raw, Ramie, raw or retted, Sisal, raw, Agave fibres, raw, n.e.c., Abaca, manila hemp, raw, Coir, raw, Other fibre crops, raw, n.e.c.
Other crops	Coffee, green, Tea leaves, Maté leaves, Cocoa beans, Pepper (Piper spp.), raw, Chillies and peppers, dry (Capsicum spp., Pimenta spp.), raw, Nutmeg, mace, cardamoms, raw, Anise, badian, coriander, cumin, caraway, fennel and juniper berries, raw, Cinnamon and cinnamon-tree flowers, raw, Cloves (whole stems), raw, Ginger, raw, Vanilla, raw, Hop cones, Chicory roots, Other stimulant, spice and aromatic crops, n.e.c., Peppermint, spearmint, Pyrethrum, dried flowers, Natural rubber in primary forms, Unmanufactured tobacco.