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Examining Rural Productivity in Brazil: A Biome-based Analysis of Large-scale and Family Farming[*]

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Abstract: Brazil, a country with a great territorial dimension and relevant and heterogeneous agricultural production, faces the challenge of climate change, of increasing productivity in the countryside, and of developing an economy with low environmental impact. This paper is designed to assess the impacts of hypothetical 1% productivity increases in large-scale and in family farming within Brazilian biomes induced by public policies that promote the adoption of sustainable agricultural practices as a strategy to address climate change. Such analysis uses a Computable General Equilibrium model specially built for analysis of the rural sectors in the Brazilian biomes: TERM-Biomas. The study reveals that less developed regions could benefit from productivity increases, potentially leading to a reduction in regional inequality if such policies were directed toward them. The cattle industry demonstrates its capacity to drive national economic growth and significantly contributes to exports. The Large-Scale Soybean sector emerges as a key contributor to economic influence. Furthermore, Soybean cultivation exhibits significant ripple effects on non-agricultural sectors such as agricultural pesticides, public utilities, and freight transportation. Initiatives resembling Sustainable Rural Project (SRP) can potentially foster widespread productivity improvements across Brazilian biomes, benefiting large-scale and family farmers.

Keywords: Climate Change, Land Productivity, Sustainable Agriculture, Family Farming, Regional Impacts
JEL Codes: D13, Q12, Q54, R13, R51

1. INTRODUCTION

In recent years, the discourse surrounding the disparate effects of global climate change has intensified. According to the Intergovernmental Panel on Climate Change (IPCC), in its fifth

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evaluation report (on Climate Change, 2014, p. 12), human influence on climate system is clear. Since the onset of the Industrial Revolution, carbon dioxide (CO2) concentrations have increased by 40%, primarily due to emissions from fossil fuels and land use alterations such as deforestation, surpassing records of the past 800,000 years. Consequently, the ramifications of this phenomenon are potentially asymmetrical across territories, biomes[1], and societal strata (on Climate Change, 2014; IPCC, 2021, 2022; **?**).

According to IPCC reports (2014; 2022), climate change has already had a significant impact on food production. Over the last three decades of the 20th century and into the 21st century, heightened concerns regarding food security have led researchers and policymakers to accord greater significance to this issue. Notably, the World Trade Organization (WTO) and regional trade negotiations have recently begun addressing food security and rural development (Jensen et al., 2010). This growing concern has sparked renewed interest in assessing the impacts of agricultural policies.

Beyond contextualizing the discourse on the impact of agricultural policies, it is important to elucidate the rationale behind this study. Climate change adversely affects agricultural productivity (Lachaud et al., 2017; Lachaud and Bravo-Ureta, 2020; Lachaud et al., 2021; Plastina et al., 2021), while greenhouse gas (GHG) emissions stemming from agricultural activities exacerbate climate change. Indeed, agricultural production, besides precipitating other environmental consequences, accounts for approximately 22% of total GHG emissions, according to IPCC (2022). This contribution to overall GHG emissions, nearly equivalent to that of industrial production (24%), and slightly surpassing emissions from the transportation sector (approximately 15%), results from various production processes including the utilization of fossil fuels, fertilizers, and ruminant digestion, among others (IPCC, 2022).

Hence, this study endeavors to examine the implications of rural development policies in Brazil, with a focus on understanding the adaptive capacity of rural activities to enhance productivity. The paper seeks to evaluate the economic ramifications of adopting more productive techniques in alignment with the Sectoral Plan for Climate Change Adaptation and Low Carbon Emission in Agriculture, in pursuit of sustainable development (ABC+). Certain programs, notably the Sustainable Rural Project (SRP), subsidize such alignment by promoting the adoption of sustainable production practices across Brazilian biomes. The hypothesis is that increases of productivity via technical alterations such as the ones proposed by SRP in the Brazilian biomes, for instance, may bring positive impacts on the whole Brazilian economy, not only on the sectors and regions of implementation.

In light of the foregoing, this study aims to address pivotal questions crucial for evidence-based decision-making. What are the implications of widespread adoption of these technologies and potential productivity increments in the field? Which sectors stand to benefit most from these changes? Do the observed effects and impacts manifest similarly when comparing family producers with large-scale producers? And how do these dynamics vary across different Brazilian biomes? By addressing these inquiries, this study endeavors to furnish invaluable insights for enhancing public policies pertaining to rural development and

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[1] The concept of biome is defined by the Brazilian Institute of Geography and Statistics (IBGE) as a set of types of vegetation, identifiable on a regional scale, with their associated flora and fauna; defined by predominant physical conditions, whether climatic, lithological, geomorphological, pedological, as well as a shared evolutionary history; and endowed with unique biological diversity (Brazil, 2019a, p. 11-12).

sustainability in the context of climate change.

From an economic perspective, a rigorous analysis of the impacts precipitated by rural development policies, such as technological innovations, necessitates a methodology that systematically considers inter-regional and inter-sectoral linkages. The comprehensive integration of these diverse elements, germane to the requisites of this study, can be achieved through Computable General Equilibrium (CGE) models. The intricate theoretical framework underpinning these models is particularly appealing as it explicitly delineates the inter-regional and inter-sectoral channels of the economic system, thereby faithfully representing the economic structure of each region, herein demarcated according to Brazilian biomes. Consequently, this study enriches existing literature by engaging with the issue on both regional and biome-specific levels, thereby enhancing comprehension of the diverse territorial effects and enriching scholarly discourse, which often leans toward qualitative or partial equilibrium analyses.

With respect to biome differentiation, Paterniani (2001) contends that tropical agriculture encounters more intricate challenges compared to temperate climates. Nonetheless, despite these challenges, Brazilian tropical agriculture remains one of the most advanced and innovative, particularly in biotechnology Paterniani (2001). Marques (2001) asserts that technological advancements must be tailored to specific regions, contingent upon edaphoclimatic conditions. Consequently, the implementation of technologies aimed at rendering production less environmentally degrading hinges on adherence to local edaphoclimatic conditions, evidencing the relevance of regionalization by biomes, in the CGE model adopted.

Therefore, the study is structured into five sections, including this introduction. In the first section, we provide a brief literature review highlighting the relationship between agriculture and climate change, emphasizing that the adverse impacts of climate phenomena can be mitigated through productivity increases achieved via sustainable production practices. Section 3 details the materials and methods employed in the study, with a particular focus on the Computable General Equilibrium (CGE) model tailored to Brazilian biomes, representing a significant contribution to the existing literature. Section 4 presents the results of the direct and indirect economic impacts of agricultural productivity improvements, along with a discussion on how adopting sustainable production practices can provide the dual benefits of enhancing productivity and reducing environmental impacts. In Section 5, we present the concluding remarks.

2. LITERATURE REVIEW

In recent years, global emissions from agricultural and livestock farming, along with other environmental impacts of the sector, have accounted for approximately 22% of total GHG emissions (IPCC, 2022). This increase has been most significant in developing countries, driven by the rising demand for food worldwide and changes in consumption patterns, particularly in countries experiencing income growth. Factors such as land use change and deforestation have also contributed to this trend. The need to increase food and intermediate input production in agriculture has led to greater utilization of natural resources, particularly land (IPCC, 2022).

In response to discussions surrounding climate impacts, sustainable public policies have been proposed, emphasizing concepts such as the green economy, low-carbon economy, and eco-development, among others. The Inter-American Development Bank (IDB), in collaboration with the Ministry of Environment (MMA) of Brazil, defines the green economy as one that enhances human well-being and social equity while significantly reducing environmental riskFramework for production modelings and ecological scarcities (IDB and MMA (Brazil), 2012, p. 8). Essentially, a green economy initiative aims to transition towards a low-carbon emission economy, promoting efficient use of natural resources and social inclusion. In the words of IDB and MMA (Brazil) (2012, p. 8), the increase of the income and employment must be boosted by public and private investments that reduce the carbon emission, while they optimize the energy matrix and avoid the loss of biodiversity, including by stimulating the conservation of environmental services.

Despite criticisms of these concepts, such actions can serve as catalysts for growth, with the goal of poverty eradication and inequality reduction. Tilman et al. (2002) argue that sustainability, a multifaceted term, involves not only income increases but also their maintenance. They highlight the challenges posed by the projected global increase in food demand in the coming decades for food production sustainability and the preservation of terrestrial and aquatic ecosystems and their societal services. Moreover, farmers are identified as primary stewards of agricultural lands worldwide, shaping the Earth's surface for years to come (Tilman et al., 2002). Meeting demands for productivity improvement without compromising environmental integrity or public health will require new incentives and policies to ensure the sustainability of rural production and ecosystem services (Tilman et al., 2002).

While agricultural production contributes to GHG emissions, numerous initiatives have been implemented to enhance productivity in the field and reduce environmental impacts. The ability of agriculture and livestock to mitigate GHG emissions, adapt to changing production conditions, and reduce environmental impact is crucial for mitigating the sector's environmental and climate change impacts (Madari, 2018). An increase in resilience and a reduction in agricultural vulnerability demand complementary and interdependence in the reduction of environmental impacts with the adaptation to new conditions.

In Brazil, the ABC+ Plan and the Sustainable Rural Project (SRP) have been implemented to enhance productivity while ensuring environmental sustainability. These programs promote the adoption of sustainable production practices through technical assistance and financial support, including Integrated Crop-Livestock-Forestry Systems (ICLF), Agroforestry Systems (AFS), biological nitrogen fixation in the soil, no-tillage farming, and the restoration of forests and degraded pastures. Such techniques are adjusted for each biome and region according to technical assistance provided by the public programs.

These production technologies, particularly ICLF and AFS, offer significant advantages in soil water retention compared to conventional monoculture-based agricultural systems. They facilitate key hydrological processes, such as percolation and infiltration, while reducing surface runoff. Furthermore, vegetative cover plays a crucial role in mitigating soil erosion and nutrient depletion, leading to substantial benefits in microclimate regulation, which is also influenced by evapotranspiration, thereby contributing to biodiversity conservation (Balbino et al., 2012; Oliveira, 2024).

Beyond their environmental benefits, the technologies promoted by the ABC+ Plan drive productivity gains that are essential for their economic viability. Balbino et al. (2011) highlight that productivity improvements result from enhanced physical, chemical, and biological soil properties due to increased organic matter, reduced incidence of pests and weeds, improved animal welfare through better thermal comfort, greater input-use efficiency, and a more favorable energy balance, especially in integrated systems.

Utilizing data from the IBGE Agricultural Census, Amaral et al. (2012) observed a 46% increase in meat production, a 50% increase in productivity, and a 3% decrease in pasture areas from 1995 to 2006. This suggests increased production with less impact on agricultural expansion and deforestation during the analysis period (Amaral et al., 2012). Additionally, various studies underscore the importance of sustainable measures for ensuring field productivity and minimizing the environmental impacts of agricultural activities. Lucas et al. (2023) argue that technological advancements in agriculture can mitigate biodiversity impacts, highlighting the crucial role of legislative measures in biodiversity preservation.

Arora (2019) has examined the impacts of climate change on agricultural production and proposed sustainable solutions, while Morgan et al. (2013) focused on impacts, trends, and sustainable solutions related to global change, particularly in European ruminants. Berkum et al. (2018) analyzed sustainable solutions for ensuring a sufficient supply of healthy foods, and Liu et al. (2020) discussed environmentally sustainable solutions for global food security. Sala et al. (2017) emphasized the quest to reduce environmental impacts associated with food production and consumption.

This body of evidence underscores the importance of understanding the impacts of increased productivity resulting from technical innovation in Brazilian agriculture. Given the influence of climate change on the regions under analysis, adopting more sustainable agricultural practices is critical for promoting adaptation and mitigating potential adverse effects of climate change (Tilman et al., 2002; Sala et al., 2017; Madari, 2018; Arora, 2019; Reis et al., 2019a; Liu et al., 2020). Pursuing technological alternatives that enhance sustainability and productivity in rural areas may serve as a catalyst for growth, aligned with poverty eradication, inequality reduction, environmental preservation, and climate impact mitigation (Amaral et al., 2012; Morgan et al., 2013; Berkum et al., 2018; Arora, 2019; Reis et al., 2019b; Lucas et al., 2023). In this way, we sought to evaluate the direct and indirect economic effects of the increase in productivity in Brazilian agriculture, resulting from the adoption of sustainable production techniques such as those fostered by the SRP, in the biomes of Brazil.

3. MATERIALS AND METHODS

In this study, we base our analysis on the theoretical framework provided by the CGE model known as The Enormous Regional Model (TERM) developed by Horridge (2011). For the purposes of this paper, we have adapted and extended the original TERM model to incorporate specific regional economic information and regionalization procedures, resulting in a customized model tailored to the diverse biomes present within each Brazilian state. This adapted version of the model is referred to as TERM-Biomes.

3.1. Definition of TERM-Biomas

Among the main characteristics of the comparative statics model employed in this study is its composition of 76 sectors representing unique products (Table A.1), with 64 of these sectors focused on agricultural breakdowns. These breakdowns include 32 sector-products associated with family farming and another 32 with large-scale agriculture, as detailed in Tables A.2, A.3, and A.4 in the appendix (as an additional file attached to this paper).

Agriculture in Brazil is characterized by two distinct groups of producers: family farming and large-scale agriculture, which differ in crops, methods, and production scale. This classification is also used in the development of public policies, with family farmers being the focus of the Ministry of Agrarian Development, and large-scale agriculture under the scope of the Ministry of Agriculture and Livestock. Accordingly, the TERM-Biomes model, employed in this study, uses a specific calibration for family farmers and large-scale agriculture sectors.

The definition of Family Farming adopted in this study is based on Law 11,326 of 2006, which was designed to guide public policies targeting this category. According to Law 11,326/06, family farmers and rural family entrepreneurs are defined as individuals who simultaneously meet the following criteria: i) do not own land exceeding four fiscal modules ; ii) predominantly use family labor; iii) derive a minimum percentage of family income from economic activities conducted on their property; and iv) manage their property with their family (Brazil, 2006).

The Brazilian legal definition aligns with that established by the Food and Agriculture Organization of the United Nations (FAO) which defines family farming as a model encompassing agricultural, forestry, fishing, and pastoral activities managed and operated by a family that primarily relies on non-wage family labor, involving both men and women. The family and the farming operation are interdependent, co-evolving and integrating economic, environmental, reproductive, social, and cultural functions. When referring to Family Farming, the term also includes artisanal fishers, pastoralists, landless workers, and Indigenous communities.

Organizationally, family farming in Brazil has distinct characteristics, such as the integration of labor and management, diversified production with an emphasis on the use of internal inputs, agile and immediate decision-making processes, reliance on family labor with wage labor as a complementary activity, and a portion of production geared toward subsistence. In contrast, large-scale agriculture is marked by a complete separation of management and labor, centralized and specialized organization, standardized agricultural practices, labor-saving technologies, reliance on purchased inputs, and production primarily oriented toward the market (Veiga, 1996).

TERM-Biomas is structured with blocks of equations that determine the relationship between supply and demand based on optimization hypotheses and market balance conditions. These blocks define various country aggregates, such as Gross Domestic Product (GDP), total employment level, price index, and trade balance. The production sector minimizes production costs under the assumption of constant income elasticity for technology. Using fixed coefficients (Leontief), this technique combines primary factors and intermediate inputs. The Constant Elasticity of Substitution (CES) function is employed to determine price substitution between domestic and imported goods, with specifications regulating the distribution of domestic products among regions.

Each region in the model has a representative family that consumes both domestic and imported goods. The choice between these goods is governed by a CES specification (Armington Hypothesis[2] The treatment of family demand utilizes a combined CES/Klein-Rubin preference system, maximizing utility through consumption. This specification results in the Linear Expenditure System (LES)[3], where expenditure on each good beyond subsistence level is a consistent share of overall subsistence spending for each family.

The TERM-Biomas database was constructed using the 2015 National Input-Output Matrix (IOM). Regional data on macroeconomic indicators, such as GDP, investment, family consumption, government expenditures, imports, and exports, were utilized in the regionalization process. Data from various sources were employed to ensure granularity, with a preference for municipal-level data, which were then aggregated to the TERM-Biomas regions, combining localities within the same Brazilian state and biome. For example, GDP data from the IBGE were collected at the municipal level, including breakdowns for agriculture, industry, services, and public administration. Data on exports and imports were sourced from the Foreign Trade Secretariat (Secex), a department of the Brazilian Ministry of Development, Industry, and Foreign Trade (MDIC).

Data from the Agricultural Census (Brazil, 2019b) were used to calibrate and distinguish the sectors in the TERM-Biomes model. The characterization of each type of producer respects its productive structure in each region of the model. To this end, municipal sectoral data were used regarding the number of workers, machinery and equipment, value and volume of production, internal consumption, use of primary and intermediate factors of production, production area, and participation in exports and imports. Regional salary data by activity sector were obtained from the 2018 Annual Social Information Report (RAIS), while family expenditure was disaggregated from the 2017-2018 Family Budget Survey (POF), also released by IBGE.

Thus, the family farming and large-scale agriculture sectors, even if they produce the same commodity, do so with a different productive structure. Therefore, the effects in terms of productivity increase evaluated in this study generate distinct direct and indirect effects on the rest of the economy. The database aligns closely with official data from Regional Accounts, the Agricultural Census, National Accounts, the IPM, IBGE information, and data from Secex, the Annual Industry Survey (PIA), and RAIS, all for the year 2018. To highlight the differentiation between the family and large-scale sectors, Table 1 presents the participation of remuneration for production factors (capital and labor).

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[2] The Armington Hypothesis posits that goods from different sources are treated as imperfect substitutes (Armington, 1969).

[3] The LES is suitable for broad aggregates of goods where specific substitutions are not considered, i.e., cross-price elasticities are equal to the income effect given in the Slutsky equation without any contribution from cross-price effects. This implies that all goods are weakly complementary. LES does not allow for the inclusion of inferior goods (negative income elasticities).

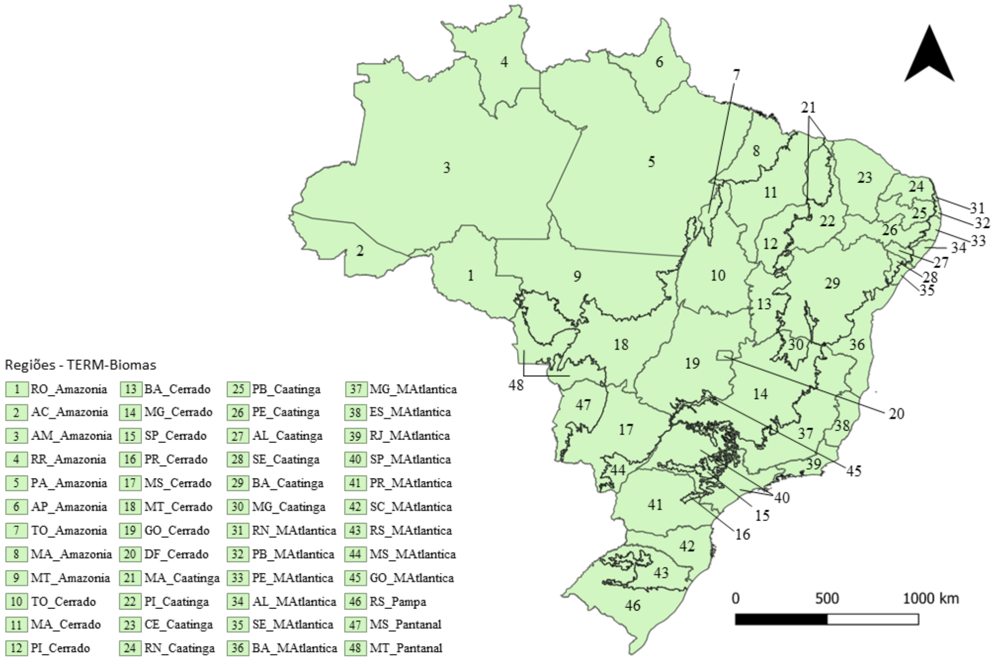
Table 1: Capital and labor, according to aggregates of family and large-scale sectors, TERM-Biomas

Sector	Capital	Labor
Family Farming	37,00%	63,00%
Large-Scale Farming	74,00%	26,00%
Family Livestock	7,00%	93,00%
Large-Scale Livestock	39,00%	61,00%
Family Silviculture and Vegetal Extraction	54,00%	46,00%
Large-Scale Silviculture and Vegetal Extraction	91,00%	9,00%

Source: own elaboration based on database from TERM-Biomas.

Table 1 illustrates the predominance of capital use in large-scale sectors compared to family farming, except for large-scale livestock, where labor represents 61% of the remuneration. Similarly, in the Silviculture and Vegetal Extraction sectors, capital participation is higher in family farming production, although still below that of the large-scale sector, which exceeds 90% (Table 1).

Figure 1: Geographic location, according to the region of the model, Brazil, 2019



Source: own elaboration based on data from IBGE Brazil (2019a).

As for the regions of the model, TERM-Biomes shows Brazil in 48 regions (R=48), composed of the intersection of the geographic meshes of the Brazilian states and biomes. This is the main methodological contribution of the paper and what makes the model distinct from other Brazilian models. It is important to represent the regions of the model in biomes because, in Brazil, some public policies are designed specifically for each biome, as is the case of the Sustainable Rural Project (SRP), which has strands for the Amazon, Atlantic Forest, Cerrado, and Caatinga. Therefore, the developed model can be used in any future studies that include the analysis of biomes.

Biomes are areas composed of specific edamorphoclimatic characteristics, such vegetation, rainfall, climate, terrain, temperature, lithology, air humidity, radiation, soil type, wind, and atmospheric conditions. These characteristics condition the agriculture carried out, especially in relation to the types of crops. In this sense, the TERM-Biomes model captures the productive specificities of the biomes. Its delimitation is composed of the aggregation of municipal productive data within the limits of each biome, and it is the intersection with the boundaries of the Brazilian Federation Units. Figure 1 illustrates the geographical distribution of the 48 TERM-Biomes regions, delineated by the intersection of Brazilian states and biomes' geographic meshes.

Table 2 provides the agricultural sectors' participation in the regions. This table is derived from the production matrix in the database of the model.

Upon analyzing the participation of the aggregate production of the agriculture, livestock, vegetal extraction, and silviculture sectors in regional production, large-scale agriculture in the Cerrado in Bahia (BA), Amazon and Cerrado in Mato Grosso do Sul (MS), as well as the Caatinga in Minas Gerais (MG), and the Atlantic Forests in MS and Goiás (GO) stand out (Table 2). In addition to these highlights, large-scale livestock in Tocantins (TO) also showed a predominance in regional production, as can also be seen in Table 2.

3.2. Framework for production modeling

In the model, each sector produces only one product, and the production level is determined by the combination of primary factors (added value), intermediate inputs, and other costs (primarily rates and grants). Producers have the flexibility to allocate capital, labor, and land for primary factors and choose from available domestic or imported intermediate inputs. When it comes to domestic goods, producers can select from different regions. The production function can be broken down into two components: one responsible for allocating primary factors and the other for managing input sources (see Figure 2).

Figure 2 illustrates the production framework in TERM-Biomas. Each sector in the model is dedicated to producing a single product for simplicity. The total number of products (c) always matches the number of sectors (i)[4], so the model presents 76 sectors and 76 products. As the main objective of the study is to evaluate the economic impacts resulting from increased agricultural productivity, the model has 64 sectors of agriculture. Of these, 32 refer to family farming and 32 to large-scale agriculture.

The production technology is determined by fixed combinations (Leontief-type function) of primary factors (land, labor, and capital) and intermediate inputs, with their sources (domestic or imported) defined by a CES function. Additionally, for domestic inputs, their regional origin is also determined by a CES function. The model operates under the assumption of imperfect substitutability between domestic and imported inputs, as well as between

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[4] Model composed of 76 sectors (or industries) and products ($I_e = C_e = 76$)

Table 2: Participation of agricultural sectors in total production, according to TERM-Biomas regions

	Sector					
Region	Family Farming	Large-Scale Farming	Family Livestock	Large-Scale Livestock	Family Silviculture and Vegetal Extraction	Large-Scale Silviculture and Vegetal Extraction
RO_Amazon	0.89%	1.95%	2.82%	2.63%	0.03%	0.06%
AC_Amazon	2.10%	0.28%	1.55%	1.87%	0.30%	0.07%
AM_Amazon	1.68%	0.39%	0.81%	0.48%	0.25%	0.05%
RR_Amazon	1.37%	1.53%	0.76%	1.02%	0.21%	0.02%
PA_Amazon	2.37%	1.47%	1.29%	2.09%	0.74%	0.39%
AP_Amazon	0.93%	0.27%	1.92%	2.63%	0.59%	0.16%
TO_Amazon	3.38%	3.43%	8.90%	25.91%	0.02%	0.26%
MA_Amazon	0.42%	0.48%	0.86%	1.06%	0.19%	0.16%
MT_Amazon	0.86%	29.55%	2.66%	5.90%	0.16%	0.57%
TO_Cerrado	0.95%	8.00%	1.39%	2.54%	0.07%	0.08%
MA_Cerrado	1.97%	9.56%	1.95%	2.05%	0.63%	0.36%
PI_Cerrado	0.19%	5.88%	0.30%	0.37%	0.04%	0.05%
BA_Cerrado	0.67%	43.48%	1.50%	2.39%	0.19%	0.11%
MG_Cerrado	1.11%	8.06%	1.19%	2.50%	0.07%	0.58%
SP_Cerrado	0.26%	4.37%	0.13%	0.56%	0.01%	0.17%
PR_Cerrado	0.39%	8.66%	1.92%	3.76%	0.30%	8.45%
MS_Cerrado	0.23%	9.97%	0.57%	4.09%	0.00%	1.02%
MT_Cerrado	0.28%	20.98%	0.49%	2.42%	0.01%	0.12%
GO_Cerrado	0.24%	7.70%	0.85%	2.47%	0.01%	0.09%
DF_Cerrado	0.01%	0.17%	0.01%	0.10%	0.00%	0.01%
MA_Caatinga	3.81%	1.72%	4.91%	2.18%	0.11%	0.19%
PI_Caatinga	4.49%	3.45%	9.29%	3.70%	1.14%	0.60%
CE_Caatinga	0.94%	0.66%	0.74%	0.97%	0.19%	0.07%
RN_Caatinga	1.38%	2.12%	1.71%	1.48%	0.09%	0.03%
PB_Caatinga	2.27%	0.88%	3.80%	2.28%	0.28%	0.08%
PE_Caatinga	2.41%	2.89%	4.67%	3.51%	0.06%	0.08%
AL_Caatinga	2.83%	1.02%	3.78%	2.68%	0.08%	0.03%
SE_Caatinga	4.58%	1.98%	8.58%	3.77%	0.01%	0.00%
BA_Caatinga	6.50%	4.80%	6.04%	2.65%	0.89%	0.21%
MG_Caatinga	7.55%	18.08%	4.21%	4.80%	0.11%	0.06%
RN_AtlanticF	0.05%	0.14%	0.04%	0.09%	0.00%	0.00%
PB_AtlanticF	0.44%	0.94%	0.07%	0.12%	0.00%	0.00%
PE_AtlanticF	0.22%	0.52%	0.19%	0.22%	0.00%	0.00%
AL_AtlanticF	0.58%	2.24%	0.20%	0.34%	0.00%	0.00%
SE_AtlanticF	0.47%	0.38%	0.38%	0.42%	0.03%	0.01%
BA_AtlanticF	0.71%	0.69%	0.18%	0.45%	0.01%	0.15%
MG_AtlanticF	0.73%	1.38%	0.41%	0.78%	0.03%	0.14%
ES_AtlanticF	1.84%	1.58%	0.29%	1.07%	0.06%	0.13%
RJ_AtlanticF	0.06%	0.04%	0.04%	0.09%	0.00%	0.00%
SP_AtlanticF	0.07%	0.61%	0.06%	0.22%	0.01%	0.03%
PR_AtlanticF	1.02%	3.44%	0.64%	1.01%	0.07%	0.51%
SC_AtlanticF	1.38%	0.98%	0.84%	0.63%	0.09%	0.59%
RS_AtlanticF	3.31%	4.25%	1.84%	1.18%	0.16%	0.12%
MS_AtlanticF	0.89%	20.42%	1.06%	3.81%	0.01%	0.04%
GO_AtlanticF	0.15%	19.63%	0.73%	9.47%	0.00%	0.00%
RS_Pampa	0.68%	3.73%	0.33%	0.89%	0.06%	0.30%
MS_Pantanal	0.59%	1.54%	0.54%	9.17%	0.00%	0.05%
MT_Pantanal	0.74%	4.79%	2.60%	10.63%	0.34%	0.92%

Notes: Results do not sum to 100% (non-agricultural sectors excluded). Colors indicate sectors with the highest participation across the table content. Source: Own elaboration based on database from TERM-Biomas.

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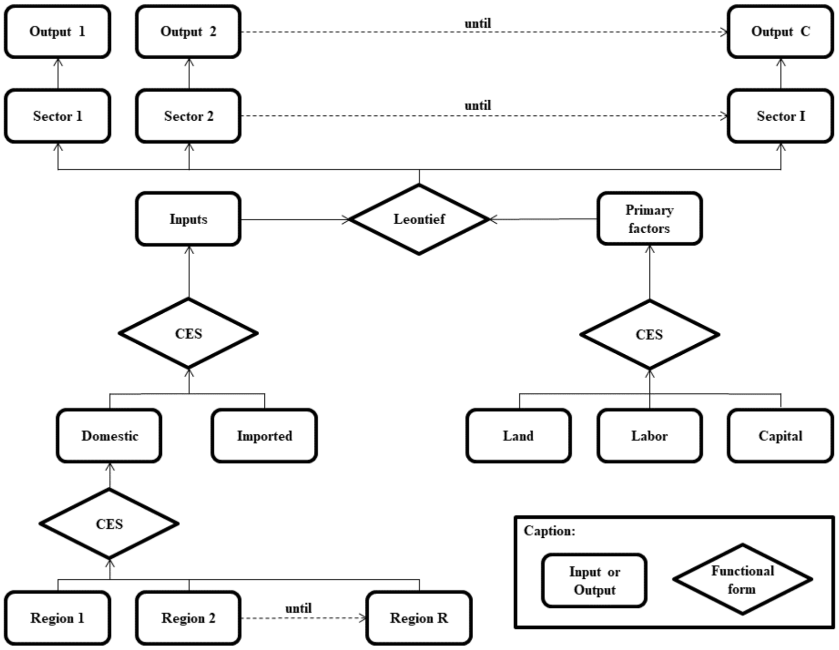
Figure 2: Production framework in TERM-Biomas.



Source: own elaboration based on Simonato (2017) and Horridge (2011).

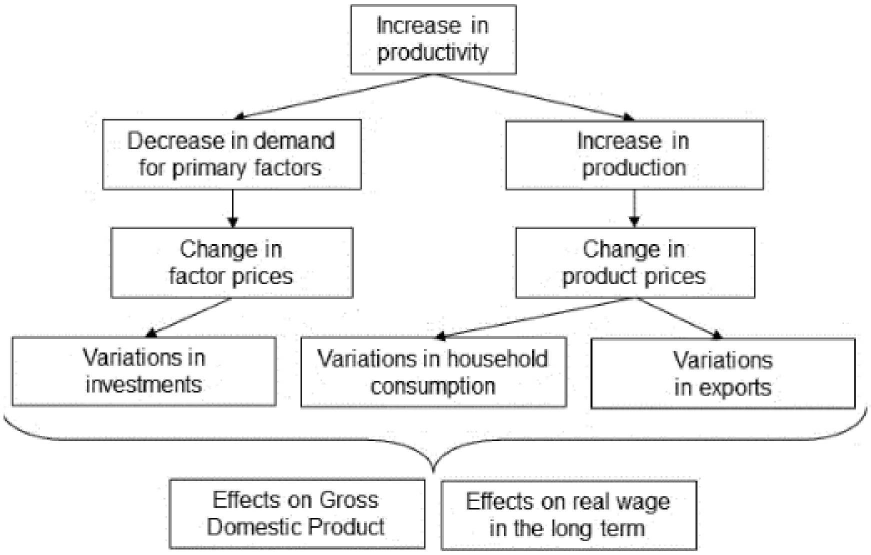
inputs from the 48 different regions, following the Armington (1969) hypothesis.

3.3. Closure, scenarios, and causal relations

For the operationalization of the simulations, a long-term closure was employed, determining endogenous and exogenous variables as follows: i. capital supply is elastic in all sectors and regions, with fixed return rates (exogenous), allowing inter-regional and inter-sectoral capital mobility; ii. national employment is exogenous, while real wages are endogenous, leading to inter-regional labor mobility driven by wage differentials; iii. national investment is endogenous, determined by the sum of sectoral investments, varying according to the aggregate capital stock that can move towards more profitable sectors with fixed return rates; iv. real consumption of families is endogenous and follows GDP variation in each region (factor remuneration); v. government consumption is exogenous; and vi. the foreign trade balance is exogenous as a proportion of GDP.

Regarding scenarios of productivity increase resulting from the adoption of more sustainable techniques by Brazilian rural producers, due to the lack of consolidated data on rural productivity across biomes for constructing shock vectors in the CGE model, a simulation strategy was employed by applying a uniform 1% shock to land productivity in different Brazilian territories to measure the elasticity of productivity increase impacts. Given the absence of studies and data quantifying the expected productivity increase from the adoption of more sustainable practices in the field, a survey based on estimates from the Brazilian Agricultural Research Corporation (Embrapa) – Reis et al. (2019a) and Reis et al. (2019b)

Figure 3: Main causal relations of the simulation adjustment mechanism, according to TERM-Biomas.



Source: own elaboration.

– was conducted, reaching the scenario assumed by SRP, which entails productivity gains in all Brazilian biomes in a project expansion perspective. These considerations are essential for understanding the potential economic implications of agricultural productivity changes, particularly in the context of climate change.

Since the objective is to assess the economic effects resulting from productivity increases in each sector and region, the simulations were conducted by applying land productivity shocks, isolated by sector and region within the model. In other words, the shocks were not implemented simultaneously, as public policies can be targeted toward specific biomes, as exemplified by the SRP. This simulation strategy allows for an evaluation of the potential impact of public policies supporting sustainable technologies that enhance productivity in specific regions of Brazil. Figure 3 illustrates the causal relations of the model, considering the shock on agricultural productivity for both large-scale and family farming frameworks.

According to the mechanisms, productivity increases reduce production costs and/or increase output given the same number of factors. These modifications alter relative prices, affecting input use, factor allocation, and product prices. These variations, in turn, have aggregate effects on consumption (product prices affect family consumption), exports (domestic price decreases make exports more attractive), and investments (the price of productive factors, such as capital, influences investment decisions). Finally, these impacts affect GDP, employment levels, and/or real wages in the economy, both regionally and nationally aggregated. These findings are crucial for understanding the potential economic implications of agricultural productivity changes, especially in the context of climate change.

4. RESULTS

The results of the study regarding the impacts of increased agricultural productivity in various regions of Brazil, with a focus on distinguishing between family and large-scale agriculture, are presented in this section. The objective is to analyze how the adoption of more productive and sustainable practices can influence the country's economy, taking into account the characteristics of different biomes and regional heterogeneity. The findings, derived from simulations involving homogeneous 1% increases in land productivity per crop, are interpreted in relation to a reference scenario. A simulation was carried out for each sector, so that the results in terms of GDP refer to the increase in productivity only in that sector. The reference scenario represents the initial state of the economy, projecting trends without the adoption of sustainable agricultural practices. Initially, aggregate impacts at the national level, such as changes in GDP, will be presented. Subsequently, detailed results will be provided for each region, considering the diversity of biomes, to understand how changes in productivity affect local economies differently based on their specific characteristics.

4.1. Macroeconomic effects of agricultural productivity increase per sector

Table 3 presents the macroeconomic results in terms of long-term percentage variations in GDP. These results illustrate the effects of the agricultural productivity shock per sector and per typology of rural producers, without considering any other structural changes. Additionally, Tables A.2, A.3, and A.4 in the appendix provide further details on other macroeconomic variables not extensively discussed in this main text.

The results indicate that large-scale soy and sugar cane, as well as livestock, both large-scale and family farming, have a significant impact on GDP due to productivity increases. For instance, a 1% productivity increase in the Soy sector would affect national GDP by 0.027%. This impact primarily stems from large-scale agriculture (0.026%), given its substantial contribution to the production and export of these commodities.

It is essential to consider the relative importance of each sector in the national economy. Sectors like soy and sugar cane play crucial roles in exports and revenue generation, which partly explains their significant GDP impact. Moreover, factors such as technology levels, domestic and foreign demand, and production chain characteristics influence these impacts. Livestock, for instance, affects GDP significantly due to its extensive production chain, including meat processing, leather, and animal feed industries.

Increases in productivity within this sector can have positive cascading effects on other economic activities. Large-scale sectors such as corn, poultry and eggs, silviculture, along with family farming sectors such as cow and other animals' milk, represent a secondary level of impact on GDP through productivity. Concerning these sectors, it is noteworthy to consider their capacity to meet both domestic and foreign demands, potentially leading to efficiency gains with increased productivity. Corn, for instance, serves as a critical input for various production chains, including meat production and the biofuel industry.

A similar analysis can be conducted for regions, aiming to determine, following the example of soy, which regions experience the most significant effects on GDP. Based on the database, it is observed that soy production is primarily concentrated in the state of Mato

Grosso (MT). Consequently, this state emerges as the leading soy producer and, consequently, exerts a more substantial impact on national GDP in response to productivity increases within this sector. Thus, the following two subsections of this study present the regional effects for the principal large-scale and family farming products, respectively.

The commodity that achieves a better balance in terms of large-scale and family farming sectors is one that represents bovines and other animals not separately considered within other sectors of the model. Bovine livestock, characterized by its significant influence on macroeconomic indicators, as depicted in Table 1, exhibits the most notable effects on GDP and its deflator.

Sugarcane also emerges prominently, primarily due to its noteworthy impact in terms of large-scale farming within the macroeconomic variables considered (Table 3). Conversely, there is a greater significance attributed to the family farming component for other commodities, such as cow and other animals' milk or cassava, based on national results (Table 3). Overall, wage increases, capital stock enhancements, and investment increments stand out concerning family farming milk (Table A.2). Additionally, notable increases in GDP and domestic consumption have been observed. Lastly, when analyzing historically familiar commodities in Brazil, such as cassava, particular attention is drawn to the influence of increased national salaries (Table A.2).

4.2. Regional impacts of family farming sector productivity growth: a comprehensive analysis

When considering the regional impacts of productivity increases per crop and rural sector, individually simulated, a distinction (for presenting the results) is once again made between the large-scale and family farming sectors. Table 4 presents the selected results – GDP – per region for the ten family farming products that most impact the macroeconomic variable of interest. The results should be interpreted as impacts on the GDP of each region, resulting from the increase in productivity, carried out non-simultaneously, in the sectors listed in their respective regions.

The highlights, in terms of the family sector, are the increases in GDP in specific regions of the Amazon and Caatinga in the Bovines and Other Animals and Cow and Other Animals Milk sectors. Moreover, a well-distributed growth across the model's regions is observed overall regarding the Poultry and Eggs sector (except for the Caatinga region in Sergipe – SE), and a significant GDP growth in the TO Amazon due to a productivity increase in family pineapple.

Considering the Family Farming Soy sector only, for instance, the spotlight shifts to the GDP increase in the Atlantic Forest. Nevertheless, it should be recalled that the Family Farming Soy sector has minimal importance nationally compared to the Large-Scale Soy sector.

Overall, the simulated increase in family farming productivity led to well-distributed GDP increases in the regions of the model. There are a few exceptions that stand out, either due to significant increases or potential contractions in regional GDP. One possible explanation for the negative values in Table 4 is the possibility of a reduction in factors employed in the production of the sector experiencing increased productivity.

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Table 3: Impacts on GDP (percentual variations) stemming from productivity increases per rural sector of the model, Brazil, long term

Simulation*	Productivity increase in the product as a whole	Productivity increases only in the family farming framework	Productivity increases only in the large-scale farming framework
1 Rice	0.0031	0.0003	0.0028
2 Wheat and other cereals	0.0008	0.0001	0.0007
3 Corn	0.0072	0.0010	0.0062
4 Temporary cotton (fiber)	0.0022	0.0000	0.0022
5 Sugar cane	0.0108	0.0005	0.0103
6 Soy	0.0277	0.0016	0.0261
7 Cassava	0.0013	0.0011	0.0002
8 Tobacco (leaves)	0.0013	0.0010	0.0003
9 Cotton trees	0.0002	0.0002	0.0001
10 Other citric fruits	0.0003	0.0001	0.0003
11 Tomato	0.0006	0.0002	0.0004
12 Irish potato	0.0007	0.0002	0.0005
13 Onion	0.0007	0.0005	0.0002
14 Peanut	0.0006	0.0003	0.0003
15 Pineapple	0.0007	0.0005	0.0002
16 Banana	0.0005	0.0003	0.0002
17 Bean	0.0012	0.0006	0.0006
18 Açaí	0.0004	0.0003	0.0001
19 Cocoa	0.0005	0.0002	0.0003
20 Cashew (nut)	0.0005	0.0002	0.0003
21 Guaraná	0.0003	0.0003	0.0000
22 Grape (wine or juice)	0.0004	0.0003	0.0001
23 Other temporaries	0.0021	0.0009	0.0011
24 Orange	0.0013	0.0002	0.0011
25 Coffee	0.0042	0.0013	0.0030
26 Other permanents	0.0007	0.0003	0.0004
27 Bovines and other animals	0.0241	0.0094	0.0147
28 Cow and other animals' milk	0.0058	0.0037	0.0020
29 Swine	0.0024	0.0009	0.0015
30 Poultry and eggs	0.0058	0.0016	0.0042
31 Silviculture	0.0043	0.0006	0.0037
32 Vegetal extractions	0.0012	0.0008	0.0004

Notes: Colors indicate sectors with the highest impact across the table content. Source: Results selected from simulations with TERM-Biomas.

*It must be highlighted that each line of Table 3 represents a different simulation, i.e., there were performed 32 different simulations. In each one of these 32 simulations, the productivity increase of 1% was provided only to the production of the commodity in question. That therefore means that a productivity increase in two different sectors responsible for the production of the said commodities: the large-scale and the family farming ones.

When assessing the productivity increase only in the Family Farming Corn sector, the most significant effects are on the GDP of the Atlantic Forest in Rio Grande do Sul (RS) and MS. Some other minor effects can be observed in several regions.

The effects of the productivity increase in the Family Farming Coffee sector on regional GDP are primarily observed in the Atlantic Forest of Espírito Santo (ES). The magnitudes of a second level would be those of the same biome and the Cerrado in MG.

The highlight, in terms of the Family Farming Bovines and Other Animals sector, is in those regions (Amazon in TO and MT) - which can be a positive signal regarding the issue of agricultural frontier expansion over the Amazon (as a positive productive shock spares land use and causes less deforestation) – with the appearance of the Caatinga in BA in a next level, in terms of GDP. Overall, positive results can be observed in all biomes, except for specific regions of the Caatinga biome (in Maranhão – MA, Piauí – PI, SE, and MG).

Regarding milk, as mentioned earlier, more expressive effects for productivity increases in the family farming sector are expected. The effects are differentiated within the same biome. The Amazon biome, for instance, presents prominent regions (in TO, MT, and Rondônia – RO). It should be compared, for instance, the Amazon in the states mentioned with the same Amazon biome in MA.

Finally, regarding cassava, with the suspicion confirmed that the results for the effects found are focused on some regions, the Amazon in general and the Acre (AC) state in particular stand out, mainly in terms of GDP. On a second level, there is the largest Brazilian producer region of this crop, that is, the Amazon in Pará (PA) state.

The productivity increase of a specific rural product directly affects the production of the same commodity. Indirectly, however, after that whole chain of causalities, it will lead to adjustments in the allocation of factors, and consequently, in the amount produced by all the sectors of the model.

4.3. Regional impacts of productivity growth in large-scale agricultural sectors

This subsection delves into the effects of productivity increases in the agricultural field on GDP. In contrast to the previous subsection, however, this section focuses on large-scale sectors (see Table 5).

The standout, in terms of large-scale sectors, is the increase in GDP attributed to productivity gains in the Large-Scale Soy sector. Notably, the regions of Amazon and Cerrado in MT, as well as the Atlantic Forest in MS and Cerrado in BA, exhibit significant growth in GDP. There is also substantial GDP growth in the Atlantic Forest in GO due to large-scale sugarcane and in the Amazon in TO due to large-scale bovine livestock. The results also reveal that regions in the Amazon and Cerrado, resulting from productivity increases in the Bovine and Other Animals, Sugarcane, and Corn sectors, demonstrate notable GDP growth.

A variety of factors contribute to the observed results. The highlighted regions boast abundant natural resources, including fertile lands and water, essential for cultivating crops such as soy, sugarcane, and corn. Moreover, the expansive land areas facilitate large-scale livestock farming. Areas like the Cerrado in MT and in BA offer vast tracts of available land, enabling increased agricultural and livestock production to meet rising demand. Farmers in

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Table 4: Percentage variations in GDP from productivity increases in selected family farming sectors by model region, Brazil, long term

	Simulation									
Region	Family Pineapple	Family Poultry and Eggs	Family Bovines and Other Animals	Family Coffee	Family Vegetal Extraction	Family Bean	Family Cow and Other Animals Milk	Family Cassava	Family Corn	Family Soybean
1 RO_Amazon	0.0011	0.0038	0.0319	0.0047	0.0012	0.0004	0.0131	0.0011	0.0014	0.0012
2 AC_Amazon	0.0030	0.0043	0.0209	0.0009	0.0046	0.0008	0.0057	0.0122	0.0025	0.0007
3 AM_Amazon	0.0029	0.0011	0.0061	0.0001	0.0025	0.0002	0.0082	0.0064	0.0002	0.0004
4 RR_Amazon	0.0004	0.0017	0.0151	0.0011	0.0010	0.0004	0.0043	0.0013	0.0010	0.0011
5 PA_Amazon	0.0037	0.0033	0.0178	0.0005	0.0062	0.0009	0.0078	0.0078	0.0014	0.0014
6 AP_Amazon	0.0027	0.0016	0.0108	0.0007	0.0027	0.0007	0.0057	0.0024	0.0003	0.0009
7 TO_Amazon	0.0228	0.0048	0.0627	0.0004	0.0011	0.0023	0.0213	0.0072	0.0025	0.0011
8 MA_Amazon	0.0006	0.0018	0.0102	0.0004	0.0014	0.0006	0.0032	0.0025	0.0008	0.0009
9 MT_Amazon	0.0008	0.0044	0.0494	0.0007	0.0025	0.0004	0.0154	0.0018	0.0024	0.0043
10 TO_Cerrado	0.0047	0.0030	0.0214	0.0004	0.0014	0.0008	0.0079	0.0024	0.0015	0.0016
11 MA_Cerrado	0.0028	0.0024	0.0225	0.0003	0.0065	0.0031	0.0039	0.0073	0.0025	0.0009
12 PI_Cerrado	0.0001	0.0007	0.0008	0.0005	-0.0001	0.0002	0.0011	0.0006	0.0005	0.0010
13 BA_Cerrado	0.0002	0.0018	0.0133	0.0005	0.0041	0.0017	0.0044	0.0015	0.0015	0.0015
14 MG_Cerrado	0.0017	0.0024	0.0164	0.0059	0.0003	0.0011	0.0104	0.0017	0.0016	0.0019
15 SP_Cerrado	-0.0001	0.0013	0.0066	0.0007	0.0005	0.0004	0.0027	0.0005	0.0007	0.0013
16 PR_Cerrado	0.0004	0.0013	0.0051	0.0003	0.0044	0.0009	0.0028	0.0006	0.0010	0.0011
17 MS_Cerrado	0.0005	0.0032	0.0220	0.0003	0.0006	0.0002	0.0092	0.0014	0.0014	0.0019
18 MT_Cerrado	0.0005	0.0029	0.0207	0.0005	0.0005	0.0006	0.0085	0.0010	0.0017	0.0025
19 GO_Cerrado	0.0004	0.0031	0.0187	0.0006	0.0003	0.0003	0.0086	0.0007	0.0017	0.0023
20 DF_Cerrado	-0.0001	0.0004	0.0066	0.0003	-0.0002	-0.0002	0.0015	-0.0001	0.0003	0.0006
21 MA_Caatinga	0.0008	0.0006	-0.0158	0.0014	0.0004	-0.0017	0.0025	-0.0014	-0.0010	0.0015
22 PI_Caatinga	0.0003	0.0003	-0.0319	0.0013	-0.0023	-0.0008	-0.0019	0.0007	0.0003	0.0017
23 CE_Caatinga	0.0011	0.0019	0.0083	0.0007	0.0013	0.0028	0.0037	0.0007	0.0015	0.0013
24 RN_Caatinga	0.0017	0.0022	0.0164	0.0003	0.0007	0.0033	0.0046	0.0018	0.0010	0.0008
25 PB_Caatinga	0.0081	0.0028	0.0214	0.0005	0.0018	0.0038	0.0107	0.0009	0.0013	0.0009
26 PE_Caatinga	0.0014	0.0040	0.0326	0.0005	0.0019	0.0049	0.0102	0.0021	0.0028	0.0011
27 AL_Caatinga	0.0010	0.0020	0.0273	0.0009	0.0006	0.0088	0.0076	0.0038	0.0025	0.0014
28 SE_Caatinga	0.0001	-0.0029	-0.0308	0.0015	0.0005	0.0000	-0.0059	0.0016	-0.0009	0.0022
29 BA_Caatinga	0.0031	0.0027	0.0487	0.0019	0.0102	0.0079	0.0107	0.0030	0.0022	0.0009
30 MG_Caatinga	0.0004	0.0005	-0.0069	0.0015	0.0002	-0.0003	-0.0012	0.0007	0.0013	0.0024
31 RN_AtlanticF	0.0004	0.0012	0.0043	0.0005	0.0000	0.0007	0.0014	0.0004	0.0005	0.0009
32 PB_AtlanticF	0.0027	0.0007	0.0052	0.0005	0.0000	0.0011	0.0013	0.0010	0.0007	0.0010
33 PE_AtlanticF	0.0015	0.0022	0.0043	0.0005	0.0016	0.0007	0.0010	0.0006	0.0015	0.0010
34 AL_AtlanticF	0.0015	0.0011	0.0069	0.0005	0.0000	0.0009	0.0014	0.0014	0.0004	0.0010
35 SE_AtlanticF	0.0003	0.0003	0.0059	0.0011	0.0006	0.0003	0.0014	0.0005	0.0003	0.0015
36 BA_AtlanticF	-0.0001	0.0012	0.0082	0.0010	0.0039	0.0005	0.0022	0.0011	0.0006	0.0009
37 MG_AtlanticF	0.0002	0.0011	0.0084	0.0063	0.0000	0.0006	0.0048	0.0006	0.0008	0.0008
38 ES_AtlanticF	0.0027	0.0016	0.0096	0.0161	0.0002	0.0006	0.0032	0.0004	0.0008	0.0008
39 RJ_AtlanticF	0.0006	0.0006	0.0087	0.0002	0.0002	0.0001	0.0016	0.0003	0.0002	0.0005
40 SP_AtlanticF	-0.0001	0.0007	0.0044	0.0004	0.0004	0.0003	0.0013	0.0003	0.0004	0.0008
41 PR_AtlanticF	0.0003	0.0033	0.0141	0.0008	0.0007	0.0018	0.0062	0.0014	0.0027	0.0049
42 SC_AtlanticF	0.0002	0.0027	0.0169	0.0005	0.0009	0.0005	0.0080	0.0009	0.0021	0.0019
43 RS_AtlanticF	0.0007	0.0083	0.0150	0.0002	0.0006	0.0017	0.0115	0.0053	0.0051	0.0119
44 MS_AtlanticF	0.0002	0.0046	0.0221	0.0004	0.0004	-0.0001	0.0098	0.0046	0.0034	0.0059
45 GO_AtlanticF	0.0001	0.0022	0.0185	0.0005	0.0004	0.0004	0.0070	0.0010	0.0016	0.0033
46 RS_Pampa	0.0002	0.0013	0.0096	0.0004	0.0002	0.0007	0.0026	0.0032	0.0009	0.0022
47 MS_Pantanal	0.0028	0.0020	0.0173	0.0003	0.0005	0.0003	0.0066	0.0017	0.0010	0.0007
48 MT_Pantanal	0.0000	0.0017	0.0096	0.0011	0.0006	0.0008	0.0052	0.0004	0.0012	0.0012

Notes: Colors indicate regions with the highest GDP variation across each table column. Source: Results selected from simulations with TERM-Biomas.

these regions, particularly those engaged in large-scale operations, have made significant investments in agricultural technology, modern machinery, genetically modified seeds, agrochemicals, and best cultivation practices. These investments enhanced land productivity, contributing to the observed results. Large-scale soy, for example, is widely used in human and animal nutrition and enjoys strong global demand. Similarly, corn has diverse applications beyond direct consumption.

Additionally, agribusiness plays a pivotal role in the Brazilian economy, with these regions standing out in this sector. Investments and productivity gains in these sectors bolster both national and regional GDP. Furthermore, agricultural incentive policies and government programs continue to support and stimulate these sectors in certain regions. In prominent areas, the production chains of these sectors are well-established, encompassing logistical infrastructure for distribution, processing industries, and mature markets.

However, it is essential to note that significant GDP growth does not always translate to equitable wealth distribution or socioeconomic development. Environmental, social, and economic challenges may arise, including deforestation, land concentration, labor issues, and environmental impacts, exacerbated by climate change. Therefore, sustainable practices and policies are crucial to ensure balanced and responsible economic growth, prioritizing environmental preservation and the well-being of local populations amidst the challenges posed by climate change. Nonetheless, the results underscore that productivity increases in both family farming and large-scale agriculture can have positive effects on the national economy and various regions. Each region, however, exhibits unique characteristics regarding the most impactful agricultural sectors. This acknowledgment of the intersection between agricultural productivity, economic growth, and climate change resilience is vital for informing future policy decisions and sustainable development initiatives.

4.4. Impacts of agricultural productivity increases on economic growth, environmental sustainability, and climate change resilience: a discussion

The primary objective of this study was to analyze the economic repercussions of productivity changes in Brazilian rural sectors, particularly examining the differentiated gains between large-scale and family farmers in Brazil, facilitated by programs like SRP, across specific rural sectors of the country. The results presented here broadly address the main agricultural sectors and their impacts on national GDP, with a particular emphasis on livestock and soy. It is therefore relevant to discuss these findings in the context outlined in the second section of this paper, which focuses on the green economy and the mitigation and adaptation to climate change. By doing so, we can explore how the outcomes of this study intersect with these critical issues for sustainable development.

Upon analyzing the productivity increases simulated in our model, it becomes evident that they influence the demand for primary factors within the chain of effects considered. These demand variations impact different regions according to their specialization in the production of the commodities in question. These dynamics, in turn, lead to fluctuations in factor prices, affecting household consumption, net exports, and investment levels, thus impacting regional and national economies. Our sectoral analysis focused on key sectors with significant national effects, both on large-scale and in family farming. The selection of Family

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Table 5: Impacts on GDP (percentual variations) stemming from productivity increases in selected large-scale sectors, according to the region of the model, Brazil, long term

	Simulation									
Region	Large-Scale Cotton (fiber)	Large-Scale Rice	Large-Scale Poultry and Eggs	Large-Scale Bovines and Other Animals	Large-Scale Coffee	Large-Scale Sugar Cane	Large-Scale Cow and Other Animals Milk	Large-Scale Corn	Large-Scale Silviculture	Large-Scale Soybean
1 RO_Amazon	0.0009	0.0032	0.0108	0.0477	0.0021	0.0012	0.0062	0.0092	0.0035	0.0312
2 AC_Amazon	0.0007	0.0008	0.0089	0.0277	0.0012	0.0159	0.0029	0.0056	0.0029	0.0105
3 AM_Amazon	0.0001	-0.0003	0.0020	0.0061	0.0003	-0.0005	0.0022	0.0004	0.0012	0.0036
4 RR_Amazon	0.0019	0.0033	0.0036	0.0146	0.0026	0.0046	0.0018	0.0053	0.0031	0.0254
5 PA_Amazon	0.0007	0.0017	0.0096	0.0287	0.0011	0.0035	0.0044	0.0065	0.0057	0.0216
6 AP_Amazon	0.0012	0.0015	0.0029	0.0148	0.0018	0.0053	0.0058	0.0038	0.0030	0.0165
7 TO_Amazon	0.0008	0.0016	0.0080	0.2132	0.0008	0.0088	0.0097	0.0209	0.0038	0.0366
8 MA_Amazon	0.0008	0.0015	0.0039	0.0174	0.0011	0.0036	0.0018	0.0051	0.0034	0.0146
9 MT_Amazon	0.0143	0.0100	0.0144	0.0924	-0.0001	0.0260	0.0069	0.0901	0.0065	0.4601
10 TO_Cerrado	0.0006	0.0231	0.0076	0.0384	0.0009	0.0144	0.0044	0.0148	0.0026	0.0942
11 MA_Cerrado	0.0006	0.0042	0.0071	0.0259	0.0007	0.0200	0.0023	0.0354	0.0083	0.1311
12 PI_Cerrado	0.0008	0.0022	0.0025	0.0081	0.0011	0.0107	0.0008	0.0238	0.0017	0.0842
13 BA_Cerrado	0.1223	0.0016	0.0075	0.0186	0.0112	0.0051	0.0025	0.0446	0.0030	0.3949
14 MG_Cerrado	0.0012	0.0012	0.0071	0.0292	0.0303	0.0370	0.0104	0.0148	0.0086	0.0435
15 SP_Cerrado	0.0012	0.0010	0.0053	0.0121	0.0035	0.0537	0.0014	0.0039	0.0050	0.0141
16 PR_Cerrado	0.0006	0.0002	0.0022	0.0097	0.0008	0.0015	0.0019	0.0110	0.0736	0.0638
17 MS_Cerrado	0.0058	0.0011	0.0088	0.0584	0.0007	0.0475	0.0051	0.0308	0.0127	0.1049
18 MT_Cerrado	0.0567	0.0025	0.0095	0.0361	0.0010	0.0114	0.0044	0.0501	0.0037	0.2283
19 GO_Cerrado	0.0012	0.0023	0.0089	0.0348	0.0013	0.0393	0.0055	0.0222	0.0025	0.0794
20 DF_Cerrado	0.0004	0.0007	0.0010	0.0084	0.0009	0.0035	0.0006	0.0021	0.0009	0.0091
21 MA_Caatinga	0.0024	0.0036	0.0051	0.0082	0.0034	0.0066	0.0008	0.0079	0.0040	0.0289
22 PI_Caatinga	0.0021	0.0027	0.0020	0.0120	0.0030	0.0060	0.0015	0.0067	0.0027	0.0258
23 CE_Caatinga	0.0020	0.0016	0.0072	0.0114	0.0016	0.0043	0.0022	0.0042	0.0026	0.0142
24 RN_Caatinga	0.0012	0.0006	0.0049	0.0165	0.0007	0.0071	0.0035	0.0022	0.0021	0.0074
25 PB_Caatinga	0.0019	0.0010	0.0045	0.0181	0.0013	0.0053	0.0044	0.0032	0.0009	0.0118
26 PE_Caatinga	0.0011	0.0014	0.0178	0.0190	0.0012	0.0056	0.0060	0.0048	0.0017	0.0118
27 AL_Caatinga	0.0014	0.0035	0.0084	0.0192	0.0020	0.0170	0.0062	0.0076	0.0019	0.0187
28 SE_Caatinga	0.0029	0.0035	0.0011	0.0081	0.0035	0.0037	-0.0004	0.0093	0.0023	0.0309
29 BA_Caatinga	0.0011	0.0009	0.0033	0.0270	0.0033	0.0129	0.0041	0.0043	0.0022	0.0099
30 MG_Caatinga	0.0022	0.0035	0.0036	0.0030	0.0034	0.0246	0.0012	0.0105	0.0030	0.0320
31 RN_AtlanticF	0.0013	0.0008	0.0028	0.0077	0.0011	0.0143	0.0007	0.0025	0.0016	0.0097
32 PB_AtlanticF	0.0019	0.0011	0.0017	0.0075	0.0013	0.0287	0.0005	0.0031	0.0015	0.0127
33 PE_AtlanticF	0.0011	0.0013	0.0043	0.0071	0.0011	0.0252	0.0005	0.0040	0.0019	0.0114
34 AL_AtlanticF	0.0011	0.0012	0.0028	0.0103	0.0013	0.0563	0.0008	0.0031	0.0018	0.0127
35 SE_AtlanticF	0.0023	0.0023	0.0013	0.0100	0.0027	0.0086	0.0005	0.0050	0.0020	0.0233
36 BA_AtlanticF	0.0010	0.0012	0.0031	0.0112	0.0037	0.0048	0.0012	0.0028	0.0042	0.0114
37 MG_AtlanticF	0.0005	0.0005	0.0037	0.0142	0.0141	0.0022	0.0037	0.0030	0.0031	0.0072
38 ES_AtlanticF	0.0004	0.0005	0.0072	0.0134	0.0174	0.0020	0.0018	0.0028	0.0036	0.0060
39 RJ_AtlanticF	0.0003	0.0002	0.0006	0.0082	0.0005	0.0014	0.0005	0.0004	0.0012	0.0040
40 SP_AtlanticF	0.0008	0.0009	0.0022	0.0071	0.0010	0.0087	0.0007	0.0020	0.0023	0.0081
41 PR_AtlanticF	0.0007	0.0014	0.0081	0.0212	0.0013	0.0062	0.0030	0.0123	0.0089	0.0436
42 SC_AtlanticF	0.0025	0.0032	0.0060	0.0222	0.0010	-0.0017	0.0032	0.0049	0.0107	0.0134
43 RS_AtlanticF	0.0005	0.0026	0.0102	0.0216	0.0005	-0.0016	0.0042	0.0087	0.0042	0.0595
44 MS_AtlanticF	0.0006	0.0020	0.0105	0.0591	0.0006	0.0718	0.0049	0.0707	0.0023	0.2298
45 GO_AtlanticF	0.0008	0.0016	0.0669	0.0492	0.0010	0.3234	0.0055	0.0138	0.0024	0.0704
46 RS_Pampa	0.0007	0.0391	0.0032	0.0187	0.0009	0.0001	0.0012	0.0037	0.0061	0.0441
47 MS_Pantanal	0.0006	0.0103	0.0051	0.0675	0.0009	0.0036	0.0036	0.0050	0.0023	0.0186
48 MT_Pantanal	0.0015	0.0021	0.0041	-0.0051	0.0027	0.0051	0.0023	0.0067	0.0030	0.0274

Notes: Colors indicate regions with the highest GDP variation across each table column. Source: Results selected from simulations with TERM-Biomas.

Farming Cassava and Large-Scale Soybean, as well as Bovines and Other Animals (for both), was made considering their economic relevance and environmental impacts, particularly in terms of GHG emissions.

These findings are consistent with existing literature and previous studies, which also underscore the importance of bovine and other animal sectors (Guilhoto et al., 2011). This is especially relevant when considering their contributions to national GDP, as supported by recent data from the Brazilian Confederation of Agriculture and Livestock (CNA) in collaboration with the Center for Advanced Studies in Applied Economics (Cepea) regarding the GDP of Brazilian agribusiness (CNA (Brazil) and Cepea (Piracicaba – SP, Brazil), 2019). Despite facing challenges, the livestock sector demonstrates a significant capacity to drive the national economy forward, even in times of sectoral crisis. While average livestock productivity in the country has been on the rise, there remain opportunities for further development, particularly when compared to other producer countries (Cepea, 2018). Similarly, the Large-Scale Soybean sector stands out in both the national and international agricultural landscapes, representing a substantial portion of Brazilian GDP and serving as a cornerstone of the country's exports (Dall'Agnol et al., 2007). This crop has seen remarkable growth in cultivated areas and has maintained a strong export focus to the European Union and China for decades (Coronel et al., 2008).

However, it is crucial to acknowledge that these sectors, while vital for the economy, also have significant environmental impacts, including GHG emissions and deforestation, especially in the Amazon region. The regionalization of the economic impacts of agricultural productivity increases represents a methodological innovation in this study. This approach has allowed us to identify regions like the Cerrado, which possess a higher potential for boosting regional economies sustainably, thereby indicating pathways for balancing economic development and environmental preservation.

The environmental impacts generated by Brazilian beef cattle sector, especially for deforestation and emissions, are relevant, given the way in which the activity has historically been developed in the country, via extensive use of pastures, with expansion of the activity in the Amazon and Cerrado biomes, from the 1970s onwards. According to Amaral et al. (2012), in the last twenty years there has been a significant change in the beef agro-industrial complex (CAI), with performance based on increased productivity, with the use of technology, to the detriment of the expansion of pasture areas. According to Alcantara et al. (2021), between 1990 and 2019, productivity gains in the agricultural sector were responsible for 87% of the increase in national production.

From the perspective of the land-sparing effect, a concept that demonstrates how improving the efficiency of cultivated areas can reduce the need for agricultural land expansion, productivity gains were the primary driver of a land-sparing effect of 400 million hectares between 1990 and 2019 – equivalent to 47% of the national territory (Alcantara et al., 2021). Using the same methodology, a study by Insper Agro (2024) estimated the land-sparing effect in livestock at 205.5 million hectares between 1997 and 2022. This evidence is further supported by current public policies, such as the National Program for the Conversion of Degraded Pastures into Sustainable Agricultural and Forestry Production Systems (PNCPD), launched in 2023. The program aims to restore 40 million hectares of degraded pastures over ten years through a financial framework, with contributions from BNDES and external resources, to fund the adoption of sustainable agricultural practices, that promotes increasing productivity, such as ICLFs and SAFs, linked to pasture recovery.

Pasture degradation typically results from two main processes: agricultural degradation and biological degradation. Agricultural degradation occurs when there is an excessive proliferation of weeds in pasture areas, making it difficult for cattle to selectively consume forage. This overgrowth of weeds reduces the productive capacity of the pasture. In contrast, biological degradation is associated with a decline in pasture productivity due to soil deterioration, characterized by an increasing proportion of bare soil. This condition exacerbates soil erosion, depletes organic matter, and reduces essential soil nutrients. Notably, biological degradation represents a more severe stage of pasture degradation, as it also entails soil degradation (Dias-Filho, 2017).

Degraded pastures significantly diminish biomass production capacity, leading to a decline in livestock productivity. Furthermore, they contribute to environmental damage by reducing soil organic matter and microbial activity, accelerating erosion, and increasing greenhouse gas (GHG) emissions. The restoration of 40 million hectares of degraded pastureland, as proposed by the PNCPD, would yield substantial environmental benefits, along with higher productivity and positive economic impacts, as pointed by this study. However, pasture recovery involves diverse techniques and substantial costs, which vary depending on the severity of degradation and the characteristics of the biome.

Research in animal genetics (herd improvement) and the adoption of technologies that promote the more intensive use of pasture areas are pointed out by Amaral et al. (2012) as the main vectors of efficiency gains in production systems, in addition to saving land for agricultural production. Among such technologies, those promoted by the SRP stand out, such as the formation, recovery and renewal of pastures; the fencing (deferral), and supplementation of pastures; the integrated crop-livestock systems (ICL); the livestock-forest integration systems (IPF); and the integrated crop-livestock-forest systems (ICLFS).

Nevertheless, in relation to GHG emissions by cattle, studies have suggested that the higher the level of intensification of pasture production, the greater the carbon sequestration, which can result in a positive balance. In this sense, the different arrangements of sustainable production systems have the potential to mitigate methane emissions from enteric fermentation of cattle (Amaral et al., 2012). Also, cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation, as pointed by Cohn et al. (2014).

A broader examination of the results also permits an assessment of potential effects on the reduction of regional inequalities, revealing that even the most vulnerable and less developed regions benefit from productivity increases. As mentioned, regional public policies, such as the Sustainable Rural Project (SRP) and its branches for the Amazon, Atlantic Forest, and Cerrado biomes, promote the adoption of biome-specific sustainable production technologies. The results highlight the magnitude of the economic impacts on GDP and income generation in each region, assessed independently within the model. This simulation strategy allowed us to assess how each region would respond in economic terms if policies of this nature were implemented in the respective regions. In other words, the simulations exhibit the growth potential for each region, independently. In this context, the targeting of public policies on less developed regions has the potential to contribute to the reduction of regional inequalities.

Comparing the effects between the regions, it is verified higher positive impacts in the regions of the Amazon biome, a less developed region in terms of GDP and HDI than the Atlantic Forest, Cerrado, Pantanal and Pampa regions, especially for family farmers. This result shows that policies of this profile have the potential to generate greater economic impacts in less developed regions. Moreover, family farming plays a critical role in food security and local sustainability, despite its smaller direct contributions to GDP. Recognizing the potential of this agricultural production form for both the economy and the environment underscores the importance of public policies that support and strengthen this activity.

Increased productivity in agricultural sectors can contribute to a greener and more sustainable economy. The adoption of more efficient and sustainable agricultural practices, such as proper soil management and the rational use of water resources, can minimize environmental impacts. However, this study validates the importance of programs like SRP, which focus on the adoption of more sustainable practices, despite their potentially modest economic impacts. Thus, these results reinforce the significance of public policies that promote the transition to a greener and less polluting agriculture.

Finally, this study provides evidence of how productivity-enhancing measures can enhance the resilience of agricultural systems in the face of extreme climatic events, such as droughts and floods, provided these measures are aligned with sustainable practices and low carbon emissions. The research conducted here suggests that initiatives like SRP, which focus on transitioning away from more polluting agricultural practices and techniques, can have more significant impacts on products and incomes, despite their modesty. This does not diminish the importance of such initiatives; indeed, local and regional actions are more critical now than ever in charting paths towards urgently needed solutions regarding climate change.

5. TOWARD SUSTAINABLE AGRICULTURAL DEVELOPMENT: CONCLUDING REMARKS

This study aimed to assess the implications of productivity increases in both large-scale and family farming sectors in Brazil. Through simulations using an CGE model tailored to the characteristics of these sectors and regionally configured for Brazilian biomes, we examined the economic effects of enhanced productivity.

The observed productivity increases led to a reduction in the demand for primary factors, resulting in price variations and subsequent effects on consumption patterns, exports, and investments. Regional GDP, wages, and employment levels reflected these changes. Bovine livestock, a cornerstone of the Brazilian economy, demonstrated its capacity to bolster the national economy and play a significant role in exports. Despite ongoing challenges, Brazil possesses many opportunities for sectoral growth.

The Large-Scale Soybean sector emerged as a major influencer of national GDP, corroborating existing literature. Soybean cultivation has ripple effects on various non-agricultural sectors in Brazil, including agricultural pesticides, public utilities, and freight transport.

Regional analyses revealed significant impacts on economic growth in the Cerrado and Amazon biomes for large-scale producers and family farmers. Moreover, the study highlights the magnitude of impacts in each analyzed region if these regions were targeted by public policies aimed at adopting sustainable technologies. We demonstrate that less developed regions could benefit from productivity increases, potentially leading to a reduction in regional inequality if such policies were directed toward them. Nonetheless, family farming, while contributing less to GDP, remains pivotal for food security and local environmental sustainability.

Initiatives like the SRP represent a concerted effort to enhance productivity across diverse Brazilian biomes, benefiting both large-scale and family farmers. These policies, emphasizing sustainable agricultural practices, have the potential to positively impact the economy, albeit modestly.

While the regionalization of Brazil into biome-state combinations (48 regions) offers a refined and policy-relevant approach that captures both ecological variation and subnational socio-economic conditions, it is important to acknowledge certain limitations inherent to this design. Specifically, although this approach enhances the granularity of the analysis by considering differences within states across biomes, the delineation of regions is based primarily on ecological and administrative criteria rather than economic integration or traditional interregional market linkages. Nevertheless, although the TERM-Biomes model captures detailed sectoral and territorial dynamics, it does not explicitly account for economic interdependencies that transcend these predefined regions, such as traditional supply chain linkages or trade flows among states. Nevertheless, given the relevance of biome-based units for environmental and agricultural policymaking in Brazil, and the alignment of public programs with these ecological divisions, the adopted approach remains appropriate and valuable for the objectives of this study.

In light of these findings, further research is essential to develop comprehensive assessment tools for agricultural policy impacts, particularly on the livelihoods of Brazilian rural communities. With robust evidence of their role in reducing rural inequalities, informed decisions can be made to promote sustainable development.

In conclusion, the pursuit of more productive and sustainable agriculture holds promise for economic development and environmental mitigation in Brazil. Well-founded policies promoting efficient and environmentally responsible agricultural practices can foster a resilient, equitable, and rural economy, crucial for addressing climate change and preserving biodiversity. Local and regional actions are pivotal in shaping this sustainable future, warranting ongoing attention and investment to realize a prosperous and responsible rural environment in Brazil.

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APPENDIX: SUPPLEMENTARY MATERIAL: MACROECONOMIC IMPACTS OF AGRICULTURAL PRODUCTIVITY INCREASES IN BRAZIL: A CLIMATE CHANGE PERSPECTIVE

Table A.1 the 76 sectors of the TERM-Biomes model, including 64 agricultural sectors – 32 corresponding to family farming and 32 to large-scale agriculture – and 12 additional non-agricultural sectors that contribute to the macroeconomic structure of the model. The inclusion of non-agricultural sectors is essential for capturing the general equilibrium effects of agricultural productivity increases, as these sectors interact with rural production through supply chains, infrastructure, and public policies. The model structure allows an assessment of how changes in agricultural productivity influence broader economic dynamics, including trade, labor, and investment.

Table A.2 shows the results of comparative static simulations of TERM-Biomas, focusing solely on the effects of increased productivity by sector and rural product, without considering other structural changes. The data represent the annual percentage variations of key macroeconomic indicators in the long term. Notably, the significant impact of soybean, corn, and coffee productivity on Brazilian exportations is highlighted. A 1% increase in the productivity of these crops would have visible effects on the country's macroeconomic variables. The Livestock and Other Animals sector also stands out for its ability to boost consumption, investment, GDP, wages, and capital.

Table A.3 focuses on the results related to family farming sectors at the national level. In this scenario, the Family Farming Coffee sector stands out for its positive effects on Brazilian exportations. Additionally, the Family Farming Livestock and Other Animals and Dairy sectors also demonstrate impact, with reduced imports and growth in consumption, investment, GDP, wages, and capital.

Table A.4 presents the results of large-scale agricultural sectors regarding productivity shocks. The Soybean and Corn sectors, along with Coffee to a lesser extent, stand out for their significant influence on national exportations and corresponding prices. Sugarcane and the Livestock and Other Animals sector also show the ability to reduce imports and boost consumption, investment, GDP, wages, and capital in Brazil when subjected to productivity shocks in their large-scale formats.

Table A1: Sectors in the TERM-Biomes Model

Code	Sector	Code	Sector
1	Family Rice	39	Family Cashew (Nut)
2	Large-Scale Rice	40	Large-Scale Cashew (Nut)
3	Family Wheat and Other Cereals	41	Family Guaraná
4	Large-Scale Wheat and Other Cereals	42	Large-Scale Guaraná
5	Family Corn	43	Family Grape (Wine or Juice)
6	Large-Scale Corn	44	Large-Scale Grape (Wine or Juice)
7	Family Temporary Cotton (Fiber)	45	Family Other Temporaries
8	Large-Scale Temporary Cotton (Fiber)	46	Large-Scale Other Temporaries
9	Family Sugar Cane	47	Family Orange
10	Large-Scale Sugar Cane	48	Large-Scale Orange
11	Family Soy	49	Family Coffee
12	Large-Scale Soy	50	Large-Scale Coffee
13	Family Cassava	51	Family Other Permanents
14	Large-Scale Cassava	52	Large-Scale Other Permanents
15	Family Tobacco (Leaves)	53	Family Bovines and Other Animals
16	Large-Scale Tobacco (Leaves)	54	Large-Scale Bovines and Other Animals
17	Family Cotton Trees	55	Family Cow and Others Milk
18	Large-Scale Cotton Trees	56	Large-Scale Cow and Others Milk
19	Family Other Citric Fruits	57	Family Swine
20	Large-Scale Other Citric Fruits	58	Large-Scale Swine
21	Family Tomato	59	Family Poultry and Eggs
22	Large-Scale Tomato	60	Large-Scale Poultry and Eggs
23	Family Irish Potato	61	Family Silviculture
24	Large-Scale Irish Potato	62	Large-Scale Silviculture
25	Family Onion	63	Family Vegetal Extractions
26	Large-Scale Onion	64	Large-Scale Vegetal Extractions
27	Family Peanut	65	Fishing and Aquaculture
28	Large-Scale Peanut	66	Mineral Extraction
29	Family Pineapple	67	Fertilizers and Soil Amendments
30	Large-Scale Pineapple	68	Agricultural Defensives and Disinfectants
31	Family Banana	69	Other Manufacturing Industries
32	Large-Scale Banana	70	Industrial Services and Public Utilities
33	Family Bean	71	Civil Construction
34	Large-Scale Bean	72	Wholesale and Retail Trade
35	Family Açaí	73	Freight Transportation
36	Large-Scale Açaí	74	Other Transportation Services
37	Family Cocoa	75	Other Services
38	Large-Scale Cocoa	76	Public Administration

Source: own elaboration based on database from TERM-Biomas.

Table A2: Macroeconomic impacts (percentage variations) stemming from productivity increases in rural sectors, model sectors, Brazil, long-term

Simulation (large-scale and family farming sectors)	Variable									
	Consumption	Investment	Exports	Imports	Real GDP	Wages	Capital Stock	GDP Deflator	CPI	Price of Exports
1 Rice	0.0031	0.0031	-0.0008	-0.0040	0.0031	0.0048	0.0030	0.0035	0.0029	0.0007
2 Wheat and other cereals	0.0008	0.0009	-0.0009	-0.0016	0.0008	0.0015	0.0009	0.0010	0.0008	0.0006
3 Corn	0.0072	0.0045	0.0255	0.0107	0.0072	0.0098	0.0048	0.0023	0.0031	-0.0169
4 Temporary cotton (fiber)	0.0022	0.0014	0.0076	0.0038	0.0022	0.0027	0.0014	0.0010	0.0014	-0.0051
5 Sugar cane	0.0108	0.0091	0.0016	-0.0157	0.0108	0.0260	0.0103	0.0044	0.0010	-0.0032
6 Soy	0.0277	0.0179	0.1158	0.0576	0.0277	0.0298	0.0181	0.0121	0.0179	-0.0764
7 Cassava	0.0013	0.0008	0.0005	-0.0020	0.0013	0.0035	0.0008	-0.0005	-0.0011	-0.0004
8 Tobacco (leaves)	0.0013	0.0009	0.0018	-0.0006	0.0013	0.0027	0.0009	-0.0004	-0.0008	-0.0013
9 Cotton trees	0.0002	0.0000	0.0000	-0.0006	0.0002	0.0003	0.0000	-0.0002	-0.0003	0.0000
10 Other citric fruits	0.0003	0.0001	0.0006	-0.0002	0.0003	0.0007	0.0001	-0.0001	-0.0002	-0.0004
11 Tomato	0.0006	-0.0003	0.0007	-0.0014	0.0006	0.0018	-0.0003	-0.0008	-0.0011	-0.0005
12 Irish potato	0.0007	-0.0002	0.0002	-0.0019	0.0007	0.0017	-0.0001	-0.0007	-0.0011	-0.0002
13 Onion	0.0007	-0.0001	0.0002	-0.0017	0.0007	0.0019	-0.0001	-0.0008	-0.0011	-0.0001
14 Peanut	0.0006	-0.0002	0.0002	-0.0018	0.0006	0.0012	-0.0002	-0.0008	-0.0012	-0.0002
15 Pineapple	0.0007	-0.0001	0.0003	-0.0017	0.0007	0.0011	-0.0001	-0.0009	-0.0012	-0.0002
16 Banana	0.0005	0.0002	-0.0001	-0.0011	0.0005	0.0011	0.0002	-0.0002	-0.0004	0.0001
17 Bean	0.0012	0.0004	0.0005	-0.0021	0.0012	0.0031	0.0005	-0.0007	-0.0012	-0.0004
18 Açaí	0.0004	0.0000	0.0004	-0.0006	0.0004	0.0008	0.0000	-0.0004	-0.0006	-0.0003
19 Cocoa	0.0005	0.0000	0.0010	-0.0003	0.0005	0.0005	0.0001	-0.0003	-0.0004	-0.0006
20 Cashew (nut)	0.0005	0.0001	0.0013	-0.0001	0.0005	0.0009	0.0001	-0.0003	-0.0004	-0.0008
21 Guaraná	0.0003	0.0000	0.0000	-0.0009	0.0003	0.0005	0.0000	-0.0004	-0.0005	0.0000
22 Grape (wine or juice)	0.0004	0.0001	0.0002	-0.0008	0.0004	0.0011	0.0001	-0.0002	-0.0005	-0.0001
23 Other temporaries	0.0021	0.0015	0.0008	-0.0027	0.0021	0.0055	0.0016	-0.0001	-0.0009	-0.0007
24 Orange	0.0013	0.0009	0.0002	-0.0020	0.0013	0.0031	0.0011	0.0001	-0.0003	-0.0003
25 Coffee	0.0042	0.0027	0.0304	0.0119	0.0042	0.0041	0.0027	0.0024	0.0034	-0.0200
26 Other permanents	0.0007	0.0005	-0.0003	-0.0014	0.0007	0.0016	0.0005	0.0000	-0.0003	0.0002
27 Bovines and other animals	0.0241	0.0324	0.0089	-0.0136	0.0241	0.0416	0.0346	0.0005	-0.0017	-0.0094
28 Cow and others milk	0.0058	0.0050	0.0020	-0.0069	0.0058	0.0113	0.0059	-0.0017	-0.0038	-0.0024
29 Swine	0.0024	0.0027	0.0005	-0.0024	0.0024	0.0050	0.0030	0.0007	0.0001	-0.0009
30 Poultry and eggs	0.0058	0.0055	0.0029	-0.0054	0.0058	0.0121	0.0061	-0.0009	-0.0026	-0.0028
31 Silviculture	0.0043	0.0046	0.0014	-0.0045	0.0043	0.0102	0.0047	0.0015	0.0002	-0.0013
32 Vegetal extractions	0.0012	0.0005	0.0021	-0.0006	0.0012	0.0021	0.0005	-0.0007	-0.0010	-0.0015

Source: results selected from simulations with TERM-Biomas.

Table A3: Macroeconomic impacts (percentage variations) stemming from productivity increases in family farming sectors, model sectors, Brazil, long-term

Simulation (family farming sectors)	Variable									
	Consumption	Investment	Exports	Imports	Real GDP	Wages	Capital Stock	GDP Deflator	CPI	Price of Exports
1 Rice	0.0003	0.0003	-0.0003	-0.0006	0.0003	0.0006	0.0003	0.0004	0.0003	0.0002
2 Wheat and other cereals	0.0001	0.0001	-0.0002	-0.0003	0.0001	0.0003	0.0001	0.0002	0.0001	0.0001
3 Corn	0.0010	0.0008	0.0006	-0.0010	0.0010	0.0016	0.0008	-0.0003	-0.0006	-0.0005
4 Temporary cotton (fiber)	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001
5 Sugar cane	0.0005	0.0005	0.0001	-0.0006	0.0005	0.0008	0.0005	0.0001	0.0000	-0.0002
6 Soy	0.0016	0.0015	0.0024	0.0000	0.0016	0.0022	0.0015	0.0004	0.0003	-0.0017
7 Cassava	0.0011	0.0008	0.0004	-0.0015	0.0011	0.0029	0.0008	-0.0004	-0.0009	-0.0003
8 Tobacco (leaves)	0.0010	0.0007	0.0004	-0.0014	0.0010	0.0024	0.0007	-0.0005	-0.0010	-0.0003
9 Cotton trees	0.0002	0.0000	0.0000	-0.0004	0.0002	0.0003	0.0000	-0.0002	-0.0003	0.0000
10 Other citric fruits	0.0001	0.0000	0.0000	-0.0002	0.0001	0.0002	0.0000	0.0000	-0.0001	0.0000
11 Tomato	0.0002	0.0000	0.0000	-0.0005	0.0002	0.0005	0.0000	-0.0003	-0.0004	0.0000
12 Irish potato	0.0002	0.0000	0.0000	-0.0005	0.0002	0.0004	0.0000	-0.0002	-0.0003	0.0000
13 Onion	0.0005	0.0001	0.0001	-0.0012	0.0005	0.0013	0.0001	-0.0005	-0.0008	-0.0001
14 Peanut	0.0003	0.0000	0.0001	-0.0008	0.0003	0.0005	0.0000	-0.0004	-0.0006	-0.0001
15 Pineapple	0.0005	0.0000	0.0002	-0.0011	0.0005	0.0008	0.0001	-0.0006	-0.0009	-0.0002
16 Banana	0.0003	0.0001	-0.0001	-0.0006	0.0003	0.0007	0.0001	-0.0001	-0.0003	0.0001
17 Bean	0.0006	0.0002	0.0002	-0.0013	0.0006	0.0017	0.0002	-0.0007	-0.0010	-0.0002
18 Açaí	0.0003	0.0000	0.0001	-0.0007	0.0003	0.0006	0.0000	-0.0004	-0.0005	-0.0001
19 Cocoa	0.0002	0.0000	0.0000	-0.0004	0.0002	0.0002	0.0000	-0.0001	-0.0002	0.0000
20 Cashew (nut)	0.0002	0.0000	0.0000	-0.0005	0.0002	0.0005	0.0000	-0.0002	-0.0004	0.0000
21 Guaraná	0.0003	0.0000	0.0000	-0.0007	0.0003	0.0005	0.0000	-0.0003	-0.0005	0.0000
22 Grape (wine or juice)	0.0003	0.0001	-0.0001	-0.0007	0.0003	0.0009	0.0001	-0.0002	-0.0004	0.0000
23 Other temporaries	0.0009	0.0006	0.0003	-0.0014	0.0009	0.0023	0.0007	-0.0004	-0.0008	-0.0003
24 Orange	0.0002	0.0001	0.0000	-0.0003	0.0002	0.0002	0.0001	-0.0001	-0.0001	0.0000
25 Coffee	0.0013	0.0008	0.0094	0.0034	0.0013	0.0013	0.0008	0.0008	0.0010	-0.0062
26 Other permanents	0.0003	0.0002	-0.0001	-0.0006	0.0003	0.0007	0.0002	-0.0001	-0.0002	0.0001
27 Bovines and other animals	0.0094	0.0132	0.0029	-0.0051	0.0094	0.0137	0.0135	-0.0005	-0.0012	-0.0032
28 Cow and others milk	0.0037	0.0041	0.0012	-0.0035	0.0037	0.0071	0.0043	-0.0008	-0.0021	-0.0014
29 Swine	0.0009	0.0010	0.0002	-0.0007	0.0009	0.0014	0.0011	0.0001	0.0000	-0.0003
30 Poultry and eggs	0.0016	0.0017	0.0006	-0.0015	0.0016	0.0025	0.0017	-0.0004	-0.0008	-0.0006
31 Silviculture	0.0006	0.0006	0.0001	-0.0008	0.0006	0.0012	0.0006	0.0000	-0.0002	-0.0001
32 Vegetal extractions	0.0008	0.0003	0.0004	-0.0012	0.0008	0.0015	0.0004	-0.0007	-0.0010	-0.0003

Source: results selected from simulations with TERM-Biomas.

Table A4: Macroeconomic impacts (percentage variations) stemming from productivity increases in large-scale farming sectors, model sectors, Brazil, long-term

Simulation (large-scale farming sectors)	Variable									
	Consumption	Investment	Exports	Imports	Real GDP	Wages	Capital Stock	GDP Deflator	CPI	Price of Exports
1 Rice	0.0028	0.0029	-0.0004	-0.0034	0.0028	0.0042	0.0027	0.0031	0.0025	0.0005
2 Wheat and other cereals	0.0007	0.0008	-0.0007	-0.0013	0.0007	0.0012	0.0008	0.0009	0.0006	0.0005
3 Corn	0.0062	0.0037	0.0249	0.0118	0.0062	0.0082	0.0039	0.0027	0.0037	-0.0164
4 Temporary cotton (fiber)	0.0022	0.0014	0.0075	0.0037	0.0022	0.0027	0.0014	0.0010	0.0014	-0.0050
5 Sugar cane	0.0103	0.0086	0.0015	-0.0151	0.0103	0.0252	0.0097	0.0044	0.0011	-0.0031
6 Soy	0.0261	0.0164	0.1134	0.0576	0.0261	0.0276	0.0165	0.0118	0.0177	-0.0747
7 Cassava	0.0002	0.0000	0.0001	-0.0005	0.0002	0.0005	0.0000	-0.0001	-0.0002	-0.0001
8 Tobacco (leaves)	0.0003	0.0002	0.0015	0.0008	0.0003	0.0003	0.0002	0.0001	0.0002	-0.0010
9 Cotton trees	0.0001	0.0000	0.0000	-0.0002	0.0001	0.0001	0.0000	-0.0001	-0.0001	0.0000
10 Other citric fruits	0.0003	0.0000	0.0007	0.0000	0.0003	0.0005	0.0000	-0.0001	-0.0001	-0.0004
11 Tomato	0.0004	-0.0004	0.0007	-0.0009	0.0004	0.0012	-0.0003	-0.0005	-0.0008	-0.0005
12 Irish potato	0.0005	-0.0002	0.0002	-0.0014	0.0005	0.0013	-0.0001	-0.0005	-0.0008	-0.0002
13 Onion	0.0002	-0.0002	0.0001	-0.0006	0.0002	0.0006	-0.0001	-0.0002	-0.0003	-0.0001
14 Peanut	0.0003	-0.0002	0.0001	-0.0010	0.0003	0.0007	-0.0002	-0.0004	-0.0006	-0.0001
15 Pineapple	0.0002	-0.0002	0.0001	-0.0006	0.0002	0.0003	-0.0001	-0.0003	-0.0004	-0.0001
16 Banana	0.0002	0.0001	0.0000	-0.0005	0.0002	0.0005	0.0001	0.0000	-0.0001	0.0000
17 Bean	0.0006	0.0002	0.0003	-0.0009	0.0006	0.0014	0.0003	0.0000	-0.0002	-0.0003
18 Açaí	0.0001	0.0000	0.0003	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	-0.0002
19 Cocoa	0.0003	0.0000	0.0010	0.0001	0.0003	0.0003	0.0000	-0.0001	-0.0002	-0.0006
20 Cashew (nut)	0.0003	0.0001	0.0013	0.0005	0.0003	0.0004	0.0001	-0.0001	0.0000	-0.0008
21 Guaraná	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0001	0.0000	-0.0001	-0.0001	0.0000
22 Grape (wine or juice)	0.0001	0.0000	0.0002	-0.0001	0.0001	0.0003	0.0000	0.0000	-0.0001	-0.0001
23 Other temporaries	0.0011	0.0009	0.0006	-0.0013	0.0011	0.0031	0.0010	0.0003	-0.0001	-0.0005
24 Orange	0.0011	0.0008	0.0002	-0.0018	0.0011	0.0028	0.0010	0.0002	-0.0002	-0.0003
25 Coffee	0.0030	0.0019	0.0210	0.0085	0.0030	0.0027	0.0019	0.0016	0.0024	-0.0138
26 Other permanents	0.0004	0.0003	-0.0002	-0.0008	0.0004	0.0009	0.0003	0.0001	0.0000	0.0001
27 Bovines and other animals	0.0147	0.0192	0.0060	-0.0085	0.0147	0.0279	0.0212	0.0010	-0.0005	-0.0062
28 Cow and other milk	0.0020	0.0009	0.0009	-0.0034	0.0020	0.0042	0.0015	-0.0009	-0.0017	-0.0010
29 Swine	0.0015	0.0016	0.0003	-0.0017	0.0015	0.0035	0.0020	0.0006	0.0001	-0.0006
30 Poultry and eggs	0.0042	0.0038	0.0023	-0.0039	0.0042	0.0096	0.0043	-0.0004	-0.0018	-0.0022
31 Silviculture	0.0037	0.0040	0.0013	-0.0037	0.0037	0.0090	0.0042	0.0015	0.0003	-0.0011
32 Vegetal extractions	0.0004	0.0002	0.0018	0.0007	0.0004	0.0006	0.0002	0.0000	0.0000	-0.0012

Source: results selected from simulations with TERM-Biomas.