Chapter 15
The Role of Transportation Infrastructure Expansion in the Transmission of Global Crop Price Shocks to the Brazilian Agriculture

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1 Introduction

The high logistics cost from farm to port is a major factor that hinders the export competitiveness of Brazilian agriculture (Tiller and Thill 2017; Fliehr et al. 2019; Mendes Dos Reis et al. 2020; Valdes 2022), especially for its inland Cerrado biome. Nonetheless, the Cerrado has experienced rapid expansion of both cropland and crop production in the last three decades (Bicudo Da Silva et al. 2020; Souza et al. 2020). For example, Meade et al. (2016) compare the crop prices at destinations and their decomposition (farm-gate crop price, inland transportation and handling cost, and ocean transportation cost) between two crop-producing sites—Sorriso in the Mato Grosso state (MT) to represent the Cerrado biome and Campo Mourão in Paraná state (PR) to represent the south/southeast region, which is better connected to global markets. Figure 15.1 illustrates these data, showing that the Cerrado biome is more disadvantaged in inland transportation than the south/southeast region, not only because the former is further from crop exporting ports but also because of its sparser transportation network, especially the railway network. As a result, although Sorriso faces similar or lower farm-gate crop prices for corn and soybean production, its inland transportation cost is about three times that of Campo Mourão. Thus, crops produced in Sorriso are more expensive for importers and less competitive in international markets (Fig. 15.1b).

Data availability statement: The files needed to replicate this application are available at https://gtap.agecon.purdue.edu/simple-g/.

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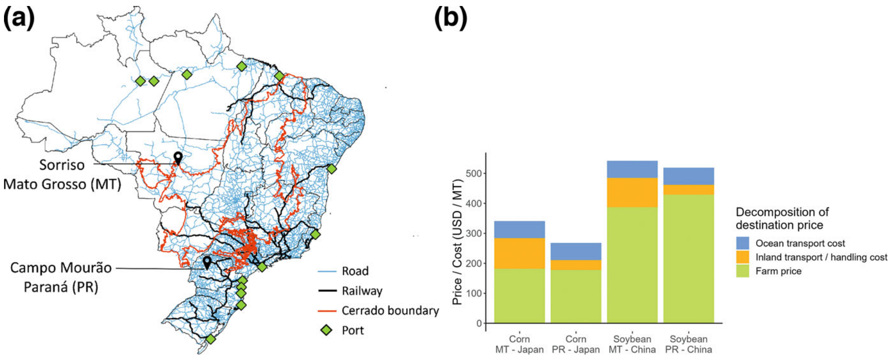

Fig. 15.1 Role of logistics costs in Brazilian crop exports. (**a**) Locations of two representative crop production sites for the Cerrado biome (*red boundary*) and south/southeast region, respectively (Sorriso in the Mato Grosso (MT) state and Campo Mourão in Paraná (PR) state) and the distribution of road, railway, and crop exporting ports in 2017. (**b**) The decomposition of destination prices from Sorriso (MT) and Campo Mourão (PR) on corn exports to Japan and soybean trade to China. (Data are obtained from Meade et al. (2016))

In 2021, Brazil launched the 2035 National Logistics Plan (PNL2035), which aims to expand domestic transportation infrastructure to improve the connectivity of inland regions to coastal regions and eventually to the global market. According to the Ministry of Infrastructure of Brazil (2022), PNL2035 will expand the railway network length by up to 90.56% upon its completion, while the expected expansion of the already developed road network would be slight (<1%). How will this large-scale infrastructure expansion plan influence the export competitiveness of crops produced from inland Brazil? To analyze the comprehensive impacts of PNL2035 on crop export competitiveness, it is necessary to capture the interactive effects between global-level crop price changes and the spatial heterogeneity of transportation cost reductions from infrastructure expansion and to consider the spillover effects among regions in Brazil. The SIMPLE-G model introduced in this book, with its global–local–global philosophy, provides an appropriate tool for this research question.

In this chapter, we use a specially designed version of SIMPLE-G to simulate the interactive impacts of global crop price change and domestic transportation infrastructure expansion on crop production, land use, and carbon balance. Brazil is the focus region (hence SIMPLE-G-Brazil), and the PNL2035 provides the policy background. Of course, the methodology described in this chapter can be generalized to other regions of the world where transportation costs are of considerable importance. First, we provide a simplified economic framework to qualitatively demonstrate the impact of a global crop price increase and domestic transportation cost reduction on both subregional and regional crop supplies. Second, we introduce SIMPLE-G-Brazil, the regional variant of SIMPLE-G developed to research gridded agricultural and environmental impacts within Brazil. In particular, we discuss the two new modules that differentiate SIMPLE-G-Brazil in this application from the fundamental SIMPLE-G framework introduced in Part III: the transportation cost and cropland supply modules. Following Wang et al. (2024), the transportation cost module connects the expansion of transportation infrastructure with the reduction in monetary transportation costs at the grid cell level, which represents the role of transportation infrastructure in local farm-gate crop prices. The cropland supply module extends the factor supply system of cropland in the basic SIMPLE-G framework to capture the impacts of conservation policy on cropland expansion potential. For example, Brazil requires that a certain share of land (depending on the biome) on each farm cannot be used as cropland to prevent deforestation from overcultivation (Metzger et al. 2019). The cropland supply module can automatically prevent cropland expansion on all grid cells that have reached or exceeded this policy constraint. Additionally, the cropland supply module allows us to conduct a sensitivity analysis with respect to the cropland supply elasticity parameters. Third, we describe the experimental design for quantitatively simulating the impacts of a global crop price change and transportation cost reduction. Finally, we report and discuss simulation results covering three aspects: the global-to-local transmission of crop prices, the corresponding response of crop production and cropland use, and, consequently, the implications for terrestrial carbon fluxes.

2 Economic Framework

In this section, we conceptually demonstrate how international crop price changes and domestic transportation cost reductions interact and influence crop production, illustrated in Fig. 15.2. In this framework, Brazil consists of two regions: coastal and inland. For simplicity, we assume that the coastal region has already fully benefited

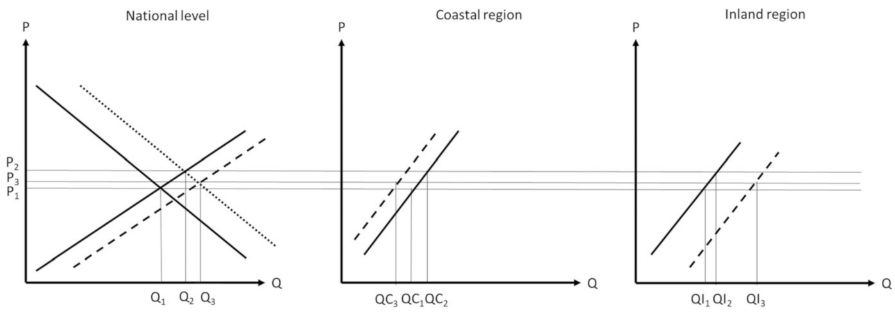

Fig. 15.2 Economic framework of national and subnational responses to a world price shock (*dotted line*) and transportation infrastructure expansion (*dashed line*). *Solid lines* show the supply–demand equilibrium without external shocks. An increase in global demand for Brazilian production shifts the national demand curve outward, resulting in an increase in the border price that producers receive for crops in both regions. They expand production to QC_2 and QI_2, respectively. The introduction of new transportation infrastructure boosts farm-gate returns in the inland region and acts as a supply shifter, resulting in output level QI_3. With the expansion of inland production, mobile input costs may increase; thus, some coastal production is displaced, as shown by the backward supply shift, resulting in production at QC_3

from existing transportation infrastructure; thus, expansion of the domestic transportation network will only reduce transportation costs in the inland region. Without external shocks, the national crop supply and crop demand (including both domestic and export demand) interact, resulting in equilibrium crop price P_1 and crop quantity Q_1. At the subnational level, the coastal and inland regions face the same free-on-board (FOB) price and produce crops QC_1 and QI_1, respectively, where $Q_1 = QC_1 + QI_1$.[1]

First, we assume an increase in Brazilian crop export demand from the global market, which is represented as the outward shifting of the demand curve (solid to dotted line) on the national level. Both the new equilibrium price, P_2, and crop quantity, Q_2, increase from the previous equilibrium. On the subnational level, without further shocks to local supply, a higher FOB price, P_2, causes local crop production (QC_2, QI_2) to increase in both regions.

In addition to the international demand shock, we consider the reduction in transportation costs for the inland region. As the farm-gate crop price equals the difference between the FOB crop price and transportation cost, a decrease in transportation costs raises the farm-gate price received by producers from the inland region and the average farm-gate price received at the national level, which is equivalent to a subsidy in production. As a result, the supply curves in both the inland region and at the national level shift rightward (solid to dashed lines). Although reductions in transportation costs do not directly influence farm-gate crop prices in the coastal region, both coastal and inland regions use factors supplied at the national level in crop production. Therefore, the reduction in transportation costs in the inland region makes it more competitive in attracting mobile factors, which reduces the availability of production factors for the coastal region and increases the cost of crop production there, resulting in an upward shift in the supply curve. The interactive effects of the increase in crop export demand and reduction in inland transportation costs cause a smaller magnitude of increase in national crop price P_3 ($P_1 < P_3 < P_2$) and further growth in national crop production Q_3 ($Q_1 < Q_2 < Q_3$). At the subnational level, we expect the reduction in transportation costs to further promote local crop production in the inland region ($QI_1 < QI_2 < QI_3$), but its spillover effect reduces crop production in the coastal region ($QC_3 < QC_1 < QC_2$).

The analysis with the simplified two-region framework provides us with the economic intuition with respect to the interactive impacts of a global crop price shock and a reduction in domestic transportation costs as well as a series of expected outcomes to be further tested as hypotheses. However, this simplified framework cannot capture the more complex agricultural production systems or rich spatial information on a fine-scale level; further analysis with the computable multiscale economic model SIMPLE-G-Brazil is needed.

[1] For simplicity, here we do not consider the transport cost between farmers and domestic consumers and instead assume that all domestic consumers face the same crop price as the FOB price. Given that the most densely populated regions in Brazil are located along its coast (IBGE 2010), this assumption is reasonable for our application.

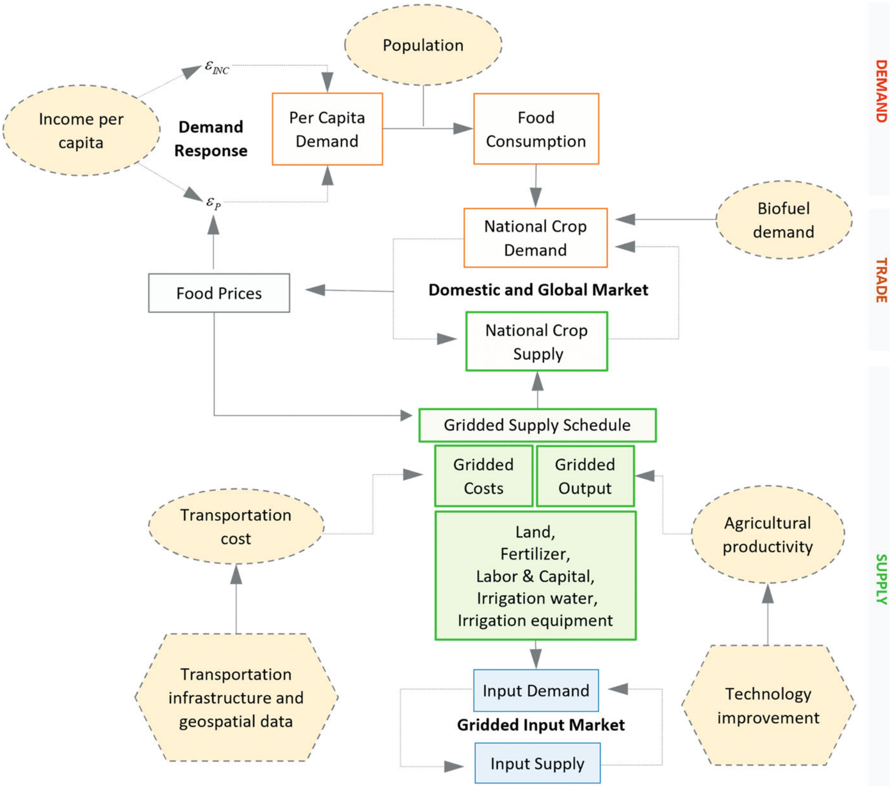

Fig. 15.3 Overview of the SIMPLE-G-Brazil model for the transportation infrastructure application. (Adapted from Wang et al. (2024))

3 SIMPLE-G-Brazil for the Transportation Application

This section takes us under the hood of the SIMPLE-G-Brazil model, showcasing key data sources and introducing two major upgrades: a nuanced land supply module to capture finer details of land use restrictions and a new transportation cost module that adds another layer of realism to the model.

3.1 Model and Data

SIMPLE-G-Brazil is constructed from the basic version of SIMPLE-G described in Part III. SIMPLE-G-Brazil divides the world into 17 regions and further disaggregates Brazil's cropland into 50,598 grid cells, each with a spatial resolution of 5 arcminutes (around 7000–8500 hectares in area, depending on latitude). Figure 15.3 summarizes the model structure of SIMPLE-G-Brazil for the transportation application. We incorporate a transportation cost module that links the Brazilian (port) crop price obtained from the national crop supply and demand equilibrium with the gridded farm-gate crop price. Furthermore, we modify the supply system of gridded cropland, which allows us to conduct a systematic sensitivity analysis (SSA) with respect to uncertainties from cropland supply parameter estimation and to control for conservation policies.

We selected 2017 as the baseline year for the model databases, and this model has been validated with historical observational data from 2000 to 2017 (for detailed information on model validation, please refer to Chap. 9). This study leverages a diverse mosaic of datasets to build a comprehensive picture of the Brazilian agricultural landscape. At the spatial level, detailed cropland area maps from *MapBiomas* (2020) are combined with yield data from Portmann et al. (2010) and further refined with microregional adjustments from the Brazilian Institute of Geography and Statistics (IBGE) (Prado Siqueira 2022). Irrigation status is estimated based on municipality-level irrigation ratios from the IBGE (2019) agricultural census. The transportation network is defined using data from the Ministry of Infrastructure of Brazil (2022), while crop exporting port locations are pinpointed via Victoria et al. (2021). Carbon stock factors from Novaes et al. (2017) are adjusted with tillage status data from Fuentes-Llanillo et al. (2021) to provide a nuanced picture of carbon storage, and vehicle carbon emission factors are drawn from Sims et al. (2014). On the aggregated level, the study draws upon FAOSTAT (FAO 2021) data for cropland area, crop output and price and World Bank open data (World Bank 2020) for population and per capita gross domestic product (GDP). Finally, GTAP database v.10 (Aguiar et al. 2019) provides insights into crop demand, while input cost shares are from Hertel and Baldos (2016). This rich tapestry of data sources fuels the intricate analyses presented in this chapter, enabling us to explore the complex interactions within the Brazilian agricultural system. Note that Table 15.1 summarizes the data sources for SIMPLE-G-Brazil and its transportation application. The simulation results from SIMPLE-G-Brazil are obtained using the GEMPACK economic modeling software (v.12) (Horridge et al. 2018).

3.2 Transportation Cost Module

To capture the role of transportation cost as the price wedge between FOB and farm-gate crop prices, this application attaches a transportation cost module to the basic SIMPLE-G model. In the basic structure, the gridded farm-gate crop price equals the national crop price (FOB price), so the transportation cost is not incorporated. In the transportation cost module, we replace the relationship between farm-gate and FOB crop prices with the following equation:

Table 15.1 Data sources for SIMPLE-G-Brazil transportation application

Variable	Data source
Spatial level	
Cropland area	*MapBiomas* (2020)
Crop yield	Portmann et al. (2010), adjusted with crop yield at the microregion level from the Brazilian Institute of Geography and Statistics (IBGE) (Prado Siqueira 2022)
Irrigation status	Calculated based on municipality-level irrigation ratio from the agricultural census (IBGE 2019)
Transportation network	Ministry of Infrastructure of Brazil (2022)
Crop exporting port location	Victoria et al. (2021)
Carbon stock factor	Novaes et al. (2017), adjusted with tillage status from Fuentes-Llanillo et al. (2021)
Vehicle emission factor	Sims et al. (2014)
Aggregated level	
Cropland area	FAOSTAT (FAO 2021)
Crop output	FAOSTAT (FAO 2021)
Crop price	FAOSTAT (FAO 2021)
Population	World Bank open data (World Bank 2020)
Per Capita GDP	World Bank open data (World Bank 2020)
Crop demand	GTAP v.10 (Aguiar et al. 2019)
Input cost share	Hertel and Baldos (2016)

$$P^{\mathrm{FOB}} = P_i^{\mathrm{FG}} + P_i^{\mathrm{TC}}, \tag{15.1}$$

where P^{FOB} is the FOB price at the national level, P_i^{TC} is the transportation cost (i.e., the least cost to transport crops from a farm to any export port) of grid cell i (the estimation of P_i^{TC} is described in Sect. 4), and P_i^{FG} is the farm-gate crop price for farmers in grid cell i. This representation is similar to modeling the margin of transportation in the general equilibrium literature.

As discussed in Chap. 5, SIMPLE-G consists of linearized equations with percentage-change form variables, so Eq. 15.1 is also linearized as follows[2]:

$$p_i^{\mathrm{FG}} = (1 + \theta_i)p^{\mathrm{FOB}} - \theta_i p_i^{\mathrm{TC}}, \tag{15.2}$$

where p^{FOB}, p_i^{TC}, and p_i^{FG} refer to the percentage changes in FOB price, gridded transportation cost, and farm-gate crop price, respectively, and θ_i represents the share of transportation cost relative to the total FOB price in the baseline dataset. Equation

[2]Recall that we use uppercase letters to represent variables in level form and lowercase letters to represent variables in linearized form.

15.2 provides an updated relationship between farm-gate crop price, FOB crop price, and transportation cost. With the transportation cost module, the farm-gate price increases with the FOB crop price (positive p^{FOB}) and with a reduction in transportation costs (negative p_i^{TC}), while the magnitude of those impacts now depends not only on changes in p^{FOB} or p_i^{TC} but also on the share of transportation cost in crop price decomposition. This representation is essential for research questions when the change in transportation costs is spatially heterogeneous, and an explicit consideration of transportation costs therefore provides a more precise analysis.

3.3 *Cropland Supply Module for SSA and Conservation Policy*

In addition to the module of transportation cost, we also update the cropland supply module in SIMPLE-G-Brazil for two purposes: applying the restriction of cropland expansion from conservation policies and allowing researchers to conduct a SSA with respect to the parameters in cropland supply elasticity estimation.

In the basic SIMPLE-G structure, the gridded cropland supply is depicted with the following equation:

$$q_i^{\mathrm{Land}} = \eta_i^{\mathrm{Land}} p_i^{\mathrm{Land}} + s_i^{\mathrm{Land}}, \tag{15.3}$$

where q_i^{Land} and p_i^{Land} are the percentage changes in the quantity and rent of cropland in grid cell i, respectively; η_i^{Land} is the supply elasticity of cropland in grid cell i; and s_i^{Land} is an exogenous slack variable. When the cropland supply module is not introduced, η_i^{Land} is estimated with the following equation from Haqiqi et al. (2023) and read into the model as a constant:

$$\eta_i^{\mathrm{Land}} = \alpha\sqrt{\mathrm{Precip}_i} + \beta \mathrm{Landshr}_i \sqrt{\mathrm{Precip}_i} + \lambda, \tag{15.4}$$

where Precip_i is the average annual precipitation (mm/year), $\mathrm{Landshr}_i$ is the share of cropland in the total area of grid cell i at baseline, and α, β, and λ are parameters estimated from regression (λ is fixed at 0 in estimation). This simple formula gives a narrow range from 0 to slightly above 1 for the land supply elasticity.

However, this basic land supply function faces two challenges. First, land supply in Brazil is controlled not only by cropland rent, p_i^{Land}, precipitation, Precip_i, and the current cropland occupancy, $\mathrm{Landshr}_i$, but also by the policy constraint of the natural vegetation protection law (Metzger et al. 2019). If a grid cell's current cropland occupancy has reached or exceeded the maximum of cropland share from the policy constraint, further expansion is prohibited. Such policy impacts should be captured in the cropland supply system. Second, the estimation of α and β from regression provides not only their value but also the uncertainty of estimation as the confidence intervals, and we wish to understand the extent to which our simulation results from

SIMPLE-G-Brazil are sensitive to the estimation of cropland supply elasticity parameters α and β.

To overcome these two challenges, we embed the cropland supply module in SIMPLE-G-Brazil, which allows the cropland supply elasticity, η_i^{Land}, to be calculated as

$$\eta_i^{\text{Land}} = \frac{\max((\text{Maxlandshr}_i - \text{Landshr}_i), 0)}{\max(|\text{Maxlandshr}_i - \text{Landshr}_i|, \text{tiny})} \times \left(\alpha\sqrt{\text{Precip}_i} + \beta\text{Landshr}_i\sqrt{\text{Precip}_i}\right) + \lambda, \tag{15.5}$$

where Maxlandshr_i is the maximum of cropland share allowed by the conservation policy and tiny refers to a sufficiently small positive value (this application uses tiny $= 0.000001$). In Eq. 15.5, if the current cropland share has reached or exceeded the maximum allowed share (i.e., $\text{Landshr}_i \geq \text{Maxlandshr}_i$), we have $\max((\text{Maxlandshr}_i - \text{Landshr}_i), 0) = 0$, but $\max(|\text{Maxlandshr}_i - \text{Landshr}_i|, \text{tiny}) = \text{tiny}$, so $\frac{\max((\text{Maxlandshr}_i - \text{Landshr}_i), 0)}{\max(|\text{Maxlandshr}_i - \text{Landshr}_i|, \text{tiny})} = 0$ and $\eta_i^{\text{Land}} = 0$. Otherwise, when $\text{Landshr}_i < \text{Maxlandshr}_i$, then $\frac{\max((\text{Maxlandshr}_i - \text{Landshr}_i), 0)}{\max(|\text{Maxlandshr}_i - \text{Landshr}_i|, \text{tiny})} = \frac{(\text{Maxlandshr}_i - \text{Landshr}_i)}{|\text{Maxlandshr}_i - \text{Landshr}_i|} = 1$ and Eq. 15.5 converts to Eq. 15.4, so the cropland supply elasticity will be calculated using the basic approach. Thus, Eq. 15.5 provides an automatic control for external policy restrictions.

Furthermore, calculating the cropland supply elasticity within the model allows us to conduct a SSA with respect to the uncertainties in parameters α and β with the help of the RunGEM software. RunGEM is a component of the GEMPACK software package that facilitates the running of SIMPLE-G models and provides tools ("Tools – SSA wrt parameters") for conducting sensitivity analyses given the mean and range of parameters. In this study, we apply triangular distributions of α and β with their estimated values as means and their 95% confidence intervals as ranges to estimate the 95% confidence intervals of the simulation results, which are reported as the error bar in Sect. 5.[3] For detailed instructions on using RunGEM to conduct an SSA, please refer to the application's "Readme Use RunGEM for SSA" folder.

4 Experimental Design

In this study, we designed three scenarios to be estimated with SIMPLE-G-Brazil. In all three scenarios, we apply the shock of a global crop price increase of 10%, while the three scenarios differ from each other with respect to the domestic transportation costs.

[3]For detailed information on SSA and other SSA approaches, please refer to Wang et al. (2024).

Business-as-usual (BAU) In this scenario, we consider a counterfactual scenario in which the PNL2035 policy has not been implemented and the transportation infrastructure and costs remain at baseline (2017) levels. In other words, this scenario contains the pure effects of a global crop price change.

Infrastructure Expansion at a Low Level Here, we define a low-level infrastructure expansion scenario (thereby referred to as the "low scenario") as the case in which all expansions that were under construction by the time when PNL2035 was launched are completed, but no new projects are implemented. The associated transportation cost reduction will be incorporated into the experiment together with the global crop price change.

Infrastructure Expansion at a High Level In contrast with the low scenario, we define a high-level infrastructure expansion scenario (thereby referred to as the "high scenario") as the case in which all the infrastructure expansion proposed in PNL2035, regardless of construction status, will be completed. Under the high scenario, further transportation cost reduction is expected on the basis of the low scenario, and the interactive effects between domestic transportation cost reduction and global crop price change are also greater.

As PNL2035 focuses on the expansion of the railway network, Fig. 15.4 illustrates the railway network at baseline and at its expected expansion under the low and high scenarios, respectively (Fig. 15.4a). The transportation cost and its reduction due to infrastructure expansion under the low and high scenarios (Fig. 15.4b–d), calculated based on Wang et al. (2024), are incorporated into the transportation cost module in order to simulate the interactive effects on farm-gate crop price and corresponding responses of crop supply, the extensive margin (cropland expansion), and the intensive margin (yield growth or multicropping). Finally, to assess the environmental impacts of transportation and agricultural production, we further simulate the impacts on carbon balance, measured as the change in CO_2 in million metric tons (Mt). We consider two drivers of carbon balance change: direct emissions of greenhouse gases from road and railway vehicles and indirect emissions from the loss of carbon stock when land with natural vegetation is converted to cropland. All simulation results are represented as the percentage changes or level changes with respect to the 2017 baseline.

5 Results and Discussion

This section briefly describes the findings of these three scenarios, both extracting expected aggregate insights and illuminating the fertile ground for future research revealed by this gridded analysis. While the aggregated results provide robust validation of theoretical frameworks, the spatial heterogeneity unveiled by the gridded results demands further exploration.

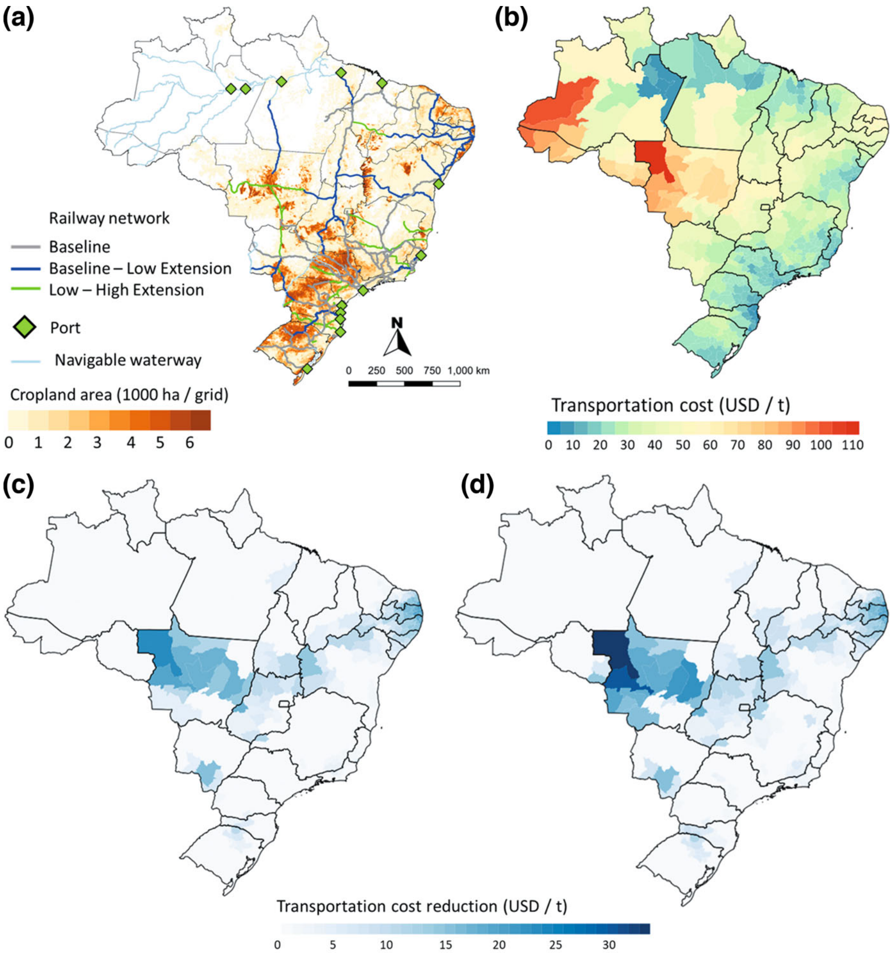

Fig. 15.4 Railway extension plan from PNL2035 and its contribution to reducing transportation costs. (**a**) The railway network in 2017 (*gray lines*) and the expansions planned in the PNL2035 low (*blue lines*) and high (*both blue and green lines*) scenarios. (**b**) Calculated transportation cost from microregion to exporting ports at the 2017 baseline. (**c**) Reduction in transportation costs under the PNL2035 low scenario. (**d**) Reduction in transportation costs under the PNL2035 high scenario. (Adapted and modified from Wang et al. (2024))

5.1 *Global-to-Local Interactive Effects on Farm-Gate Crop Price*

When the global crop price shock and the domestic transportation cost reduction shocks are applied in SIMPLE-G Brazil, their direct impact is an increase in the farm-gate crop price. At the national level, the crop price in Brazil increases due to the increase in the global crop price but decreases with the reduction in

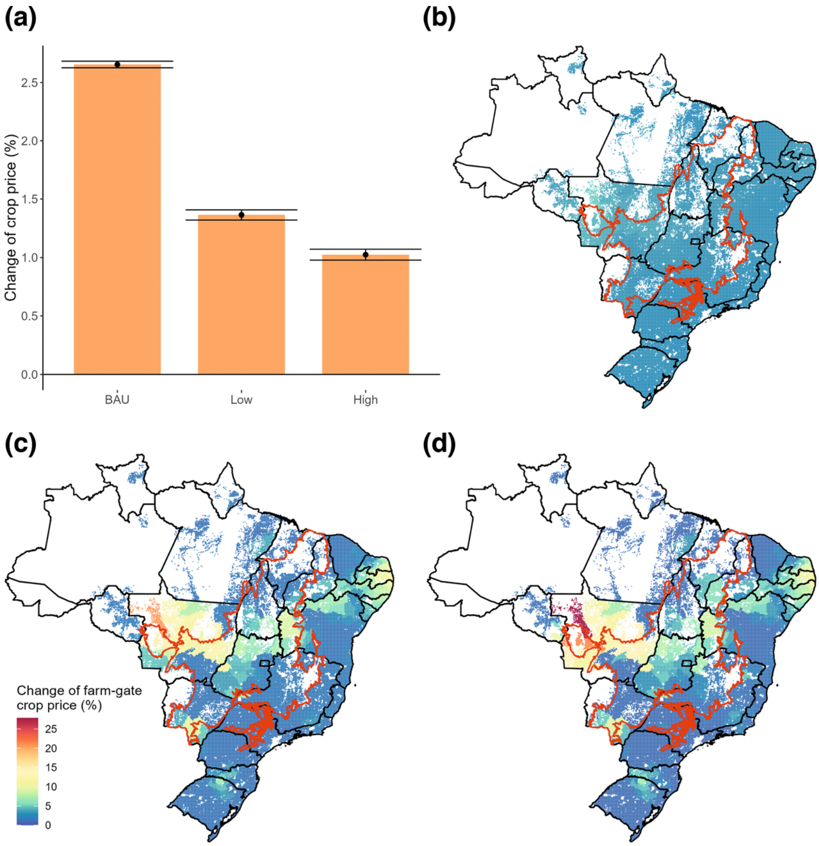

Fig. 15.5 (**a**) Percentage change in national crop price levels under the business-as-usual (BAU), low, and high transportation expansion scenarios. Gridded farm-gate crop price received under (**b**) the BAU scenario, (**c**) the low scenario, and (**d**) the high scenario. Error bars show the 95% confidence intervals from land supply elasticity estimation. The *red boundary* refers to the Cerrado biome and the *black boundaries* indicate state boundaries

transportation costs and the subsequent increase in supply (Fig. 15.5a). The reduction in transportation costs increases the profitability of farmers, encouraging them to expand crop production at the margin. Consequently, national crop production rises, resulting in higher equilibrium crop production but lower equilibrium crop prices, consistent with our graphical analysis (Fig. 15.2).

At the grid cell level, the interactive impacts of these two shocks cause spatially heterogeneous changes in local farm-gate crop prices, as shown in Fig. 15.5b–d. When only the global crop price shock is implemented under the BAU scenario, all grid cells in Brazil experience a slight increase in the farm-gate crop price received, similar to the change in the national crop price. However, when the reduction in transportation costs is incorporated, states in the Cerrado biome benefit from a much higher increase in farm-gate crop prices (10–25%), while the increase in farm-gate crop prices in the south/southeast becomes even smaller compared with the BAU scenario. That is, whereas an increase in the global crop price brings an almost uniform stimulus to all of Brazil, the reduction in domestic transportation costs mainly improves the profitability of farming in the Cerrado region but does little to benefit farming in the south/southeast region. This change in relative spatial profitability causes a shift in the pattern of national crop production and land use.

5.2 Spillover Effects on Crop Production and Land Use

Figure 15.6 illustrates the simulated percentage change in state-level crop output and its decomposition by the extensive margin (change in cropland area), intensive margin (change in crop yield due to intensive nonland input use or multicropping), and their interactions. Figure 15.6 highlights the results from the top eight crop-producing states in Brazil. These eight states accounted for 81% of the national cropland area and 92% of national crop production in 2017, so they capture the overall pattern of agricultural impacts. The first group of states is located in the south/southeast region: São Paulo (SP), Paraná (PR), Rio Grande do Sul (RS), and Minas Gerais (MG)[4]; the second group is located in the core region of the inland Cerrado biome: Mato Grosso (MT), Goiás (GO), Mato Grosso do Sul (MS), and Bahia (BA). Within each group, states are ranked by their baseline crop production in descending order. Results from the remaining states (aggregated as "Rest of Brazil (ROB)") and the entire country are also reported.

Figure 15.6 reveals state-level responses and spillover effects on crop production and land use. Under the BAU scenario, all states show a moderate increase in crop production, driven by both extensive and intensive margins (Fig. 15.6a). However, results under the low scenario show that as the Cerrado biome gains a relative advantage in farming due to the increase in farm-gate crop prices, farmers in Cerrado further expand crop production both by cultivating more cropland and, more importantly, by attracting more mobile inputs (e.g., fertilizer, labor, and capital) (Fig. 15.6b). On the other hand, although the south/southeast region also experiences an increase in farm-gate crop prices, the magnitude of the price increase is much lower than that in the Cerrado region, making the south/southeast region relatively disadvantaged in farming and less competitive in attracting mobile inputs. States in the south/southeast region exhibit reductions in crop output across both the intensive and extensive margins, which indicates that the expansion of transportation infrastructure will not only improve the connectivity of the Cerrado biome and benefit its agricultural production, but also cause spillover effects in the south/southeast region. Furthermore, the increase in crop production in Brazil is greater in the low scenario than in the BAU scenario, indicating that the gains from Cerrado overwhelm the

[4]While SP and MG belong to the southeast region of Brazil, they also partially overlap with the Cerrado biome.

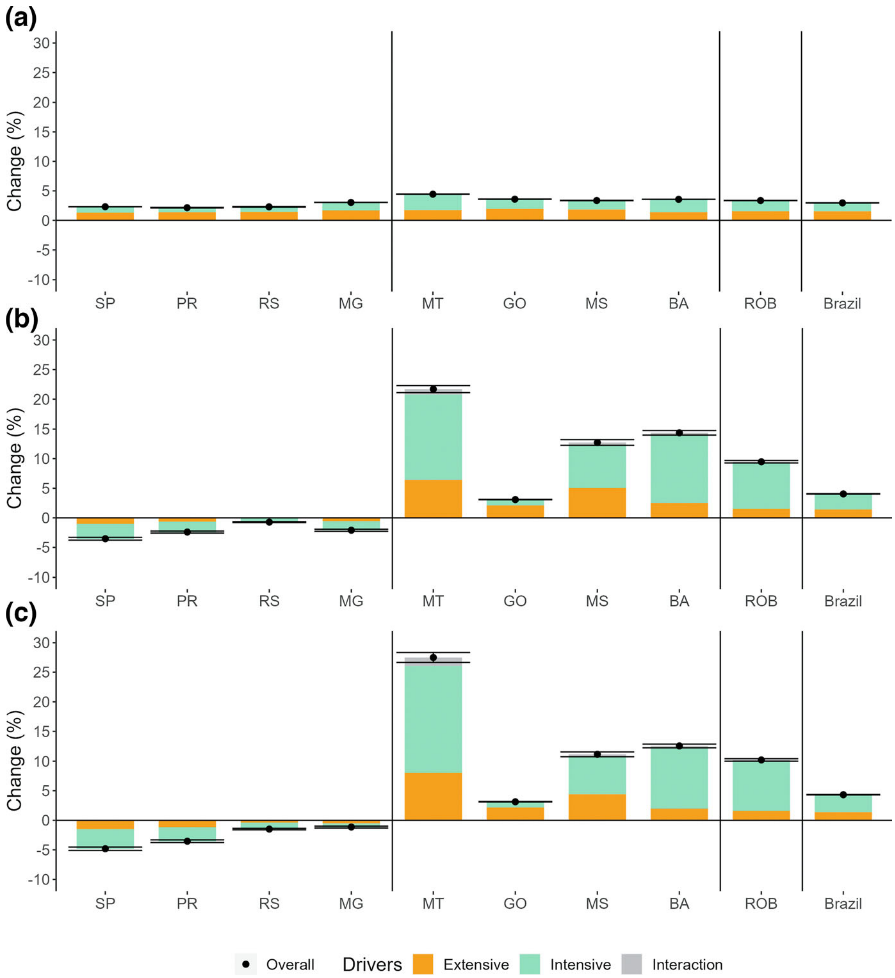

Fig. 15.6 Simulated changes in crop production and the decomposition by extensive margins, intensive margins, and their interactions at the state and national level under (**a**) the BAU scenario, (**b**) the low scenario, and (**c**) the high scenario. Error bars show 95% confidence intervals from the land supply elasticity estimation, as obtained by using the SSA feature of RunGEM

losses in the south/southeast region, also consistent with the graphical analysis (Fig. 15.2). Finally, the simulation results under the high scenario are similar to those under the low scenario but with greater magnitudes, which is due to the fact that transportation infrastructure under the high scenario includes all constructions under low scenario, with further expansion.

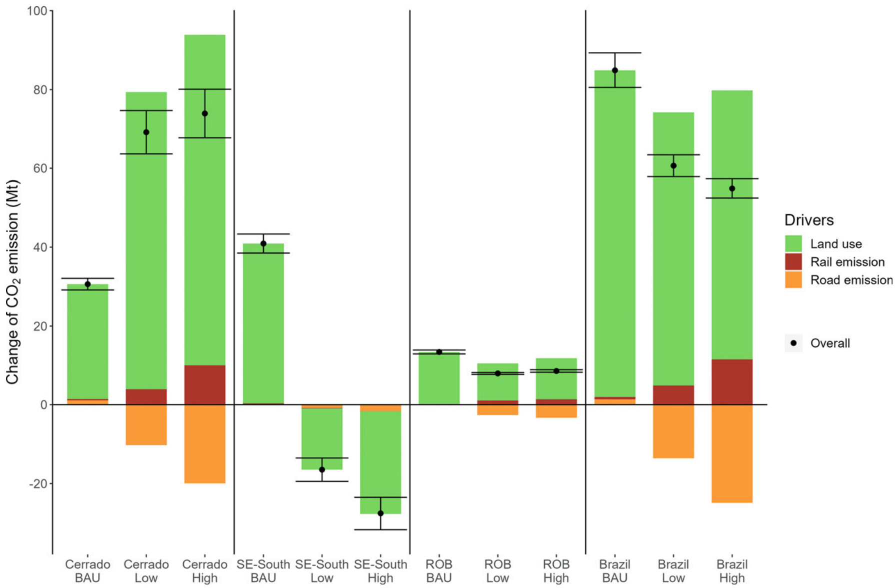

Fig. 15.7 Simulated changes in greenhouse gas emissions and the decomposition by drivers. Error bars show 95% confidence intervals from the land supply elasticity estimation. We further aggregate the first group of states in Fig. 15.6 into the "south/southeast"(SE-South) subnational region and aggregate the second group of states into the "Cerrado" subnational region

5.3 Environmental Impacts on Carbon Balance

In addition to the impacts on crop price, crop production, and land use, the global crop price and transportation infrastructure have considerable direct and indirect impacts on carbon emissions in Brazil. Figure 15.7 reports the net changes in greenhouse gas emissions at the national and subnational levels (Cerrado, south/southeast, ROB); their decomposition by direct emission from vehicles (for road and rail transportation); and indirect emissions from the loss of carbon stock due to cropland expansion. Under the BAU scenario, since all states in Brazil experience crop production growth and cropland expansion (Fig. 15.6a), the global crop price shocks cause a net increase in CO_2 emissions, mainly from the carbon stock loss from cropland replacing natural vegetation. When the expansion of transportation infrastructure is also incorporated into the simulation under the low and high scenarios, a considerable amount of the national crop production pattern shifts from the south/southeast region to the Cerrado biome (Fig. 15.6b and c), which causes carbon emissions from land use change in the Cerrado to become more than double of the amount under BAU scenario, while the land use-related carbon emissions in the south/southeast region are overturned and become negative. Moreover, as PNL2035 markedly extends the railway network but barely improves the roadway network, more crops are transported over more cost-efficient and carbon-efficient railways instead of roadways. As a result, under the low and high scenarios, CO_2 emissions from railway transportation increase in the Cerrado biome, but this effect is fully countered by the much higher reduction of CO_2 emissions from roadways. In total, national CO_2 emissions decrease from 84.9 Mt under the BAU scenario to 60.6 Mt under the low scenario and 54.9 Mt under the high scenario. The implication of this carbon balance analysis is that an increase in global crop prices would boost crop production in Brazil, but it also threatens deforestation and increases carbon emissions. The expansion of transportation infrastructure would exacerbate local carbon emissions in the Cerrado biome, but this impact could be offset by the reduction of cropland demand in the south/southeast region due to the spillover effect. Thus, the expanded infrastructure facilitates Brazil's crop supply to the global level in a more carbon-efficient way.

This research has significant implications for policymakers and stakeholders striving to balance economic vitality and environmental responsibility. By understanding the intricate dance between global markets, domestic infrastructure, and carbon emissions, we can design policies that unlock the economic potential of Brazilian agriculture while safeguarding the country's precious natural heritage.

5.4 Limitations and Future Directions

Several avenues for future research emerge from the limitations encountered in this chapter's analysis. To fully unpack the complexities explored in this chapter, it is crucial to acknowledge and address the following limitations. First, the expansion of transportation infrastructure would reduce transportation costs not only for crops but also for mobile inputs such as fertilizers, machinery, labor, and other capital inputs. However, this analysis does not include the role of infrastructure expansion in reducing farm input costs. In Wang et al. (2024), we extend the analysis with additional scenarios on the impact of transportation infrastructure on factor mobility and find that when the impacts of infrastructure on factor mobility are considered, our conclusions do not change qualitatively, but the magnitude of the results is strengthened quantitatively with better factor mobility. Additionally, farm-gate crop prices can be influenced by factors other than global crop prices and the expansion of infrastructure networks, including the market power of transporters, road status, and congestion. In this chapter, we consider only the global price and transportation infrastructure shocks to illustrate the capacity of SIMPLE-G for studying the interaction between global and local level shocks. We encourage interested readers to build on this framework and further extend this analysis or generalize it to similar research questions.

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