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The Economic and Ecological Impact of Soy in Brazil: A Synthetic Control Method Approach

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ABSTRACT

In recent decades, soy expansion in Brazil has generated significant environmental, social and economic impacts. However, there is no consensus about benefits and drawbacks, calling for a more careful account of the economic and ecological diversity of the territories where this phenomenon has been unfolding. By acknowledging this diversity, we investigate the economic and ecological impacts of soy by applying a synthetic control method to longitudinal data (1990–2019) at state level. We focus on three indicators (GDP, CO₂ emissions and deforestation) and explore how these indicators vary in five states (Goiás, Paraná, Piauí, Rio Grande do Sul, Tocantins). These states differ in terms of underlying conditions and timing of soy expansion but have in common a significant contribution of soy to their GDP. From an environmental perspective, the states where soy consolidated its presence during the period considered (Goiás and Paraná) experienced a general improvement compared to their synthetic counterfactuals, especially in terms of deforestation, while a pioneer state in soy production such as Rio Grande do Sul saw a worsening in environmental indicators, especially right after the 2008 global financial crisis. This is also reflected in the impact of soy on GDP, which has been negative in this state, suggesting that it may have suffered from being a plantation economy, with soy subtracting resources from potentially more beneficial sectors. This geographical and temporal heterogeneity indicates that the economic and environmental impact of soy cannot be reduced to a single dominant trend. The outcome depends on the trade-offs with other sectors, which is in turn linked to the level of economic development of the state when soy took off.

1 | Introduction

Brazil is one of the world's largest food producers and exporters. Since the 1960s, the Brazilian government has invested heavily in federal and state-level programmes to support export-oriented agri-food producers and in developing financial and physical infrastructures for boosting the country's agricultural productivity (Stabile et al. 2020), especially the cultivation of soy (Weinhold et al. 2013; Wesz Junior et al. 2023).

Scholars have extensively discussed the economic, societal and environmental impacts of soy in the Brazilian context. From a purely economic perspective, the mainstream narrative argues

that the transition towards a farming system based on soy and its derived products has positively impacted the economic performance of the country. Income levels have increased (Dreoni et al. 2021), lines of credit and financial support have been established for small and large farmers, and new jobs have been created (Richards et al. 2015; VanWey et al. 2013). On the other hand, inequality and poverty have increased too (see, among others, Weinhold et al. 2013; Russo Lopes et al. 2021). For instance, soy is mainly grown by large producers, with 60% of the output coming from farms of over one thousand hectares, and its trade is controlled by a small number of large agri-food corporations (Niederle and Wesz Junior 2020). Moreover, the implementation of a large-scale soy production system has often required

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the displacement of small farmers, which has a negative impact on their income and creates tensions between them and the agrarian elites (Maluf et al. 2022).

Additionally, researchers and policymakers have been raising concerns about the environmental issues connected to soy. Scholars have highlighted the negative impact of soy on the Amazon biome, especially in terms of deforestation, biodiversity reduction and increased CO₂ emissions (Gibbs et al. 2015; Noojipady et al. 2017). Soy has also started to be used as animal feed, which has had a significant impact on the transformation of the agricultural systems of Brazil and other South American countries (Gudynas 2008). The resulting pasture expansion may have been a larger driver of deforestation than soy expansion itself (Arima et al. 2011; Barona et al. 2010). However, while cattle ranching may have contributed more significantly to forest loss, soy expansion has played a central role in land-use change, often replacing pastures and indirectly driving deforestation by pushing cattle ranching into new forested areas (Song et al. 2021).

We are thus in the presence of complex trade-offs between environmental and economic outcomes, with interdependencies across agricultural and non-agricultural sectors, and non-trivial spill-overs across territories. As a result, a broad consensus on the benefits and drawbacks of soy expansion for Brazil's diverse territory has yet to be reached. This lack of consensus is also due to the different analytical lenses and geographical scales adopted by previous studies. These studies have focused mainly on municipalities (Bustos et al. 2016; Martinelli et al. 2017; Piras et al. 2021) or bioregions and ecoregions (Rausch et al. 2019). However, the 26 Brazilian states and the Federal District have their own legal, institutional and policy frameworks. The Brazilian Constitution (Chapter V, Article 23) establishes that 'the promotion of agriculture and the organisation of the supply of foodstuff' as well as 'the preservation of nature, the defence of soil and natural resources, the protection of the environment and the control of pollution' are shared by the union, the states and the municipalities. Nevertheless, only the states have full legislative competence on the latter in the absence of federal laws (Constitution of the Federative Republic of Brazil 2010).

Some authors (Gollnow and Lakes 2014; Severo dos Santos and Naval 2022) have focused on specific states or groups of states primarily affected by the expansion of soy. This approach censors the range of variability in the explanatory and outcome variables. Meanwhile, previous research has found that the marginal benefits of soy production on different dimensions of human development are decreasing and could possibly become negative, pointing to the need to consider a more holistic picture (Piras et al. 2021). Given the relevant policymaking role of the states and the need to avoid censoring the range of underlying socio-economic and environmental conditions and outcomes, this paper focuses on state-level case studies in a longitudinal perspective while accounting for the characteristics of all Brazilian states.

Given the above premises, we apply an up-to-date impact evaluation approach that is particularly well-suited for studies involving macro-level units and such non-randomised interventions as the expansion of soy: the synthetic control method (SCM). The SCM represents a significant advancement over traditional

regression-based approaches for causal inference in comparative case studies (Abadie and Gardeazabal 2003; Abadie et al. 2010). After identifying the treated units, it provides a transparent and data-driven means of estimating counterfactual outcomes by constructing a weighted combination of untreated units that closely replicates the pre-intervention characteristics of the former. To mention an application in the agri-food sector, it has been recently used to assess the impact of regional economic integration on agri-food imports and exports in small post-Soviet economies (Bekbolotova et al. 2025).

We focus on the period between 1990 and 2019, examining five states that we consider 'treated' with soy production starting from the year when the value added coming from soy overcame a given share of the state GDP. The other 'non-treated' states are used to create a counterfactual (i.e., 'synthetic') version of each treated state.¹ For each treated state, the comparison of the trends in the GDP, CO₂ emissions and deforestation between them and their synthetic version allow us to assess the impact of soy production on these variables at state-level. The results are discussed comparatively for the five states to gain in-depth insights on how the pattern of soy expansion interacts with pre-existing socio-economic and environmental conditions, to shape local outcomes.

Our work combines innovations in the level of analysis, temporal and geographical scope and methodological approach to provide a unique picture across Brazil. The impact of soy on GDP differs for different treated states: it is positive in consolidated soy producing states such as Goiás and Paraná, and negative in Rio Grande do Sul, a pioneer state in soy production (Martinelli et al. 2017). Moreover, the impact is stronger in the post-2008 financial crisis period. This can be explained by differences in industrialisation levels and structures of the state-level economy when soy took off, and therefore the trade-offs with other non-agricultural sectors. In contrast, in agricultural frontier states such as Piauí and Tocantins, where soy cultivation continues to expand, the contribution to economic growth remains comparatively limited. At the same time, environmental damages connected with soy production are particularly significant in Rio Grande do Sul, while Goiás and Paraná have experienced a reduction in deforestation and CO₂ emissions with respect to their counterfactuals. Since we controlled for other environmentally impactful land-based activities, namely livestock production, our results suggest that the net impact of soy depends on the carbon- and deforestation-intensiveness of non-agricultural sectors, and soy's environmental impact depends on what kinds of activities expand or contract because of soy growth.

The rest of the paper is structured as follows. The next section reviews the relevant literature. Section 3 illustrates the analytical method and the data used. Section 4 presents and discusses the results, while the last section concludes and presents potential policy implications.

2 | Soy Expansion in Brazil

Latin American countries have seen an exponential increase in soy-related agricultural activities in recent decades. In particular, Southern Cone countries (Argentina, Brazil, Paraguay

and Uruguay) have experienced sizeable growth in both land area and production, which has led to the development of almost entirely commodity-dependent economies (Choumert and Phélinas 2015; Wesz Junior 2016). Moving towards what can be considered a 'soy monoculture system' has had direct implications for food supply chains and the overall agribusiness sector. The Southern Cone nowadays accounts for over half of the global soy production, while in the 1970s, only 4% of the soy produced in the world came from this area (Correia 2019; Wesz Junior 2022). This expansion has been achieved through land expropriation and deforestation, policies supporting the use of agrochemicals, private control over water resources, use of novel technologies and incentives for exporting to foreign markets (Correia 2019; Eloy et al. 2023). The decision of Argentina, Brazil, Paraguay and Uruguay to use soy monoculture as a driver of economic growth has also determined the typology of soy producers. Large transnational companies have started operating in the above countries since the 1990s, and after a series of acquisitions of local companies, they were able to create a sort of 'chain oligopoly' in the industry (Oliveira and Schneider 2016; Wesz Junior 2016).

Among these countries, Brazil has been the first to implement policies aimed at expanding this monoculture. Commercial soy cultivation began in the 1960s in the state of Rio Grande do Sul, which constitutes one of our five state case studies. After a few decades, it reached the northern part of the country, with soy being cultivated also in the Amazon biome and in the Brazilian Cerrado (Piras et al. 2021; Rausch et al. 2019; Sauer 2018). From 2000 to 2021, the cultivated area almost tripled, jumping from 13.6 to 39.1 million hectares (IBGE 2025). Although soy has been expanding in all Brazilian regions in recent years, in the Amazon, its growth has not been as fast as in other areas because of pro-environmental initiatives, such as the Amazon Soy Moratorium. However, soy expansion has continued at high speed in the Cerrado, and especially in the Matopiba macro-region, which includes the states of Maranhão, Tocantins, Piauí and Bahia (Lima et al. 2019). Two of these states (Tocantins and Piauí) are included among the case studies analysed in this paper, alongside Goiás, which is also located in the Cerrado ecoregion. This expansion towards the north consolidated Brazil's role as the largest producer and exporter of soy in the world (USDA 2022).

Research on the impact of soy expansion in Brazil has focused on different geographical levels, namely municipalities, ecological biomes and states. The studies focusing on municipalities have used different approaches, both in terms of analytical perspective and context of analysis. Weinhold et al. (2013) focused on the municipalities in the Legal Amazon—a socio-geographic division used in Brazil for indicating the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima (none of which are considered as case studies in this paper), and part of Maranhão. These scholars have used mixed-methods approaches combining spatial regression models and interviews with key stakeholders of the soy industry, concluding that soy expansion has increased household income but also inequality. Bustos et al. (2016) used municipality-level data from the 1996 and 2006 agricultural censuses to show that soy expansion resulted in the growth of other sectors and the improvement of such economic indicators as productivity and employment.

More recent studies have focused on all municipalities jointly (Piras et al. 2021; Russo Lopes et al. 2021; Lima-de-Oliveira and Alonso 2017; Martinelli et al. 2017), reporting rather conflicting results. Martinelli et al. (2017) and Piras et al. (2021) identified a positive impact on the Municipal Human Development Index (MHDI), even if this impact has been decreasing over time and is mainly driven by the index's GDP dimension. Lima-de-Oliveira and Alonso (2017) highlighted that the commodity boom experienced by Brazil did not contribute to increasing inequality. This stands in contrast to Russo Lopes et al. (2021), who conducted a qualitative study of 18 municipalities in Maranhão, Tocantins, Piauí and Bahia, and found that soy expansion has led to concentration of power and income, and thus more income inequality. Le Polain de Waroux et al. (2019) went even further in their analysis, examining the dynamics of both soy and cattle expansion in municipalities and provinces of Argentina, Bolivia, Brazil, Paraguay and Uruguay. Their models suggest that more restrictive deforestation regulation at local levels is associated with more deforestation, but this might be due to regulations being tightened where expansion rates are higher. In turn, regulations have modified trade patterns in a non-trivial way across countries and sub-national states in Latin America, and they may have created deforestation loopholes outside the region. Hence, most of the studies that adopted municipalities as the unit of analysis have focused on the socio-economic and political aspects of soy expansion (on which there is less consensus) and less on the environmental aspects, with environmental damage receiving more robust confirmation.

Research focusing on ecological biomes and states has mostly investigated the environmental aspects related to soy. Overall, a majority of these studies agree on the negative impact of soy expansion in Brazil. Lima et al. (2019) suggested that soy production continues to be a driver of deforestation despite the initiatives for supporting responsible and sustainable production. Macedo et al. (2012) and Gollnow and Lakes (2014) employed quantitative methods to assess the impact of soy expansion on deforestation in Mato Grosso and Pará, finding that there is indeed a relationship. However, the deforestation trend is decelerating due to the implementation of federal policies to protect Brazilian forests. Mato Grosso—one of the states with the largest soy cultivated area in 2018 but excluded from our analysis due to data constraints—was studied in depth by Richards et al. (2015) and VanWey et al. (2013). These authors identified a positive impact of soy expansion on non-agricultural employment and economic growth besides environmental impact, intended as carbon equivalent emissions.

Other recent studies have examined ecological biomes in order to control for the geographical and environmental characteristics of the territory, which are key for crop productivity. Two main biomes have been explored in the literature: Amazon and Cerrado. The former is characterised by a variety of natural ecoregions and is the largest biome in Brazil, while the latter is considered particularly well-suited for agriculture and livestock production. Baletti (2014) argued that federal anti-deforestation programmes in the Amazon biome have reduced soy expansion there, but problems of land property and social conflicts persist. More recently, Sauer (2018) and Rausch et al. (2019) observed a similar trend of reduced deforestation rates, but also an increase in land conflicts and environmental damage. This could potentially lead to increasing inequality

TABLE 1 | Economic and environmental impacts of soy production in Brazil.

| Author(s) (year) | Level of analysis | Finding(s) |
|------------------------------------|--|--|
| Baletti (2014) | Single state (Pará) | Land property issues. Social conflicts. Legislation for deforestation stopped soy expansion. |
| Bustos et al. (2016) | Brazilian municipalities | Increase in productivity. Increase in employment. Economic growth of non-agricultural sectors. |
| Gollnow and Lakes (2014) | Brazilian Amazon | Increase in deforestation. |
| Heilmayr et al. (2020) | Amazon and Cerrado biomes | Legislation for deforestation stopped soy expansion. |
| Lima et al. (2019) | Amazon biome | Increase in deforestation. |
| Lima-de-Oliveira and Alonso (2017) | Brazilian municipalities | Regional inequalities not a direct consequence of the commodity boom. |
| Macedo et al. (2012) | Single state (Mato Grosso) | Increase in deforestation. |
| Martinelli et al. (2017) | Brazilian municipalities | Positive impact on the Human Development Index but mainly linked to increase in GDP. |
| Piras et al. (2021) | Brazilian municipalities | Positive impact on the Human Development Index but mainly linked to increase in GDP. |
| Rausch et al. (2019) | Single state (Cerrado) | Increase in deforestation. Land property issues. Environmental damage. |
| Richards et al. (2015) | Single state (Mato Grosso) | Economic growth. |
| Russo Lopes et al. (2021) | Municipalities in Maranhão, Tocantins, Piauí and Bahia | Increase in inequality. |
| Sauer (2018) | Single state (Pará) | Increase in deforestation. Land property issues. Environmental damage. |
| VanWey et al. (2013) | Single state (Mato Grosso) | Increase in employment. |
| Weinhold et al. (2013) | Municipalities in the Legal Amazon | Increase in income. Increase in inequality. |

in the Amazon and Cerrado macro-regions. Equally, despite the recent implementation of initiatives such as the Amazon Soy Moratorium, which reduced the deforestation directly due to soy (Heilmayr et al. 2020), Brazil continues to rely on soy exports to support its economic growth. This is why, in recent years, social movements and other stakeholders have accused the Brazilian government of encouraging 'greenwashing' practices (Grabs et al. 2021).

To summarise the main insights emerging from the literature, scholars have generally observed a positive impact of soy production on the size of the economy, but a negative impact on the environment. There is a broad consensus that income and GDP have increased at municipal levels, but a majority of researchers also agree on the increase in inequality. From an environmental perspective, scholars have acknowledged the negative impact of soy production on deforestation and greenhouse gas emissions. Moreover, some have noted a reduction in soy production

specifically linked to the implementation of dedicated legislation on forest protection. Table 1 below provides an overview of these findings.

Still, a longitudinal analysis at the state level that makes use of the same methodological protocol for comparison is notably absent. Such an analysis would allow us to account for the initial economic and ecological conditions in each territory, and for trade-offs between soy and other agricultural and non-agricultural sectors that may be complementary or substitutive. For instance, soy's overall impact on the environment would depend on whether this commodity has offset other, more impactful land-based activities. Equally, soy could either represent an intermediate input for more profitable industrial productions or generate vested interests that subtract resources from more innovative off-farm industries. These nuances can only be appreciated by considering different states comparatively, and for a sufficiently long period.

Given the above premises, this paper models the relationship between soy production and economic and environmental outcomes by comparing the evolution of three indicators of economic and environmental performance across five Brazilian states: GDP, CO₂ emissions and deforestation. The selection of these few critical economic and environmental indicators that we may expect to be impacted by agricultural systems allows us to streamline the analysis and facilitates the interpretation of the results.

3 | Data and Methods

This paper uses the SCM to estimate the impact of soy on the evolution of three indicators: GDP; CO₂ emissions from agriculture, livestock and land-use change²; and deforestation.³ In particular, our analysis concentrates on the states of Goiás, Paraná, Piauí, Rio Grande do Sul and Tocantins.

Originally developed by Abadie and Gardeazabal (2003), the SCM represents one of the most influential recent methodological contributions for investigating the effects of a given treatment (Athey and Imbens 2017). It is a data-driven econometric technique that builds a counterfactual ('synthetic') unit to show how the treated unit would have performed if the treatment had not occurred. The synthetic unit is built using appropriately weighted 'donor' units, with donors not having been exposed to the treatment. The difference between the synthetic and observed values provides a measure of the treatment effect. The possibility of combining multiple donors represents a methodological innovation compared to employing a single comparison unit. The weighted combination that creates the synthetic unit provides a statistically superior fit for the unit of observation.

The SCM has several advantages compared to standard regression-based methods. First, it precludes extrapolation and uses interpolation instead (King and Zeng 2006), as the estimated causal effect is always based on comparison between some outcome in a given year and a counterfactual in the same year. Second, the non-negative weights assigned to the donor units are made explicit, thereby allowing one to determine how each unit contributes to the counterfactual. Regression analysis *de facto* weights the data without making said weights explicit. Third, in terms of reliability, Abadie et al. (2010) noted that if there is a sufficiently large number of observations in the pre-intervention period, then matching on pre-intervention outcomes allows us to control for heterogeneity of responses to multiple unobserved factors. The intuition here is that only observations that behave in the same way with respect to both unobserved and observed variables would follow a similar pre-treatment trend.

Despite the smaller number of data points, we ran the analysis at the state rather than municipality or microregion⁴ level because of the previously mentioned role of the states in policy design, as well as because it provides a more comprehensive picture while simplifying the interpretation of the results. Additionally, the state level is the only one for which a wide range of data is available.

Our five state case studies are considered 'treated' starting from the year in which soy and related economic activities first exceeded 5% of the state's GDP (Figure 1). Therefore, the treatment is represented by 'soy and related economic activities exceeding 5% of GDP.' As a robustness check, we implemented the SCM analysis also using 3% and 7% thresholds, and thus the years when they were first exceeded in the selected states. The results, reported in the Figures A1–A6 and Tables A2–A5, do not vary significantly, although the number of treated states was reduced to three with the 7% threshold and increased to six with the 3% threshold. The SCM is then used to assess whether these states would have performed differently in terms of GDP, CO₂ emissions and size of land affected by deforestation if soy production had remained below 5% of GDP.⁵ The 20 donor units used to build the synthetic units for each state and indicator were the remaining 19 Brazilian states and the Federal District, where the production of soy never exceeded the 5% threshold during the observation period. Despite being particularly relevant in terms of soy production (Carnielli et al. 1996), Mato Grosso and Mato Grosso do Sul had to be excluded from both the lists of 'treated' and 'donor' units because their shares of GDP derived from soy was already above the threshold at the beginning of the time series (1990), meaning that a pre-intervention period could not be established.⁶

From the computational point of view, the synthetic units were constructed with an optimal combination of non-negative weights that minimised the distance (the root mean squared of the prediction error) in terms of outcome variables between the prospective 'treated' unit and its corresponding synthetic unit in the years preceding the intervention. In terms of notation, t is the year, where 1 corresponds to 1990, and T to the state-specific year in which the treatment starts; m are 21 federal units,

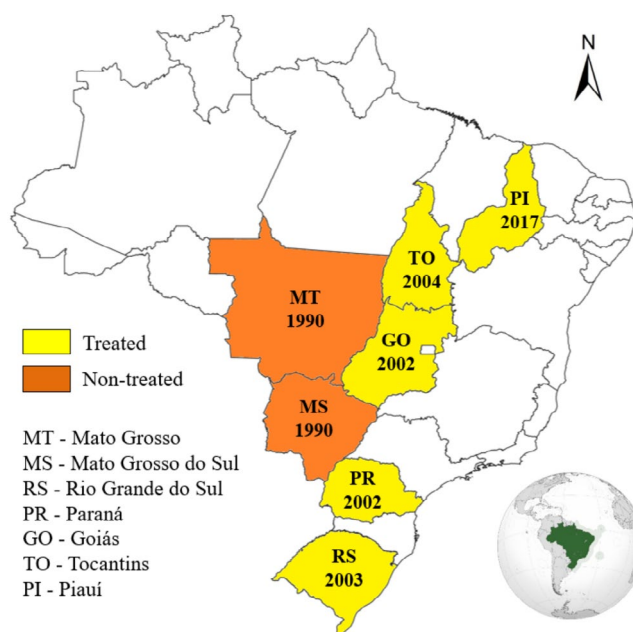


FIGURE 1 | States with soy and related economic activities exceeding 5% of the state's GDP. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

TABLE 2 | Summary statistics for the outcome and predictor variables in the SCM (1990–2019).

| Variable's function | Variable | Number of obs. | Mean | Standard deviation | Min. | Max. |
|-----------------------|---|----------------|-----------|--------------------|---------|--------------|
| Outcome variable | GDP (in million R\$) | 810 | 89,788.51 | 204,811.60 | 0.01 | 1,975,310.00 |
| | CO ₂ emissions per square km | 810 | 279.33 | 165.94 | 10.56 | 1304.40 |
| | Deforestation per 1000 square km | 810 | 4.37 | 3.33 | 0.25 | 22.30 |
| Predictor (covariate) | Exports (in million R\$) | 810 | 10,926.15 | 25,174.47 | 0.00 | 238,958.60 |
| | Imports (in million R\$) | 621 | 11,581.05 | 26,937.62 | 1.02 | 234,232.30 |
| | Population (inhabitants) | 810 | 6,682,037 | 7,964,676 | 216,424 | 45,900,000 |
| | Unemployment rate (%) | 756 | 8.09 | 2.68 | 2.50 | 20.54 |
| | GDP from soy (in million R\$) | 810 | 1390.15 | 3806.17 | 0.00 | 32,764.47 |
| | Number of cows per square km | 808 | 28.24 | 18.49 | 0.38 | 69.95 |

Note: The sample consists of 27 units of observation (26 Brazilian states and the Federal District) observed over a 30-year period (from 1990 to 2019). The sample size should have consisted of 810 observations, but is smaller for some variables due to the presence of missing values. No outcome variables contain missing values in either the pre-treatment or post-treatment periods. The values of the predictors for the donor units in the post-treatment period are not used; therefore, any missing values do not affect the applicability of the method. Similarly, missing values for some predictors and donor units in the pre-treatment period do not compromise the results, as the SCM relies on averages across all available years in that period while ignoring missing values; no predictor is imputed.

Source: Authors' calculation from the datasets.

including the treated and the 20 control units; and $W = (w_2; \dots; w_{21})$ is an $(m \times 1)$ vector of non-negative weights which sum up to 1. Using our notation, the vector of weights w_m attributed to the m control states was chosen to minimise the distance indicated in (1):

$$\sum_{t=1}^{T-1} \left[X_{1,t} - \sum_{m=2}^{21} (X_{m,t} W_m) \right]^2 \text{ subject to } w_m \geq 0, \quad (1)$$

where X_1 represents the value of the outcome variable for the treated state, and the sum in parentheses is the synthetically generated value of the variable in each year of the pre-treatment period. This value is built as the sum of the products between the value of the outcome variable in each of the m donor states, X_m , and their corresponding weights W_m . The SCM routine finds an ideal synthetic Brazilian state when the difference in (1) is minimised over the pre-intervention period, so that the synthetic and observed states are statistically similar along that period.

The data used in our analysis cover the period 1990–2019. We excluded the years from the COVID-19 pandemic since they would have caused strong breaks in the time series. The pre-treatment period varies from state to state, depending on when the soy-related share of GDP exceeded 5% for the first time: 2002 in Goiás and Paraná, 2003 in Rio Grande do Sul, 2004 in Tocantins, and 2017 in Piauí. The years after the intervention and until 2019 constitute the treatment period. Our data were sourced from the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*, IBGE⁷), the Greenhouse Gas Emission and Removal Estimating System (*Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa*, SEEG⁸), and the Annual Mapping Project for Land Use and Land Cover in Brazil (*Projeto de Mapeamento Anual do Uso e Cobertura da Terra no Brasil*, MapBiomass⁹). The post-treatment period allowed us to

capture both the short- and medium-term effects generated by soy production.

To construct the synthetic states, we compiled a list of predictors for the indicators (Table 2). The SCM is data-driven, meaning that the predicting covariates were chosen on the basis of availability and their ability to statistically explain the outcomes of interest. Some covariates, such as the population, have been used in previous papers studying the impact of soy on a set of socio-economic indicators (e.g., Piras et al. 2021). The number of cows per square kilometre (livestock intensity) was included to control for what may be a significant driver of change in our outcome indicators besides soy. In addition to the covariates, following Abadie et al. (2015), we included the lagged values of the state's GDP, CO₂ emissions and deforestation as predictors in the pre-treatment period. The inclusion of these predictors helps reduce the sensitivity of the weighting procedure to unobservable factors and produces a better-fitting pre-intervention model (Villar and Papyrakis 2017; Pellegrini et al. 2021; Papyrakis et al. 2022).

Using the SCM, we produced a synthetic state for each treated state and outcome variable. The specific weights used for creating these synthetic states are reported in Table A1. Although we observe some similarity in the weights for the same state, these change for each indicator, even for the same state. This suggests that the states that most closely resemble the treated one in the pre-treatment period vary depending on the indicator considered, and do not necessarily belong to the same ecological region. In most cases, only a few states are sufficient to obtain a good fit and are therefore assigned non-zero weights. Any deviations between the observed and synthetic observations after the intervention can be attributed to the treatment (i.e., soy production).

The statistical significance of the differences was derived through *ex-post* placebo tests (Galiani and Quistorff 2017).

These placebo tests replicate the SCM analysis for all the ‘donor’ units and assess the probability that they experienced an effect of similar or larger magnitude.

3.1 | Overview of the Case Studies

The five state case studies were identified endogenously after defining the treatment, rather than being selected a priori to maximise heterogeneity for comparative reasons. Nevertheless, they differ significantly in terms of both environmental conditions and agricultural systems.

In 1990, the area covered by native vegetation ranged from 92% in Piauí and 82% in Tocantins to 58% in Rio Grande do Sul, 43% in Goiás, and as little as 27% in Paraná. Native vegetation includes both forest and non-forest formations such as grassland, whose suppression jointly contributes to deforestation. By 2019, this area had declined in nearly all states, reaching 84% in Piauí, 63% in Tocantins, 47% in Rio Grande do Sul, and 33% in Goiás, while remaining almost unchanged at 26% in Paraná (MapBiomias 2025).

In contrast, the area devoted to agriculture had remained close to 70% in Paraná while increasing in the other states: from 52% to 62% in Goiás, from 34% to 45% in Rio Grande do Sul, from 17% to 33% in Tocantins, and from 8% to 15% in Piauí (MapBiomias 2025). In Rio Grande do Sul, soy has been the dominant crop since 1990, with a considerable margin over other crops, whereas in Goiás and Paraná it has shared this position with maize and wheat (IBGE 2025). By contrast, Piauí and Tocantins have focused on other relevant crops. Cotton, rice, cassava, beans, manioc and maize in Piauí (with maize accounting for around 30% of the agricultural area and rotated with soy); rice (until the early 2000s), soy and maize in Tocantins (IBGE 2025).

Although soy production drives the demand for related agricultural equipment, only Rio Grande do Sul hosts an important agro-industrial and export hub alongside São Paulo. Paraná has some production, but at a relatively minor scale (Anfavea 2025). Regarding other resource-intensive sectors, mining is not significant in any of the five states. Land-use change was the primary source of CO₂ emissions in all five states in 1990 and has remained above 90% throughout the period in Piauí and Tocantins, which are frontier areas of agricultural expansion (SEEG 2025). By 2019, agriculture was the main source of emissions in Rio Grande do Sul, Paraná and Goiás. Because Paraná and Rio Grande do Sul are more industrialised, emissions from the energy sector are also significant (SEEG 2025).

The historical expansion of the soy frontier is also interconnected with the structural characteristics of the above states. In the academic debate regarding the creation of new soy-growing areas, whether they originate from former pasture areas or from deforestation, Barona et al. (2010) found that pasture area decreased in Tocantins and in parts of its neighbour Mato Grosso at the beginning of the century. Deforestation was likely driven by soy expansion in those areas. Focusing instead on the Legal Amazon (which includes Tocantins), Barreto et al. (2025) recently discovered that ‘while cattle ranching emerges as the

primary direct driver, agricultural expansion may still contribute to deforestation indirectly through land displacement dynamics’ (p. 1050). This may not have been the case for states such as Goiás, where livestock activity and pasture crops have likely been the responsible for deforestation in recent years (Barbosa et al. 2023). Furthermore, when considering the five states’ economies, differences emerge between Paraná and Rio Grande do Sul on the one hand, where soy production ‘was an important factor in changing land-use practices and land-cover change’ (Garrett and Rausch 2016), and Piauí and Tocantins on the other hand, which are relatively recent frontiers of cropland expansion, resulting from the conversion of native vegetation (Filho and Costa 2016).

The above overview suggests that we may observe different impacts of soy in the five states due to the different potential for the suppression of native vegetation and the replacement of other industrial crops. Table 3 below synthesises the above information by reporting the average value of each indicator for Brazil, for the ‘treated’ states, and their synthetic versions during the pre-treatment periods. These statistics show that, besides differing from each other, the treated states differ from the rest of Brazil on average. The existence of these differences before the treatment confirms that a simple comparison of economic and environmental indicators between the treated and donor states would deliver biased results. On the other hand, the treated states show strong similarity with their synthetic counterparts.

4 | Results and Discussion

This section presents and discusses the results. We limit our discussion to the differences between the real and synthetic states that are statistically significant based on the placebo tests. These significant differences are reported in Table 4. Table 5 then reports the magnitude of the treatment effect as a percentage of the synthetic value, that is, with respect to the value we would have observed in the absence of the treatment. Although other differences may seem visually relevant, they are likely to be random: a deviation of similar size could be observed in the non-treated states with significant probability.

The evolution of the GDP in the single states compared to their synthetic versions is plotted in Figure 2, while the difference between the actual and synthetic values, and the economic significance of this difference in each year are reported in the top rows of Tables 4 and 5. We observe a positive impact of soy production on GDP in Goiás and Paraná, and, limited to 2016, in Tocantins. This impact amounted to between 11% and 33% of GDP depending on the state and year, while the single, marginally significant difference for Tocantins reached 44%. In turn, this effect was negative¹⁰ in Rio Grande do Sul: between 14% and 22% of this state's GDP. These impacts can be interpreted as representing the whole spill-over effects of soy as an engine of economic growth.

The states where soy appears to have had a positive impact on GDP (Goiás, Paraná and Tocantins) are those where this commodity strongly contributes to the local rural economy (Oderich 2020). In Paraná and Tocantins, the impact of soy was positive and significant mainly in later years. This is because

TABLE 3 | Comparison between observed and synthetic treated states in the pre-intervention periods (year of the intervention in brackets).

| Indicator | GDP (in million R\$) | CO ₂ emissions per square km | Deforestation per 1000 square km |
|-----------------------------|----------------------|---|----------------------------------|
| Brazil | 25,018 (a) | 292 (a) | 5.15 (a) |
| Goiás (2002) | 14,823 | 388 | 6.44 |
| Synthetic Goiás | 14,547 | 385 | 6.49 |
| Brazil | 24,091 (a) | 291 (a) | 5.31 (a) |
| Paraná (2002) | 38,921 | 429 | 2.28 |
| Synthetic Paraná | 38,572 | 427 | 2.29 |
| Brazil | 82,409 | 287 | 4.52 |
| Piauí (2017) | 13,096 | 90 | 3.39 |
| Synthetic Piauí | 13,205 | 92 | 3.34 |
| Brazil | 25,853 | 293 | 5.17 |
| Rio Grande do Sul (2003) | 50,635 | 458 | 6.75 |
| Synthetic Rio Grande do Sul | 50,677 | 448 | 6.54 |
| Brazil | 30,110 | 301 | 5.24 |
| Tocantins (2004) | 2577 | 287 | 5.11 |
| Synthetic Tocantins | 2625 | 291 | 4.9 |

Note: The values reported are averages for the pre-intervention period, whose duration varies between states. The values for Brazil refer to all the states apart from those considered as 'treated.' This is why the values of the indicators marked with (a) differ slightly even if the starting year of the treatment for Goiás and Paraná is the same, 2002.

Source: Authors' calculation from the dataset.

in these states, the economic size of the soy-related economy overcame the 5% GDP share early, but remained limited until the mid-2010s, when it started increasing significantly. Goiás is the state where the positive impact of soy on GDP is more pronounced (up to 33% if considering the treatment effect). In Goiás, soy's contribution to GDP expanded rapidly from 1995 to 2004, only to then stabilise (IBGE 2025); this may explain why the impact was positive and significant, with continuity, since 2009.

In Rio Grande do Sul, GDP was lower than its synthetic value in all years since 2005, indicating a negative impact of soy on GDP, although the difference was only significant until 2014. This might suggest that soy production has been subtracting resources and investments from other activities that could have been more economically beneficial. Rio Grande do Sul is one of the most industrialised states in Brazil (IBGE 2025). Nevertheless, in the early 2000s and 2010s, this state may have suffered from the curse of being a plantation economy, whereby a monoculture is implemented on very large farm areas to serve export markets, preventing resources from being invested in other sectors (Best and Levitt 2009).

Figure 3 reports the graphs for CO₂ emissions in the treated states and their synthetic versions, while the significant differences and their relative magnitudes are reported in the central rows of the tables. In most states, we observe no significant increase in CO₂ emissions due to soy cultivation, with the notable exception of Rio Grande do Sul. This state seems to have experienced a large increase in its yearly CO₂ emissions per square km compared to its synthetic counterpart (between 18% and 23%), statistically

significant from 2011 to 2013. Our results for Rio Grande do Sul confirm previous findings (e.g., Cerri et al. 2017; Noojipady et al. 2017) that soy production has been causing an increase in CO₂ emissions because of land-use change and other agricultural production stages. This is especially true in those areas where there has been a shift from extensive to highly intensive agricultural systems. In Goiás, Piauí and Tocantins, soy cultivation appears to have had no impact on CO₂ emissions when compared to their synthetic counterparts.

In Paraná, we observe a significant decrease in CO₂ due to soy cultivation, but only at the very beginning of the post-treatment period (2004–2006), and smaller in absolute terms than the impact detected in Rio Grande do Sul (between 9% and 13%). This unexpected result may be due to the presence of economic activities that may generate more CO₂ emissions than soy. This is the case of livestock farming: in 2020, 'the raising of oxen and cows account[ed] for no less than 75% of the 577 million tons [of CO₂] emitted by the [farming] sector' (SEEG 2023, 14). Nevertheless, it should not be neglected that a considerable share of the soy produced in Brazil is used as animal feed. Therefore, soy expansion is indirectly linked to livestock emissions. Additionally, the fact that we identified no significant increase in CO₂ emissions in the states of the Cerrado biome (Goiás, Piauí and Tocantins) may be due to the more recent expansion of soy in this region.

Finally, the deforestation patterns in the treated states and their synthetic representations are plotted in Figure 4 and reported in the bottom rows of the tables. Deforestation seems to have increased significantly because of soy production in Tocantins and

TABLE 4 | Differences between the observed and synthetic values of the outcome indicators, and significance of the difference.

| Indicator | State (treatment) | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | |
|---|--------------------------|------|-----------|------|------|----------|------------|------------|------------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|------|------|--|
| GDP (1000,000 R\$) | Goiás (2002) | | 5809*** | | | | | | 15,343*** | 15,230* | 24,412* | 27,213*** | 34,492*** | 39,965*** | 41,652*** | 35,270*** | 37,032*** | | | |
| | Paraná (2002) | | 12,961*** | | | | | | | | | | | | 34,679* | 38,405* | | | | |
| CO ₂ emissions (tons per sq. km) | Piauí (2017) | | | | | | | | | | | | | | | | | | | |
| | Rio Grande do Sul (2003) | | | | | -24,645* | -25,076*** | -28,623*** | -42,528*** | -58,171* | -69,502* | -59,471* | | | | | | | | |
| | Tocantins (2004) | | | | | | | | | | | | | | | 8748* | | | | |
| | Goiás (2002) | | | | | | | | | | | | | | | | | | | |
| Deforestation (sq. km per 1000 sq. km) | Paraná (2002) | | | | | -40,3* | -53,2*** | -55,9*** | | | | | | | | | | | | |
| | Piauí (2017) | | | | | | | | | | | | | | | | | | | |
| | Rio Grande do Sul (2003) | | | | | | | | | 87,8* | 69,6*** | 92,3*** | | | | | | | | |
| | Tocantins (2004) | | | | | | | | | | | | | | | | | | | |
| Deforestation (sq. km per 1000 sq. km) | Goiás (2002) | | | | | -2,2* | -2,4* | -2,3*** | -1,8*** | -1,4*** | -2,0* | -2,3*** | -2,5*** | -1,5*** | -2,3*** | -2,3*** | -1,4*** | | | |
| | Paraná (2002) | | | | | | | | | | | | | | | | | | | |
| | Piauí (2017) | | | | | | | | | | | | | | | | | | | |
| | Rio Grande do Sul (2003) | | | | | | | | | | | | | | | | | | | |
| Deforestation (sq. km per 1000 sq. km) | Tocantins (2004) | | | | | | | | | | | | | | | | | | | |
| | Goiás (2002) | | | | | | | | | | | | | | | | | | | |
| | Paraná (2002) | | | | | | | | | | | | | | | | | | | |
| | Piauí (2017) | | | | | | | | | | | | | | | | | | | |
| Deforestation (sq. km per 1000 sq. km) | Rio Grande do Sul (2003) | | | | | | | | | | | | | | | | | | | |
| | Tocantins (2004) | | | | | | | | | | | | | | | | | | | |
| | Goiás (2002) | | | | | | | | | | | | | | | | | | | |
| | Paraná (2002) | | | | | | | | | | | | | | | | | | | |

Note: ***, ** and * refer to the 1%, 5% and 10% significance levels, respectively. The cells coloured in grey indicate that the state had not yet been treated in that year. The table only reports the differences that are significant. Positive values are in green, negative ones in red.

Source: Authors' calculation from the dataset.

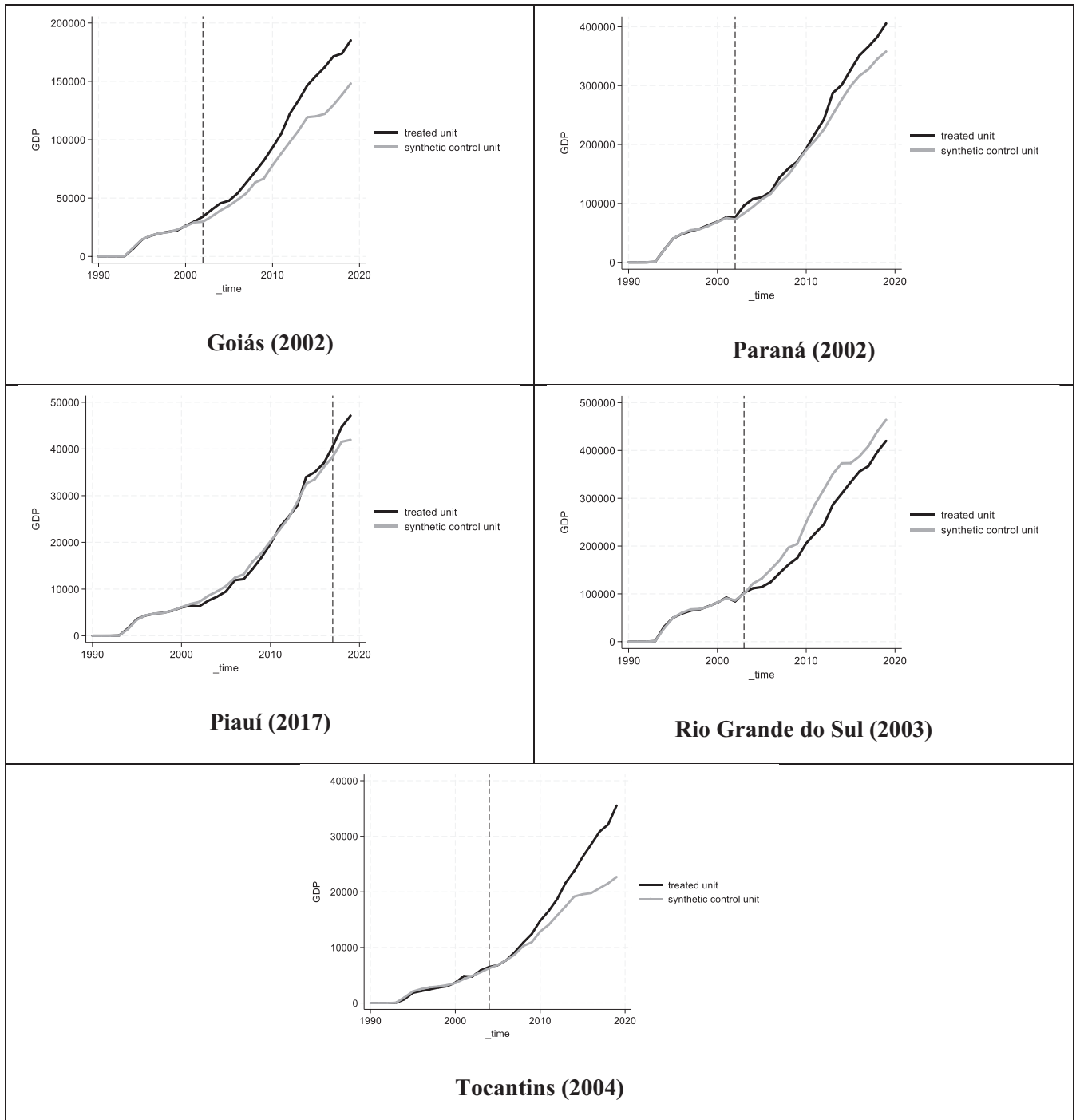


FIGURE 2 | GDP in Goiás, Paraná, Piauí, Rio Grande do Sul and Tocantins. *Source:* Authors' calculation from the dataset.

Rio Grande do Sul. In Rio Grande do Sul, this trend was found to be significant over almost the entire period under study, with the impact in terms of yearly loss of native vegetation ranging from 32% up to 192% of the synthetic counterfactual. In contrast, for Tocantins, this increase is found mainly in the final years of the time series, and with a generally smaller effect, although still noteworthy (between 52% and 81% of the synthetic version). As mentioned in Section 3.1, Tocantins is part of the Brazilian agricultural frontier, which is characterised by a strong deforestation rate for agricultural purposes. In this state, the area dedicated to soy has grown more than 15 times in the last 20 years (IBGE 2025), and deforestation has progressed in parallel, causing the loss of native

vegetation in an area greater than Switzerland (MapBiomias 2025). These results align with Lima et al. (2019) and Polizel et al. (2021), who found a positive relationship between deforestation and soy cultivation, especially in the Matopiba macro-region.

In Rio Grande do Sul, the area cultivated with soy has doubled over the last two decades (IBGE 2025), and soy production has since moved towards the Pampa biome, at the border with Uruguay (MapBiomias 2025). In light of these dynamics, our results confirm previous findings (see, for instance, Macedo et al. 2012; Gollnow and Lakes 2014) that soy is linked to the suppression of native vegetation where related activities strongly

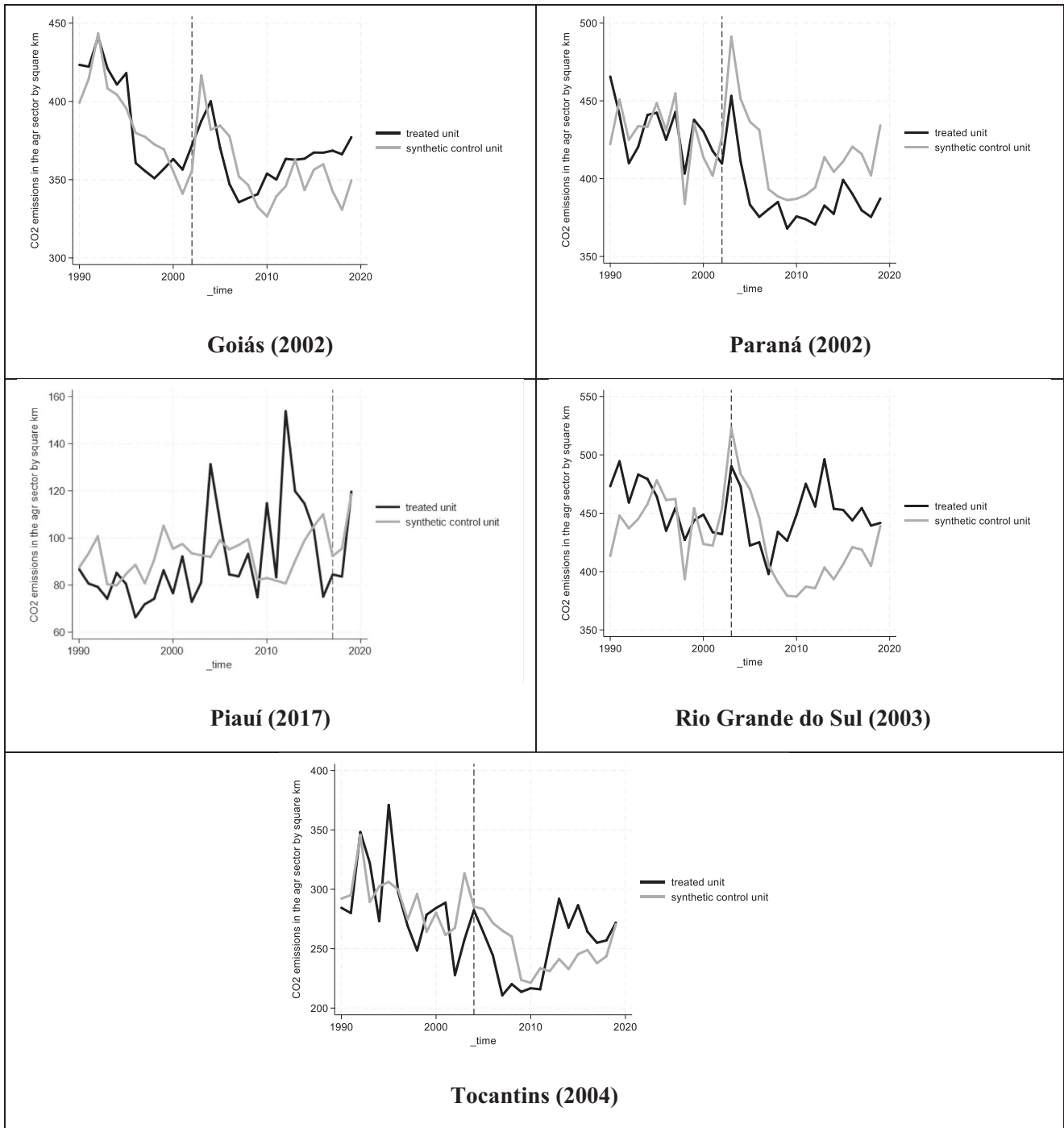


FIGURE 3 | CO₂ emissions in Goiás, Paraná, Piauí, Rio Grande do Sul and Tocantins. *Source:* Authors' calculation from the dataset.

affect the broader local economy and intensive practices modify the agricultural system (Mengue et al. 2020).

On the other hand, we observe a statistically significant decrease in deforestation in Goiás and Paraná, even if it was less pronounced in the latter (29%–61% vs. 14%–41% of the synthetic counterfactual, depending on the year). This result again suggests that soy production may be an economic activity with a lower potential for deforestation in consolidated agricultural regions, where natural vegetation has already been cleared (unlike Rio Grande do Sul, where soy production is moving towards the Pampa biome).

Although in Brazil there are cases where native vegetation is cleared and immediately replaced by soybean fields, the more common pattern is a sequential process in which newly deforested areas are first converted into pasture (Crepin 2024). Over time, as infrastructure improves, land values rise, and the productive frontier consolidates, these pastures are gradually replaced by mechanised agriculture, especially soy. This pattern has been unfolding in Goiás and Paraná. In this vein, we can say that where the soy frontier is still expanding (Rio Grande do Sul and Tocantins, even if for different reasons), deforestation increases, while in areas characterised by

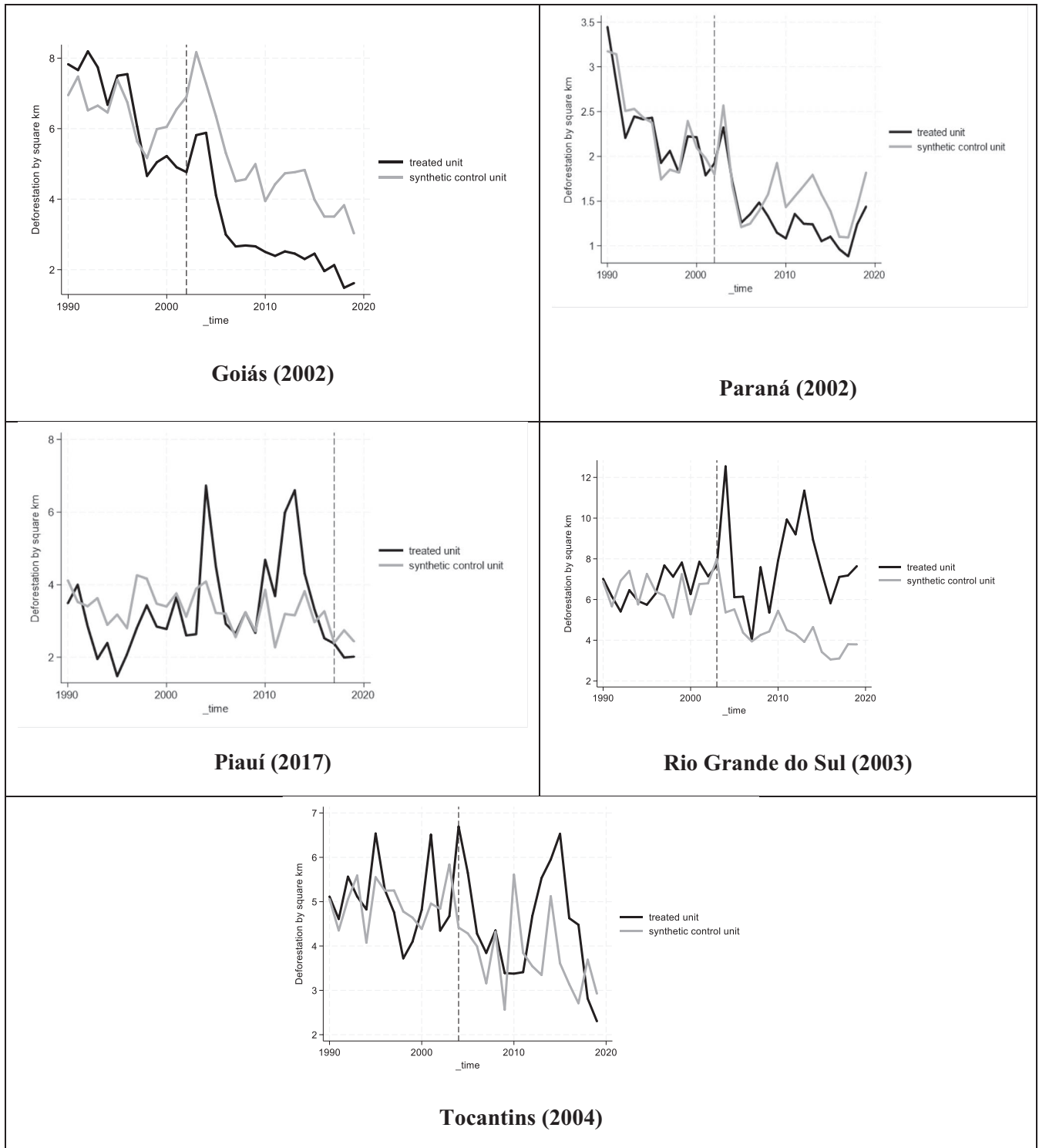


FIGURE 4 | Deforestation in Goiás, Paraná, Piauí, Rio Grande do Sul and Tocantins. *Source:* Authors' calculation from the dataset.

the intensification of existing farmland (Goiás and Paraná), outcomes are different, likely because of pasture-to-crop conversion.

5 | Conclusions

Soy production has had, and still has, a relevant impact on the Brazilian economy, having modified its agri-food system and

agricultural and natural landscapes. This research contributed to advancing our understanding of this phenomenon by considering the overall country system comparatively. Accounting for the diverging trajectories of Brazilian states, we have yielded counterfactual outcomes for the states most affected by the expansion of soy production since the beginning of the century. We used the SCM to analyse a longitudinal dataset covering almost 30 years, and tested the impact of soy on GDP, CO₂ emissions and deforestation.

Our results unveiled a heterogeneous picture across Brazilian states, which, however, can be seen as part of a common pattern depending on the states' characteristics and their historical positioning in the soy expansion process. In recent decades, the Brazilian economy has experienced increasing deindustrialisation, and a renewed importance of the primary (agricultural and mining) sectors based on intense exploitation of natural resources (Lamoso 2020; Cooney 2021; Andrade 2022; Vieira and Santos 2022). We found that, while soy did play a role in supporting the country's economic growth, Brazilian states experienced different impacts on their economy, which can be explained by their varying industrialisation levels and the different economic structures characterising rural areas. In regions where soy has been consolidating its presence (Goiás and Paraná), the economy is driven by soy expansion. By contrast, in the agricultural frontier (Piauí and Tocantins), economic (GDP-related) gains are not as large as in the previous states because soy-related infrastructures and supply chains are still developing (Peine 2021). Besides, the negative impact observed on the GDP in Rio Grande do Sul may have been induced by economic saturation: this is a pioneer state in soy production, and the expansion that occurred at the beginning of the century has probably crowded out more productive industrial activities.

Equally, we found evidence of negative environmental impacts, especially in terms of increased deforestation, in Rio Grande do Sul and Tocantins. This result suggests that in these states, native vegetation was replaced directly by soy plantations. However, the lack of significant impact in other states suggests that soy expanded primarily on areas devoted to other agricultural activities, such as livestock farming, and might be potentially less harmful than these (IPCC 2019; Vogel et al. 2021).

We acknowledge two main limitations of this study. One derives from our exclusive focus on soy production, despite the relevant role played by other agricultural activities in the Brazilian rural economy. Corn, cotton and sugarcane represent additional strategic productions in some areas, and they rely on practices and technologies similar to those used for soy, namely high mechanisation, intense input use, cultivation on large areas, and inclination towards a monocultural system. Further studies may concentrate on these agricultural products and replicate our work to investigate their impact. Some other activities such as livestock farming are closely intertwined with soy. On the one hand, intensive livestock farming of (mainly) pork and poultry generates a growing demand for soybeans and stimulates an increase in their production. On the other hand, soy production moves to regions with extensive pasturelands, pushing livestock to the frontier of deforestation (Arima et al. 2011; Oliveira and Hecht 2016). Moreover, Richards et al. (2015) highlighted that soy production can lead to indirect land-use change via the occupation of pasture and, therefore, the reduction of local beef supplies, thereby incentivising small farmers to move towards frontier regions. Equally, in the absence of soy, livestock farming would be most likely to expand towards the areas currently or potentially occupied by this crop: this is a trade-off that should not be ignored.

The second limitation of this study, already highlighted in Section 3, is that Mato Grosso and Mato Grosso do Sul, despite

being important soy producers among Brazilian states, had to be excluded from both the list of 'treated' and 'donor' units due to the limited length of the time series employed in our analysis. Future studies can concentrate on collecting longitudinal data from longer time series and include these two states in their analyses.

As in other Latin American countries, the agricultural sector in Brazil has been an important driver of the overall economy, with soy acting as one of the main protagonists in recent decades. The alternatives that could potentially replace soy (sugarcane, cotton, corn, coffee, or livestock), which already dominate the agricultural landscape in some Brazilian states, tend to reproduce or even amplify the impacts and economic trade-offs of soy. In this sense, the underlying issue is not the specific product, but the practices, technologies, and institutions behind it, which need to be problematised and addressed in order to promote a pathway towards more sustainable agri-food systems in Brazil and beyond (Niederle and Wesz Junior 2020). Fostering initiatives that encourage less environmentally impactful productions is essential, as well as stimulating productive activities that are more resilient to climate-related issues. Given that almost 80% of the soy produced in Brazil is exported, and that internal political challenges limit the Brazilian government's ability to implement stricter regulations, international pressure to purchase products from non-deforested areas becomes a key factor for Brazilian producers. On this aspect, several initiatives are already in place or are currently being implemented, such as the EU Deforestation Regulation (EUDR), the Amazon Soy Moratorium, and the environmental provisions of the EU-Mercosur Partnership Agreement.

Finally, we suggest that federal economic programmes and policies promoting more sustainable practices should be strongly interlinked with state-level initiatives, taking into account the specific socio-economic and pedoclimatic characteristics of each state. In this regard, federal, state and non-state actors play a significant role. However, multilevel governance may be problematic when it comes to grand challenges.¹¹ Accordingly, it is crucial to promote development strategies that consider Brazilian states' unique circumstances and needs.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

¹ Unfortunately, the states where the importance of soy was above the threshold from the start of the time series (Mato Grosso and Mato Grosso do Sul) cannot be included among the 'treated,' and have thus

been excluded from the analysis. See Section 3 for an in-depth discussion on this aspect.

² Our indicator of CO₂ emissions covers two sectors: (i) agriculture and livestock, which accounts for perennial and non-perennial agricultural production activities (e.g., the chemical and organic fertilisation of soil), as well as animal husbandry and production, including cattle, chicken, goats, buffaloes, and mules; and (ii) change in the use of land and forests, which accounts for the emissions from deforestation, and in 2022 represented 49% of Brazil's total emissions (SEEG 2023). Our indicator is measured in terms of tons of CO₂ emissions per square kilometre of area of a state.

³ Mapbiomas (2025) defines deforestation as the complete or almost complete suppression of existing native vegetation in a given area. For more information, see https://storage.googleapis.com/alerta-public/dashboard/rad/2022/RAD_2022.pdf. Our deforestation indicator is measured in terms of square kilometres of native vegetation (including trees, shrubs, etc.) lost per 1000 km² of area of a state.

⁴ Microregions refer to groups of contiguous municipalities with similar characteristics, being a regional geographic division of Brazil elaborated by the Brazilian Institute of Geography and Statistics (IBGE). They are used for statistical purposes, and while their use in economic analyses could help overcome the challenge represented by spatial spillovers between small municipalities (see, for instance, Bustos et al. 2016), they do not have legislative or regulatory power that could result in different policy frameworks influencing the evolution of their agricultural and food systems.

⁵ The GDP is reported in real, fixed prices for the year 2010. The value added of soy at state level is derived from the Municipal Agricultural Production (PAM) dataset, while GDP was sourced from the Brazilian National Accounts, both calculated by the IBGE (2022).

⁶ Even when using the threshold of 7% of GDP in the robustness analysis, we were unable to identify a pre-treatment period for these two states. Higher thresholds would have reduced the length of the treated period for the treated states, resulting in the inclusion in the pre-treatment period of states where soy already represented a significant share of the GDP. As our case studies are single states, the exclusion of Mato Grosso and Mato Grosso do Sul is less impactful for the analysis than what is suggested by their relative incidence on Brazilian soy production.

⁷ <https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9088-produto-interno-bruto-dos-municipios.html> [last accessed 27 November 2025].

⁸ <http://seeg.eco.br/download> [last accessed 27 November 2025].

⁹ <https://mapbiomas.org/estatisticas> [last accessed 27 November 2025].

¹⁰ This does not indicate that soy caused a decrease in GDP across years, but that the GDP is lower than what it would have been if soy were below the 5% threshold.

¹¹ For an overview of climate policies in Brazil, see Maia et al. (2024).

References

Abadie, A., A. Diamond, and J. Hainmueller. 2010. "Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program." *Journal of the American Statistical Association* 105, no. 490: 493–505.

Abadie, A., A. Diamond, and J. Hainmueller. 2015. "Comparative Politics and the Synthetic Control Method." *American Journal of Political Science* 59, no. 2: 495–510.

Abadie, A., and J. Gardeazabal. 2003. "The Economic Costs of Conflict: A Case Study of the Basque Country." *American Economic Review* 93, no. 1: 113–132.

Andrade, D. 2022. "Neoliberal Extractivism: Brazil in the Twenty-First Century." *Journal of Peasant Studies* 49, no. 4: 793–816. <https://doi.org/10.1080/03066150.2022.2030314>.

Anfavea. 2025. *Anuário 2025*. Associação Nacional dos Fabricantes de Veículos Automotores. <https://anfavea.com.br/site/anuarios-2/>.

Arima, E. Y., P. Richards, R. Walker, and M. M. Caldas. 2011. "Statistical Confirmation of Indirect Land Use Change in the Brazilian Amazon." *Environmental Research Letters* 6, no. 2: 024010.

Athey, S., and G. W. Imbens. 2017. "The State of Applied Econometrics: Causality and Policy Evaluation." *Journal of Economic Perspectives* 31, no. 2: 3–32.

Baletti, B. 2014. "Saving the Amazon? Sustainable Soy and the New Extractivism." *Environment and Planning A* 46, no. 1: 5–25.

Barbosa, V. A., J. A. Nabout, and H. F. da Cunha. 2023. "Spatial and Temporal Deforestation in the Brazilian Savanna: The Discrepancy Between Observed and Licensed Deforestation in the State of Goiás." *Land Use Policy* 131: 106730.

Barona, E., N. Ramankutty, G. Hyman, and O. T. Coomes. 2010. "The Role of Pasture and Soybean in Deforestation of the Brazilian Amazon." *Environmental Research Letters* 5: 024002.

Barreto, A. C., T. Martins, and A. M. Souza. 2025. "Modeling Deforestation Drivers in the Brazilian Amazon: A Comparison of Quantitative Approaches." *Big Earth Data* 9, no. 4: 1023–1057.

Bekbolotova, S., N. Djanibekov, and T. Herzfeld. 2025. "How Does Regional Economic Integration Impact Trade in Small Economies? Evidence From Armenia and Kyrgyzstan's EAEU Accession." *Eurasian Geography and Economics*: 1–29.

Best, L., and K. Levitt. 2009. *Essays on the Theory of Plantation Economy: A Historical and Institutional Approach to Caribbean Economic Development*. University of the West Indies Press.

Bustos, P., B. Caprettini, and J. Ponticelli. 2016. "Agricultural Productivity and Structural Transformation: Evidence From Brazil." *American Economic Review* 106, no. 6: 1320–1365.

Carnielli, A., N. L. Zuffo, and W. H. Higashi. 1996. *Soja: Caracterização Das Cultivares Recomendadas Para Mato Grosso e Mato Grosso do Sul*. Embrapa-CPAO.

Cerri, C. E. P., X. You, M. R. Cherubin, et al. 2017. "Assessing the Greenhouse Gas Emissions of Brazilian Soybean Biodiesel Production." *PLoS One* 12, no. 5: e0176948.

Choumert, J., and P. Phélinas. 2015. "Determinants of Agricultural Land Values in Argentina." *Ecological Economics* 110: 134–140.

Constitution of the Federative Republic of Brazil. 2010. *Constitution of the Federative Republic of Brazil*. 3rd ed. Chamber of Deputies, Documentation and Information Center. https://www.oas.org/es/sla/ddi/docs/acceso_informacion_base_dc_leyes_pais_b_1_en.pdf.

Cooney, P. 2021. *Paths of Development in the Southern Cone: Deindustrialization and Reprimarization and Their Social and Environmental Consequences*. Palgrave Macmillan.

Correia, J. E. 2019. "Soy States: Resource Politics, Violent Environments and Soybean Territorialization in Paraguay." *Journal of Peasant Studies* 46, no. 2: 316–336.

Crepin, L. 2024. "Do Forest Conservation Policies Undermine the Soybean Sector in the Brazilian Amazon? Evidence From the Priority Listing of Municipalities." *Ecological Economics* 224: 108212.

Dreoni, I., M. Schaafsma, and Z. Matthews. 2021. "The Social Impacts of Soy Production: A Systematic Review." UKRI GCRF TRADE Hub.

Eloy, L., A. L. da Silva, O. Coelho Filho, and S. Ghiotti. 2023. "The Water Frontier: Agribusiness vs. Smallholder Communities in the Brazilian Cerrado." *Water Alternatives* 16, no. 3: 869–891.

- Filho, A. C., and K. Costa. 2016. *The Expansion of Soybean Production in the Cerrado: Paths to Sustainable Territorial Occupation, Land Use and Production*. Agroicone.
- Galiani, S., and B. Quistorff. 2017. "The Synth_runner Package: Utilities to Automate Synthetic Control Estimation Using Synth." *Stata Journal* 17, no. 4: 834–849.
- Garrett, R. D., and L. L. Rausch. 2016. "Green for gold: social and ecological tradeoffs influencing the sustainability of the Brazilian soy industry." *Journal of Peasant Studies* 43, no. 2: 461–493. <https://doi.org/10.1080/03066150.2015.1010077>.
- Gibbs, H. K., L. Rausch, J. Munger, et al. 2015. "Brazil's Soy Moratorium: Supply-Chain Governance Is Needed to Avoid Deforestation." *Science* 347: 377–378.
- Gollnow, F., and T. Lakes. 2014. "Policy Change, Land Use, and Agriculture: The Case of Soy Production and Cattle Ranching in Brazil, 2001–2012." *Applied Geography* 55: 203–211.
- Grabs, J., F. Cammelli, S. A. Levy, and R. D. Garrett. 2021. "Designing Effective and Equitable Zero-Deforestation Supply Chain Policies." *Global Environmental Change* 70: 102357.
- Gudynas, E. 2008. "The New Bonfire of Vanities: Soybean Cultivation and Globalization in South America." *Development* 51: 512–518.
- Heilmayr, R., L. L. Rausch, J. Munger, and H. K. Gibbs. 2020. "Brazil's Amazon Soy Moratorium Reduced Deforestation." *Nature Food* 1: 801–810.
- IBGE. 2025. *Instituto Brasileiro de Geografia e Estatística - Brazilian Institute of Geography and Statistics*. Sistema IBGE de Recuperação Automática– IBGE Automatic Data Retrieval System – SIDRA. <https://sidra.ibge.gov.br/>.
- IPCC. 2019. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. United Nations.
- King, G., and L. Zeng. 2006. "The Dangers of Extreme Counterfactuals." *Political Analysis* 14, no. 2: 131–159.
- Lamoso, L. P. 2020. "Reprimarização no Território Brasileiro." *Espaço e Economia* 9, no. 19: 1–32.
- Le Polain de Waroux, Y., R. D. Garrett, J. Graesser, C. Nolte, C. White, and E. F. Lambin. 2019. "The Restructuring of South American Soy and Beef Production and Trade Under Changing Environmental Regulations." *World Development* 121: 188–202.
- Lima, M., C. A. D. Silva Junior, L. Rausch, H. K. Gibbs, and J. A. Johann. 2019. "Demystifying Sustainable Soy in Brazil." *Land Use Policy* 82: 349–352.
- Lima-de-Oliveira, R., and M. L. Alonso. 2017. "Fueling Development? Assessing the Impact of Oil and Soybean Wealth on Municipalities in Brazil." *Extractive Industries and Society* 4, no. 3: 576–585.
- Macedo, M. N., R. S. DeFries, D. C. Morton, C. M. Stickler, G. L. Galford, and Y. E. Shimabukuro. 2012. "Decoupling of Deforestation and Soy Production in the Southern Amazon During the Late 2000s." *Proceedings of the National Academy of Sciences of the United States of America* 109, no. 4: 1341–1346.
- Maia, M., L. Serafim, and E. Alves. 2024. "Implementation of a Climate Policy Monitoring System in Brazil: Political Challenges for Coordination on Multilevel Governance Arrangements." *Brazilian Political Science Review* 18, no. 2: 1–43.
- Maluf, R. S., L. Burlandy, R. P. Cintrão, E. Jomalinis, T. C. O. Carvalho, and T. Tribaldos. 2022. "Sustainability, Justice and Equity in Food Systems: Ideas and Proposals in Dispute in Brazil." *Environmental Innovation and Societal Transitions* 45: 183–199.
- MapBiomass. 2025. *Cobertura e Uso de Solo do Brasil*. MapBiomass. <https://plataforma.brasil.mapbiomas.org/>.
- Martinelli, L. A., M. Batistella, R. F. B. da Silva, and E. Moran. 2017. "Soy Expansion and Socioeconomic Development in Municipalities of Brazil." *Land* 6: 62.
- Mengue, V. P., M. W. Dias de Freitas, T. Silva da Silva, D. C. Fontana, and F. C. Scottá. 2020. "LAND-USE and Land-Cover Change Processes in Pampa Biome and Relation With Environmental and Socioeconomic Data." *Applied Geography* 125: 102342.
- Niederle, P. A., and V. J. Wesz Junior. 2020. *Agri-food System Transitions in Brazil: New Food Orders*. Routledge.
- Noojipady, P., C. D. Morton, N. M. Macedo, et al. 2017. "Forest Carbon Emissions From Cropland Expansion in the Brazilian Cerrado Biome." *Environmental Research Letters* 12, no. 2: 025004.
- Oderich, E. H. 2020. "Dinâmicas Socioeconômicas da Expansão Agrícola no Brasil: Situações e Tendências Dos Municípios e Regiões da Soja e da Cana-De-Açúcar (Doctoral Thesis)." Federal University of Rio Grande do Sul. Program in Rural Development.
- Oliveira, G. D. L. T., and S. Hecht. 2016. "Sacred Groves, Sacrifice Zones and Soy Production: Globalization, Intensification and Neo-Nature in South America." *Journal of Peasant Studies* 43, no. 2: 251–285.
- Oliveira, G. D. L. T., and M. Schneider. 2016. "The Politics of Flexing Soybeans: China, Brazil and Global Agroindustrial Restructuring." *Journal of Peasant Studies* 43, no. 1: 167–194.
- Papyrakis, E., L. Pellegrini, and L. Tasciotti. 2022. "Impacts of the Brexit Referendum on UK Employment: A Synthetic Control Method Approach." *Applied Economics Letters* 30, no. 11: 1407–1410.
- Peine, E. K. 2021. "Chinese Investment in the Brazilian Soybean Sector: Navigating Relations of Private Governance." *Journal of Agrarian Change* 21: 71–89.
- Pellegrini, L., L. Tasciotti, and A. Spartaco. 2021. "A Regional Resource Curse? A Synthetic-Control Approach to Oil Extraction in Basilicata, Italy." *Ecological Economics* 185: 107041.
- Piras, S., V. J. Wesz Junior, and S. Ghinoi. 2021. "Soy Expansion, Environment, and Human Development: An Analysis Across Brazilian Municipalities." *Sustainability* 13: 7246.
- Polizel, S. P., R. M. D. S. P. Vieira, J. Pompeu, et al. 2021. "Analysing the Dynamics of Land Use in the Context of Current Conservation Policies and Land Tenure in the Cerrado–MATOPIBA Region (Brazil)." *Land Use Policy* 109: 105713.
- Rausch, L. L., H. K. Gibbs, I. Schelly, et al. 2019. "Soy Expansion in Brazil's Cerrado." *Conservation Letters* 12, no. 6: e12671.
- Richards, P., H. Pellegrina, L. VanWey, and S. Spera. 2015. "Soybean Development: The Impact of a Decade of Agricultural Change on Urban and Economic Growth in Mato Grosso, Brazil." *PLOS One* 10: e0122510.
- Russo Lopes, G., M. G. Bastos Lima, and T. N. P. D. Reis. 2021. "Maldevelopment Revisited: Inclusiveness and Social Impacts of Soy Expansion Over Brazil's Cerrado in Matopiba." *World Development* 139: 105316.
- Sauer, S. 2018. "Soy Expansion Into the Agricultural Frontiers of the Brazilian Amazon: The Agribusiness Economy and Its Social and Environmental Conflicts." *Land Use Policy* 79: 326–338.
- SEEG. 2023. "Análise Das Emissões Brasileiras de Gases Efeito Estufa e Suas Implicações Para as Metas Climáticas do Brasil (1970–2021)." Observatorio do Clima. <https://www.oc.eco.br/wp-content/uploads/2023/03/SEEG-10-anos-v4.pdf>.
- SEEG. 2025. "Emissões Totais Por Categoria." <https://plataforma.seeg.eco.br/>.
- Severo dos Santos, J. F., and L. P. Naval. 2022. "Soy Water Footprint and Socioeconomic Development: An Analysis in the New Agricultural Expansion Areas of the Brazilian Cerrado (Brazilian Savanna)." *Environmental Development* 42: 100670.

- Song, X.-P., M. C. Hansen, P. Potapov, et al. 2021. "Massive Soybean Expansion in South America Since 2000 and Implications for Conservation." *Nature Sustainability* 4, no. 9: 784–792.
- Stabile, M. C. C., A. L. Guimarães, D. S. Silva, et al. 2020. "Solving Brazil's Land Use Puzzle: Increasing Production and Slowing Amazon Deforestation." *Land Use Policy* 91: 104362.
- USDA. 2022. "Soybean Explorer." <https://ipad.fas.usda.gov/cropexplorer/cropview/commodityView.aspx?cropid=2222000>.
- VanWey, L. K., S. Spera, R. de Sa, D. Mahr, and J. F. Mustard. 2013. "Socioeconomic Development and Agricultural Intensification in Mato Grosso." *Philosophical Transactions of the Royal Society of London, Series B* 368, no. 1619: 20120168. <https://doi.org/10.1098/rstb.2012.0168>.
- Vieira, E. T., and M. J. Santos. 2022. "Brazilian Deindustrialization: The Precarious Insertion of Brazil in the Globalization Process." *Revista Brasileira de Gestão e Desenvolvimento Regional* 18, no. 2: 183–200.
- Villar, P. F., and E. Papyrakis. 2017. "Evaluating the Impact of the Extractive Industries Transparency Initiative (EITI) on Corruption in Zambia." *Extractive Industries and Society* 4, no. 4: 795–805.
- Vogel, E., G. Martinelli, and F. D. Artuzo. 2021. "Environmental and Economic Performance of Paddy Field-Based Crop-Livestock Systems in Southern Brazil." *Agricultural Systems* 190: 103109.
- Weinhold, D., E. Killick, and E. J. Reis. 2013. "Soybeans, Poverty and Inequality in the Brazilian Amazon." *World Development* 52: 132–143.
- Wesz Junior, V. J. 2016. "Strategies and Hybrid Dynamics of Soy Transnational Companies in the Southern Cone." *Journal of Peasant Studies* 43, no. 2: 286–312.
- Wesz Junior, V. J. 2022. "Soybean Production in Paraguay: Agribusiness, Economic Change and Agrarian Transformations." *Journal of Agrarian Change* 22, no. 2: 317–340.
- Wesz Junior, V. J., F. Escher, and T. M. Fares. 2023. "Why and How Is China Reordering the Food Regime? The Brazil–China Soy-Meat Complex and COFCO'S Global Strategy in the Southern Cone." *Journal of Peasant Studies* 50, no. 4: 1376–1404.

Appendix A

TABLE A1 | List of SCM 'donors' by state and indicator, and weights associated to each 'donor'.

| GDP (1000 R\$) | CO ₂ emissions per square km | Deforestation per 1000 square km |
|---------------------|---|----------------------------------|
| Goiás | | |
| Rondônia (11) | Rondônia (7) | Rondônia (18) |
| Sergipe (53) | Maranhão (14) | Bahia (56) |
| Rio de Janeiro (6) | Sergipe (49) | Minas Gerais (26) |
| Santa Catarina (30) | Rio de Janeiro (7) | |
| | Santa Catarina (23) | |
| Paraná | | |
| Bahia (94) | Rondônia (8) | Sergipe (6) |
| São Paulo (6) | Espírito Santo (10) | Minas Gerais (15) |
| | São Paulo (12) | Espírito Santo (29) |
| | Santa Catarina (70) | Rio de Janeiro (36) |
| | | São Paulo (7) |
| | | Santa Catarina (7) |
| Piauí | | |
| Amazonas (66) | Roraima (30) | Roraima (64) |
| Maranhão (24) | Amapá (35) | Maranhão (4) |
| Ceará (9) | Ceará (17) | Rio Grande do Norte (8) |
| Paraíba (1) | Pernambuco (15) | Bahia (24) |
| | Alagoas (3) | |
| Rio Grande | | |
| Minas Gerais (76) | Rondônia (12) | Rondônia (21) |
| Espírito Santo (24) | São Paulo (31) | Paraíba (15) |
| | Santa Catarina (57) | Sergipe (21) |
| | | São Paulo (14) |
| | | Santa Catarina (29) |
| Tocantins | | |
| Acre (51) | Rondônia (5) | Rondônia (13) |
| Roraima (15) | Roraima (10) | Roraima (30) |
| Sergipe (34) | Maranhão (23) | Maranhão (4) |
| | Paraíba (41) | Paraíba (21) |
| | Sergipe (16) | Sergipe (6) |
| | Santa Catarina (5) | Espírito Santo (21) |
| | | Santa Catarina (5) |

Note: The numbers in parentheses indicate the percentage contribution of a given state in the SCM analysis, that is, the non-negative weights used to construct the 'synthetic' value of each indicator for the state specified in bold. The list of donors include the following states: Acre, Alagoas, Amapá, Amazonas, Bahia, Ceará, Espírito Santo, Maranhão, Minas Gerais, Paraíba, Pernambuco, Rio de Janeiro, Rio Grande do Norte, Rondônia, Roraima, Santa Catarina, São Paulo and Sergipe.

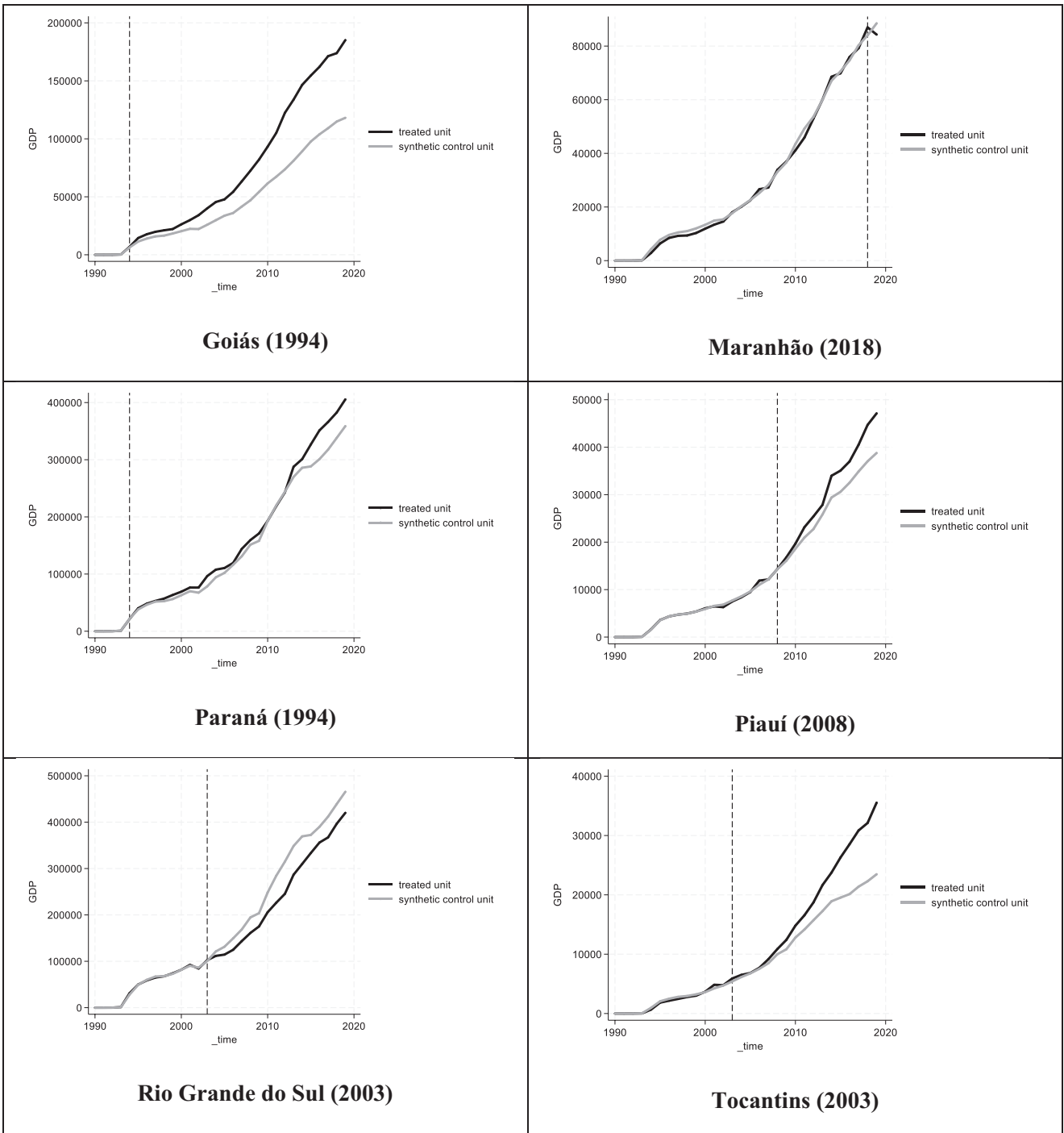


FIGURE A1 | GDP in Goiás, Maranhão, Paraná, Piauí, Rio Grande do Sul and Tocantins (3% of the GDP used as threshold for identifying the treatment year). *Source:* Authors' calculation from the dataset.

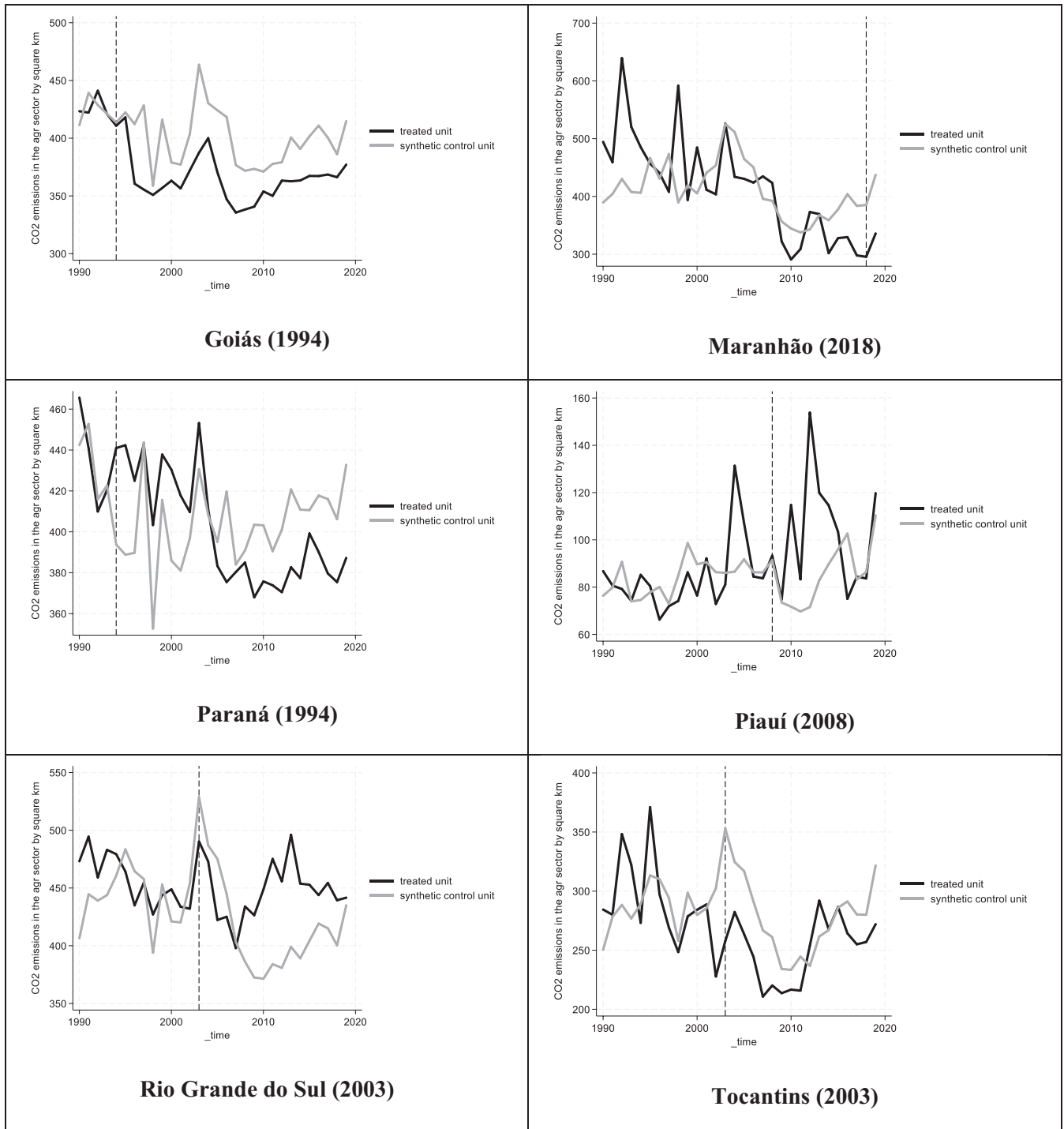


FIGURE A2 | CO₂ emissions in Goiás, Maranhão, Paraná, Piauí, Rio Grande do Sul and Tocantins (3% of the GDP used as threshold for identifying the treatment year). *Source:* Authors' calculation from the dataset.

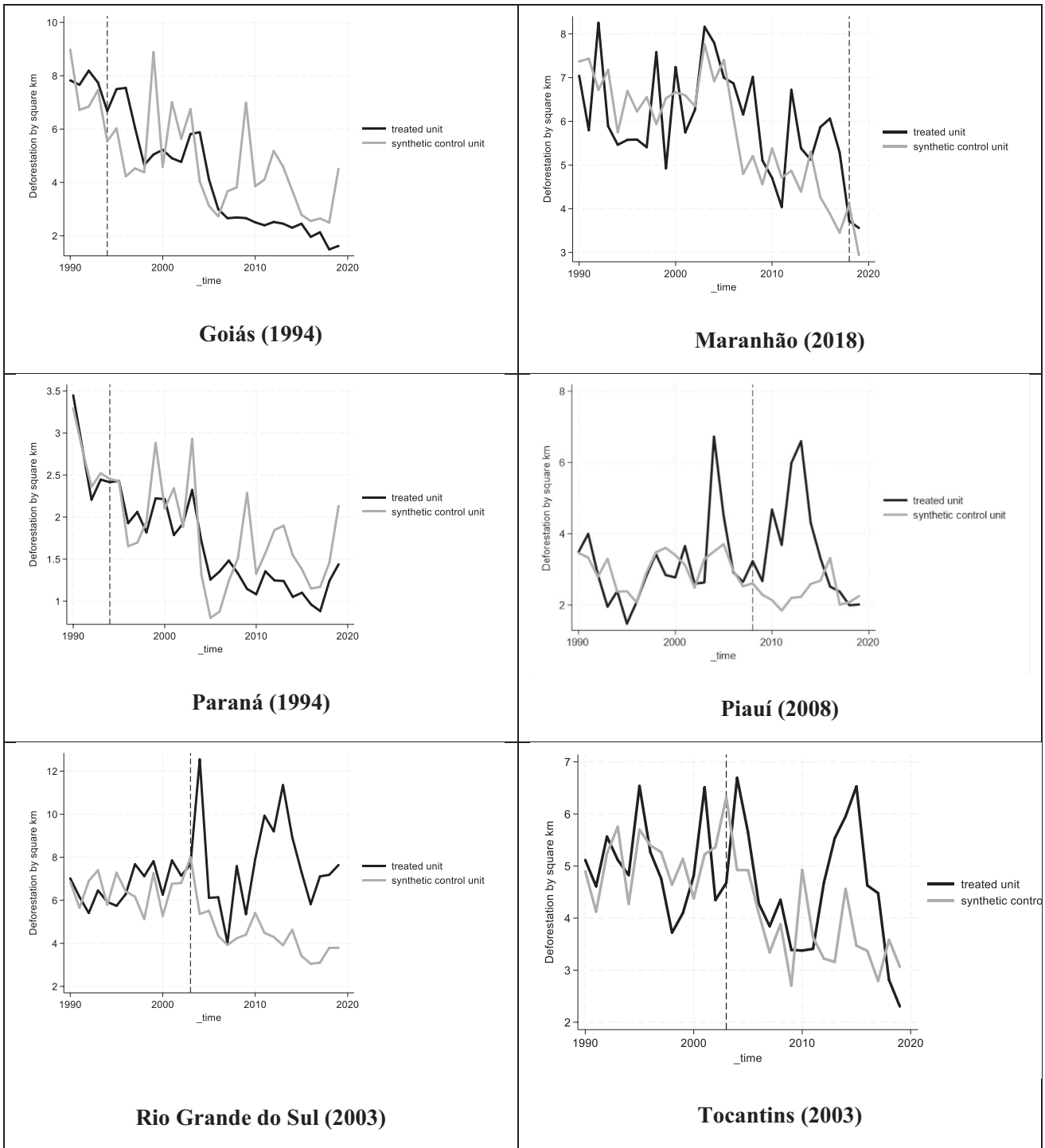


FIGURE A3 | Deforestation in Goiás, Maranhão, Paraná, Piauí, Rio Grande do Sul and Tocantins (3% of the GDP used as threshold for identifying the treatment year). *Source:* Authors' calculation from the dataset.

TABLE A3 | (Continued)

| Indicator | State (treatment year) | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|------------------------|------|------|-------|--------|-----------|-----------|-----------|-----------|-----------|-----------|----------|----------|------|
| CO ₂ emissions (tons per sq. km) | Goiás (1994) | | | | | | | | | | -10.6* | | | |
| | Maranhão (2018) | | | | | | | | | | | | | |
| | Paraná (1994) | | | | | | | | | | | | | |
| | Piauí (2008) | | | 59.9* | | 115.0**** | 44.7**** | | | | -26.9* | | | |
| | Rio Grande (2003) | | | | 22.8* | 18.1* | 23.0**** | | | | | | | |
| | Tocantins (2003) | | | | | | | | | | | | | |
| Deforestation (sq. km per 1000 sq. km) | Goiás (1994) | | | | | | | | | | | | | |
| | Maranhão (2018) | | | | | | | | | | | | | |
| | Paraná (1994) | | | | | | | | | | | | | |
| | Piauí (2008) | | | | 118.8* | | 172.1**** | 195.4**** | | | | | | |
| | Rio Grande (2003) | | | | | 125.9**** | 118.7**** | 192.5**** | 101.4**** | 116.0**** | 126.0**** | 91.7**** | 99.4**** | |
| | Tocantins (2003) | | | | | | | 80.7**** | | 95.1**** | 62.9**** | | | |

Note: ****, ** and * refer to the 1%, 5% and 10% significance levels, respectively. The cells coloured in grey indicate that the state had not yet been treated in that year. The table only reports the differences that are significant. Green values are positive and red values are negative.

Source: Authors' calculation from the dataset.

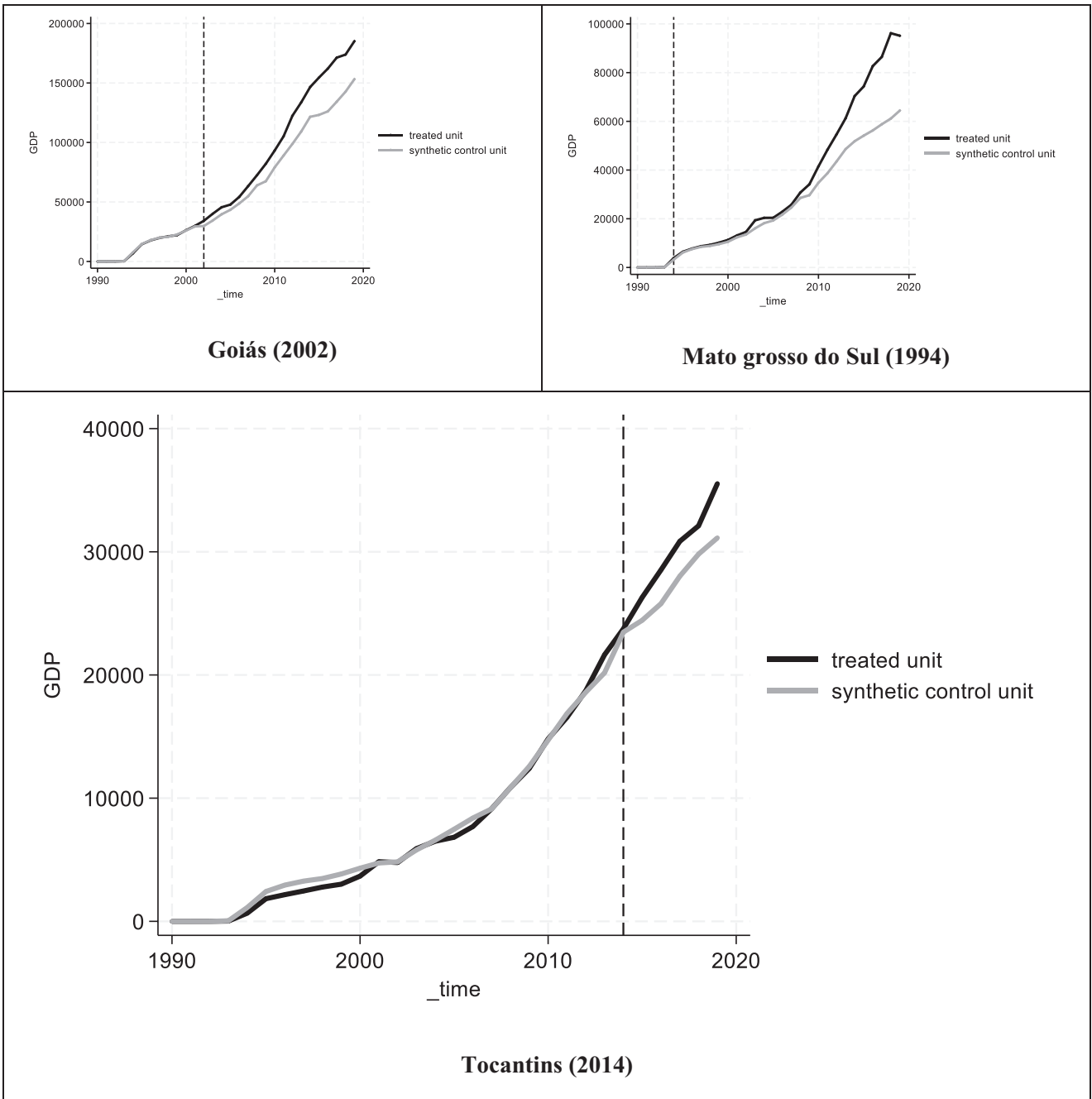


FIGURE A4 | GDP in Goiás, Paraná and Tocantins (7% of the GDP used as threshold for identifying the treatment year). Piauí and Rio Grande do Sul were not available as they did not reach the threshold during the study period. *Source:* Authors' calculation from the dataset.

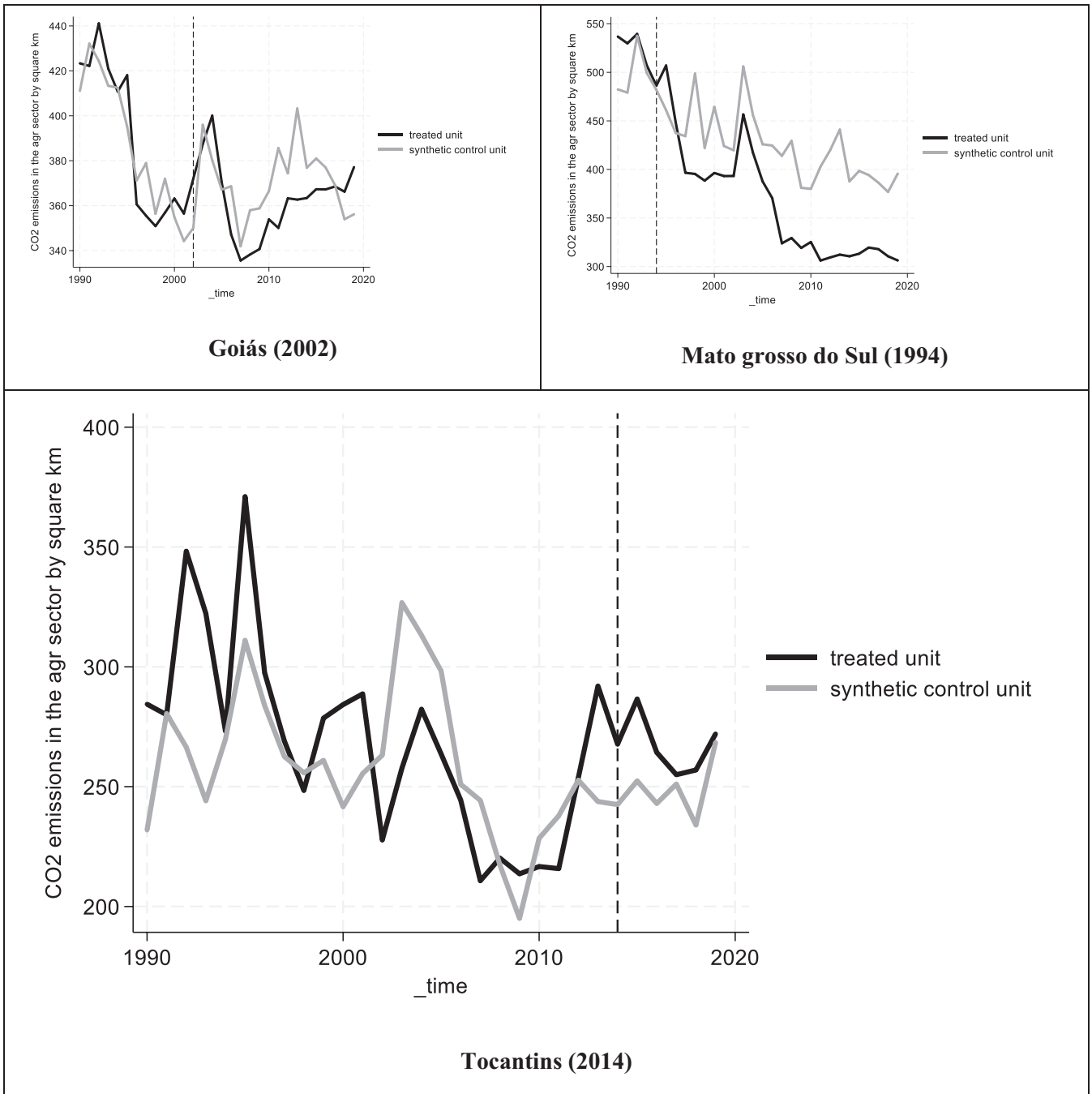


FIGURE A5 | CO₂ emissions in Goiás, Paraná and Tocantins (7% of the GDP used as threshold for identifying the treatment year). Piauí and Rio Grande do Sul were not available as they did not reach the threshold during the study period. *Source:* Authors' calculation from the dataset.

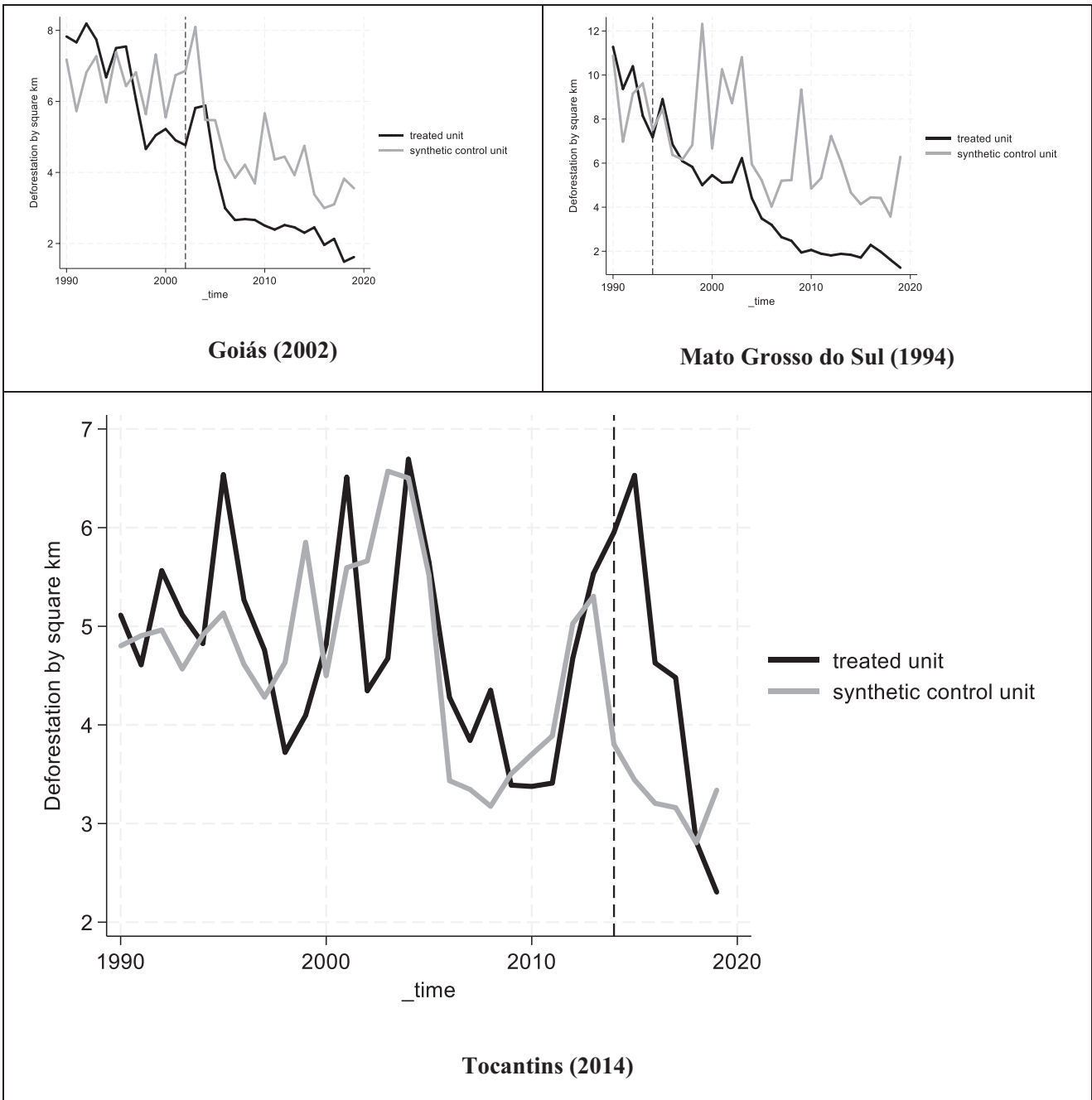


FIGURE A6 | Deforestation in Goiás, Paraná and Tocantins (7% of the GDP used as threshold for identifying the treatment year). Piauí and Rio Grande do Sul were available since they did not reach the threshold during the study period. *Source:* Authors' calculation from the dataset.

TABLE A4 | Difference between the observed and synthetic values of the outcome indicators, and significance of the difference (7% of the GDP used as threshold for identifying the treatment year).

| Indicator | State (treatment year) | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---------------------------|-----------|---------|---------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|--------|--------|
| GDP (1000.000 R\$) | Goiás (2002) | | | | | | | | | 4363** | | | | |
| | Mato Grosso do Sul (1994) | 639* | | | | | | | | | 3276*** | 2175** | | |
| | Tocantins (2014) | | | | | | | | | | | | | |
| CO ₂ emissions (tons per sq. km) | Goiás (2002) | | | | | | | | | | | | | |
| | Mato Grosso do Sul (1994) | | | | | | | | | | | | | |
| | Tocantins (2014) | | | | | | | | | | | | | |
| Deforestation (sq. km per 1000 sq. km) | Goiás (2002) | | | | | | | | | | | | | |
| | Mato Grosso do Sul (1994) | 0.5* | | | -0.1** | -1.0*** | -7.3* | | | | | -1.5* | -1.7** | -0.8** |
| | Tocantins (2014) | | | | | | | | | | | | | |
| Indicator | State (treatment year) | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| GDP (1000.000 R\$) | Goiás (2002) | 14,680*** | 14,182* | | | | | | | 31,384* | 35,966* | 37,032* | | |
| | Mato Grosso do Sul (1994) | 4470* | 6699** | 9650** | 11,124** | 12,655** | 18,532** | 20,188** | 26,413*** | 27,645*** | 35,046*** | 30,690*** | | |
| | Tocantins (2014) | | | | | | | | | | | | | |
| CO ₂ emissions (tons per sq. km) | Goiás (2002) | | | | | | | | | | | | | |
| | Mato Grosso do Sul (1994) | | | | | | | | | | | | | |
| | Tocantins (2014) | | | | | | | | | | | | | |
| Deforestation (sq. km per 1000 sq. km) | Goiás (2002) | | | | | | | | | | | | | |
| | Mato Grosso do Sul (1994) | -2.6** | -2.8* | -2.8*** | -3.4** | -5.4* | -4.2** | -2.8*** | -2.4** | -2.4* | -2.0* | -2.7* | | |
| | Tocantins (2014) | | | | | | | | | | | | | |
| GDP (1000.000 R\$) | Goiás (2002) | | | | | | | | | | | | | |
| | Mato Grosso do Sul (1994) | | | | | | | | | | | | | |
| | Tocantins (2014) | | | | | | | | | | | | | |

Note: ***, ** and * refer to the 1%, 5% and 10% significance levels, respectively. The cells coloured in grey indicate that the state had not yet been treated in that year. The table only reports the differences that are significant. Green values are positive and red values are negative.

Source: Authors' calculation from the dataset.

