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GTAP-SIMPLEG: An Integrated Model for Coupling Gridded Land Use, Crop Production and Environment Impacts with Global Supply Chain and Bilateral Trade System

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Abstract

The relationship between global trade drivers and local agricultural and environmental responses has been an increasingly important research question. When international trade policy shocks the supply-demand equilibrium for a certain country, such impacts will not be uniform but show spatial heterogeneity at local level, in particular for agricultural production, land use and the corresponding environmental implications. In this study, we developed an innovative general-equilibrium economic model, GTAP-SIMPLEG, to capture the relationship between global drivers and local responses. This model extends the current GTAP framework by embedding a gridded multiple-crop (eight GTAP crop categories) supply and multiple-land use (cropland, pasture and forest) system in the focused region (here is Brazil). Taking the soybean trade between the US, Brazil and China as an example, we apply GTAP-SIMPLEG to simulate Brazil's crop production, land conversion and carbon balance at fine spatial scale in response to China's retaliatory tariffs on soybean produced from the US. Finding of this study indicates the importance of incorporating spatial response in international trade analysis for the more comprehensive evaluation.

1. Introduction

The Global-to-Local-to-Global (GLG) approach of analyzing the nexus of agricultural and environmental systems has received increasing attention. In the real world, the external drivers faced by the agricultural system are usually not single-ended, but a mixture of multi-scale factors and their interactions. For example, the recent soybean production in Brazil has reached record high, one of its main drivers is the increasing demand of import from China, as the outcome of the US-China trade war and China's retaliatory tariffs on soybean produced from the US (fig. 1a). As a result, Brazilian farmers receive the strong stimulus of boost soybean production, but their capability of cropland expansion is restricted by the native vegetation production law as a sub-national driver (fig. 1b). Furthermore, the domestic transportation cost of crops in inland Brazil is up to three times of the cost for the coastal region, which becomes the long-time bottleneck of agricultural production and export in Brazil (Meade et al. 2016; Fliehr, Zimmer, and Smith 2019). The newly launched national logistic plan aims to expand national railway network by 90% at maximum (Ministry of Infrastructure 2022), which would promote soybean production as a gridded driver that varies spatially (fig. 1c). Besides impacts from multi-scale drivers, it is also important to capture how does the agricultural system, and its associated environmental effect (land use conversion, deforestation, carbon emission, etc.), respond to those drivers on both global and local level, in order to capture the spatial heterogeneity of agriculture-environment system and the spillover effects within and across regions.

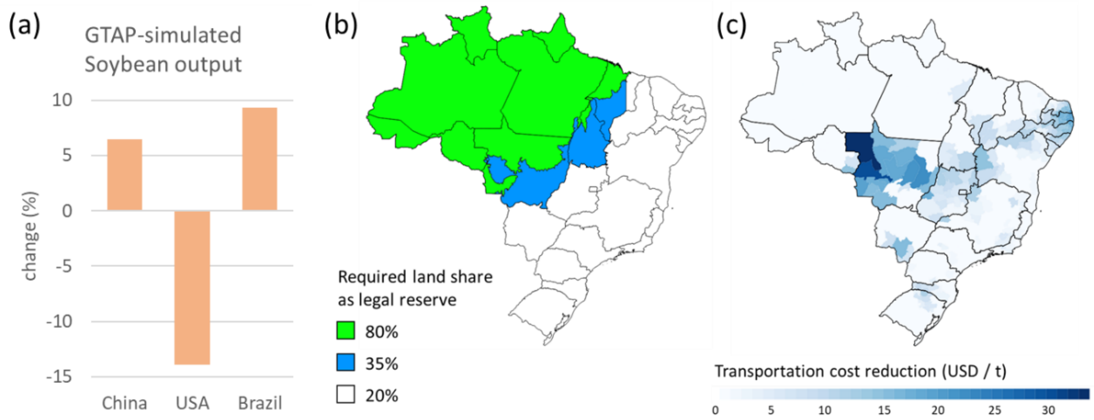

Fig. 1: Multi-scale drivers of Brazilian agriculture. (a) Global level: simulation of the US-China trade war's impact on soybean production (Carvalho, Azevedo and Massuquetti 2019). (b) Sub-national level: the native vegetation protection law on cropland expansion (Metzger et al. 2019). (c) Gridded level: Reduction of transportation cost due to railway expansion (Wang et al. 2023).

Existing studies have analyzed impacts from both global and local drivers of Brazilian agriculture. However, analyses from global aspects tend to provide aggregated simulation results on national or sub-national level, leaving the spatial pattern of impacts and spillover effect within the country outside of research scope. On the other side, studies that focused on local responses usually treated drivers from national or global level as external shocks but did not further explore how do local responses provide feedback to more aggregated systems endogenously. These gaps in the literature enhance the demand for GLG based analysis that couples both drivers and responses on multi-scale, which is still on its early stage.

In this study, we develop an innovative general-equilibrium economic model, the GTAP-SIMPLEG model, and apply it to research the interactive impacts of global trade policy, national conservation policy and region-specific infrastructure 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). 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 exogenous 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.

2. Model.

Fig.2 provides an overview of the GTAP-SIMPLE's model structure. For sectors that do not use land as direct input, we reserve the existing supply system as the standard GTAP model (fig.2a). For land-using sectors (multiple crop production, forestry and livestock), we replace the supply system with a fine-scale gridded land use and production system (fig.2b). This gridded system disaggregated certain regions (here is Brazil) in GTAP into five-arcmin grids. On each grid, the total usable land is allocated to forest, pasture and cropland with the constant elasticity of transformation (CET) functions in response to land rent change. For cropland, it is further allocated to the cropland for irrigated and rainfed farming with irrigation water availability data. For each irrigation type, a nested constant elasticity of substitution (CES) structure is developed to simulate the production of multiple crops with cropland, water, labor, capital and other intermediate inputs, while inputs other than cropland and water are further connected with the factor endowment (for labor and capital) and commodity production (for intermediate inputs) systems in GTAP. Finally, outputs of crops, forestry and pasture are aggregated at regional level and connects with the trade and demand systems in GTAP, similar with non-land-using sectors. Data and parameter sources of GTAP-SIMPLE are available from Aguiar et al. (2022) and Wang et al. (2023).

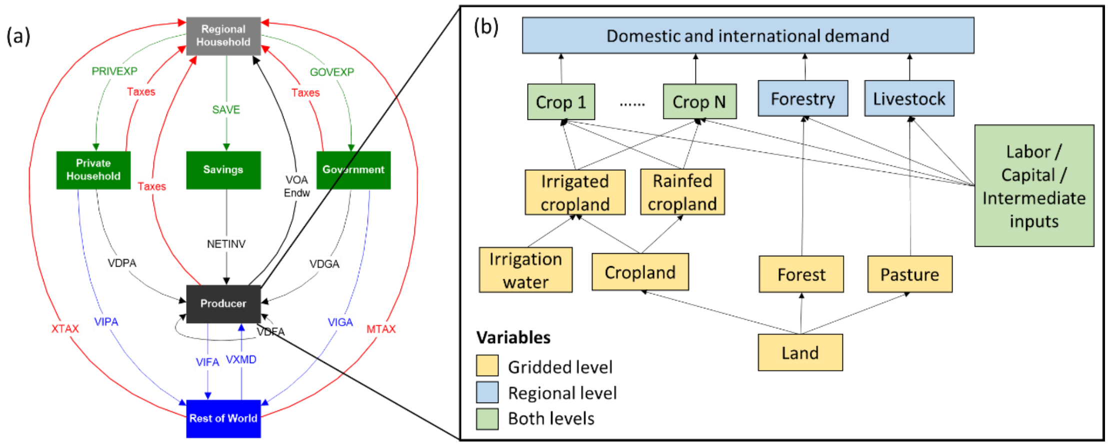

Fig. 2: Structure of GTAP-SIMPLEG model. (a) The multi-region GTAP framework (Brockmeier 2001). (b) The gridded land use and production (including crop production, forestry and livestock) system.

3. Simulations.

In this study, we simulate GTAP-SIMPLEG with three groups of shocks: (1) China's retaliatory tariffs on the US's soybean exports. Although not directly influencing Brazil, this shock results in the increased demand of Brazilian soybean exports as the spillover effect from global market. (2) Brazil's internal conservation policies, or what if Brazil strengthen the constriction of cropland expansion to pursue its zero-deforestation objectives (Cuff 2022), or to relieve the constriction for further growth in agricultural sector. (3) Brazil's transportation infrastructure expansion plan, which aims to improve the connectivity of inland Brazil to coastal regions, and eventually global markets, to promote its crop export competitiveness. We use GTAP-SIMPLEG to evaluate the contribution of each group of shock and their interactive effects on the crop production, land use, carbon stock and carbon emission from gridded to national level, the spillover effects across states and districts in Brazil, as well as the leakage of Brazil specific drivers to other regions, for example the US and China, in order to provide comprehensive analysis of the agricultural-environmental systems.

We find impacts of these shocks vary both spatially and in their aggregate impacts. Take the total cropland use as an example (fig 1), the combined impacts show the cropland expansion with marked spatial heterogeneity (a). China's tariff on US soybean drives Brazilian cropland to expand by 1.10 million ha (Mha), which promotes cultivation nationally (b). While the conservation policy reduces cropland expansion by 0.09 Mha, mainly Mato Grosso state (c). Although the net contribution of infrastructure drivers is just the half of the tariff's impact (0.49 Mha), it shows the strongest impact on cropland pattern, shifting cropland demand from southeast-south to center-west (d) and further influencing the cropland-pasture rotation.

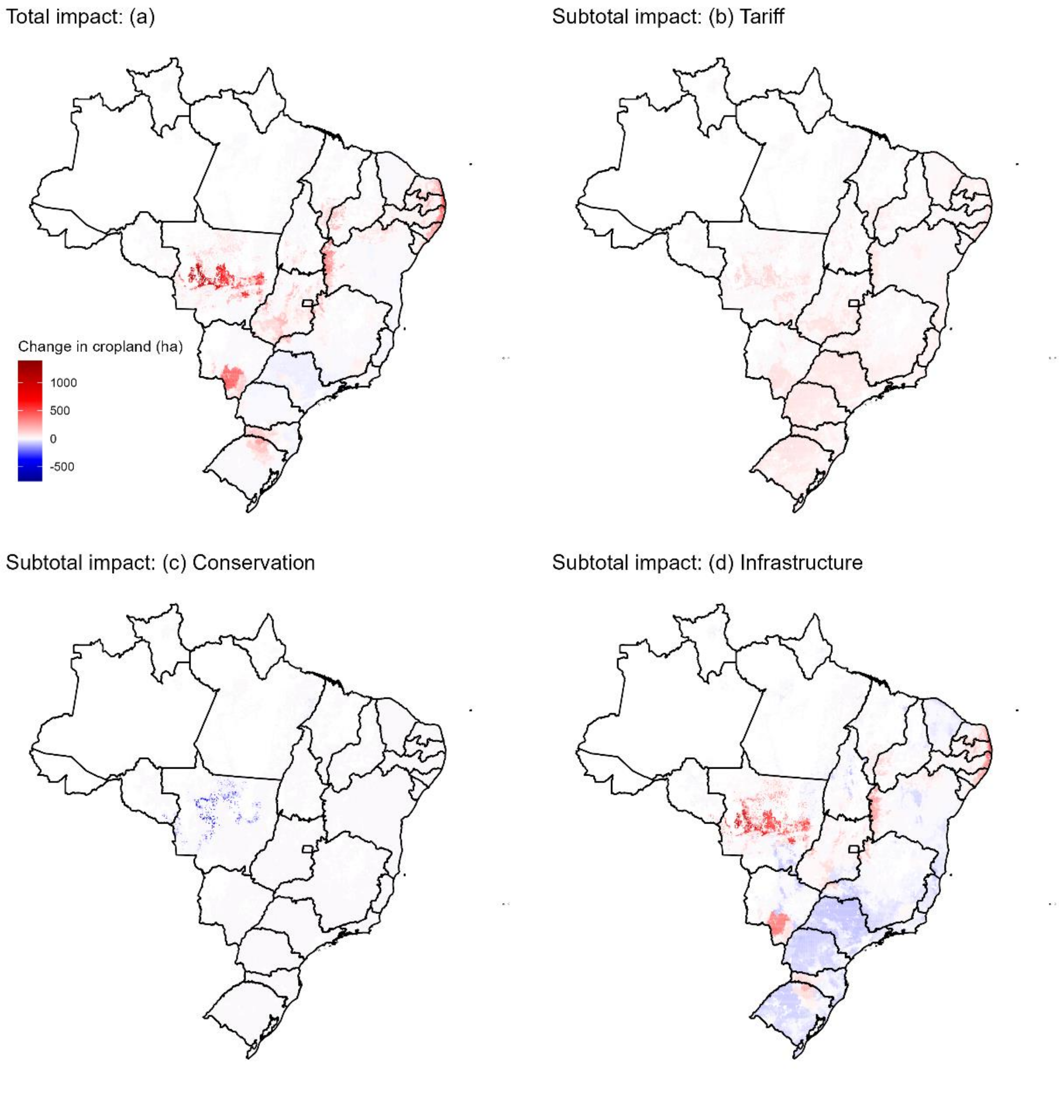

Fig. 3: Primary results of cropland use. The total impacts (a) on cropland use is decomposed by soybean tariff (b), conservation policy (c) and infrastructure expansion (d)

4. Next steps and future directions.

While in this study, only Brazil is selected as the region to be disaggregated to grid level, the GTAP-SIMPLEG model allows researchers to disaggregate any number of regions to any resolution of grids, as long as relevant gridded data are available. So, the next step of the current study is to incorporate gridded crop production and land use of the US and China into GTAP-SIMPLEG, in order to research impacts from trade and domestic policy on local agricultural production and environment for the top three player on global crop trade.

Furthermore, the GTAP-SIMPLEG model can be generalized to other research questions that cannot be fully analyzed from global or local aspect only, especially where shocks from global trade interact with spatial heterogenous drivers (policy, infrastructure, disease or disaster, etc.), in order to facilitate and promote GLG analysis.

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