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Impact of Pronaf on soybean production in Paraná and Rio Grande do Sul

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Abstract. This study analyzed the effects of coverage under the National Program for Strength-ening Family Farming (Pronaf) on soybean production in the municipalities of Paraná and Rio Grande do Sul in 2022. Using the Generalized Propensity Score (GPS) method with municipal-level data, Pronaf coverage was treated as a continuous vari-able to estimate the dose-response function. The results show an inverted U-shaped relationship, meaning that access to credit initially increases soybean production, but the effects diminish at higher coverage levels, providing an optimal efficiency point. Regional contrasts between states highlight the need for territorially sensitive policies and the integration of Pronaf with complementary measures to increase the program's effectiveness.
Keywords. Family Farming; Pronaf; Soy; Dose-Response Function; Generalized Propensity Score.
JEL. Q02; Q11; Q13; Q18.

1. Introduction

Brazilian agricultural production plays a central role in the country's economic development, consolidat-ing its position as one of the most dynamic and competitive in the world. Brazil is among the largest global exporters of several commodities, such as soybeans, which in the 2023/2024 harvest produced approximately 147,382 tons and planted 46,029.8 hectares, thanks to tech-nological innovation and favorable soil and climate conditions (National Supply Company - CONAB, 2024).

In this context, the analysis by Buainain et al. (2014) highlights that public policies aimed at developing the agricultural sector play a strategic role, especially those related to production financing. Rural credit, in addition to facilitating access to inputs, technologies, and technical services, becomes an essential instrument for increasing productivity, reducing regional inequalities, and strengthening family farming. Among the most relevant public sup-port policies is the National Program for Strengthening Family Farming (Pronaf), created in 1996, which became a concrete attempt by the State to democratize access to credit for family farming (Bianchini, 2015; Mattei, 2014; Schneider, 2003).

Historically, access to rural credit in Brazil has been concentrated among large produc-ers and in more developed regions, such as the South, and with

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less reach among the poorest and most vulnerable farmers, as is the case in the Northeast. This dynamic has contributed to the reproduction of structural inequalities in rural areas, as public financial resources have, for decades, been channeled primarily to producers already inserted in structured production chains and with greater investment capacity (Machado et al., 2022).

According to Leite and Wesz Junior (2015), rural credit policies in Brazil tend to cen-tralize access. This characteristic has been evidenced in Agricultural Censuses since 1960, which show an emphasis on large producers, especially those with larger land areas. Further-more, the authors highlight that certain products, such as soybeans, and the southern region of the country stand out in this context. A significant concentration in the average value of rural credit contracts is also observed. Based on data from the Central Bank of Brazil (BACEN, 2022), the value of rural credit contracts in Brazil was approximately R$361,585 million, but the region with the highest value was the South, with approximately R$116,457 million in contracts, of which R$35,944 million was allocated to soybean production.

At the same time, the strategic importance of soybeans in the Brazilian agricultural sec-tor is highlighted. As Brazil's main export crop, soybeans play a crucial role in the production and revenues of the country's agricultural sector. Their contribution to the national economy is extremely significant (Vieira Filho, 2024). The states of Paraná and Rio Grande do Sul have historically stood out as major soybean producers, due to a combination of factors such as advanced mechanization and a well-structured technical and financial support system. Ac-cording to information from CONAB (2023a), the states of Paraná and Rio Grande do Sul, when analyzed together, accounted for approximately 30% of soybean production in Brazil in 2022. Paraná stood out as the second-largest producer of the grain in the country, behind only Mato Grosso, while Rio Grande do Sul ranked fifth.

However, despite the strong presence of medium- and large-scale rural producers in the South, family farming also plays a significant role in this grain production chain, especially in regions where soybean cultivation has been adapted to smaller scales with the help of rural credit. In these cases, Pronaf has acted as a driving force for productivity, enabling access to improved seeds, fertilizers, small-scale machinery, and sustainable management practices (Conterato & Bráz, 2019; Noskoski et al., 2024; Stamm & Avelar, 2019).

Considering these facts, Pronaf was designed as an institutional response to the finan-cial exclusion that exists in rural areas, seeking to promote support for family farming through credit lines tailored to the productive and socioeconomic profile of these farmers (Bianchini, 2015; Mattei, 2014; Ramos & Martha Junior, 2010; Schneider, 2003). Therefore, despite the significant advances provided by Pronaf, recent evidence suggests that there are still signifi-cant inequalities in access to the program, both among types of farmers and between regions of the country.

More recent studies, such as those by Alves et al. (2025), Araújo et al. (2020), and Ma-chado et al. (2022), have shown that Pronaf resources remain heavily concentrated in southern Brazil, a region that, although representing a significant portion of Brazilian family farming, already has a more consolidated productive structure compared to other regions, such as the North and Northeast. This reality raises questions about the program's effectiveness in reduc-ing regional disparities in access to rural credit and promoting broader inclusion of vulnerable producers.

Analyzing the production of soybeans, the country's main export crop, in regions with high access to credit, such as Paraná and Rio Grande do Sul, allows us to investigate the ex-tent to which rural credit has been a driver of productive development. By investigating the relationship between the intensity of access to Pronaf and soybean production in these two states, we seek to contribute empirical evidence that can support more effective public policies that are sensitive to regional inequalities.

Therefore, the main objective of this study is to evaluate the impacts of Pronaf cover-age on soybean production in the municipalities of Paraná and Rio Grande do Sul in 2022. To this end, we used the Generalized Propensity Score (GPS) method, which allows us to esti-mate the impacts of rural credit on variables such as production, considering different levels of credit access intensity. GPS is particularly effective for causality analyses, as it controls for potential selection biases and observable heterogeneity, ensuring more robust and reliable re-sults.

In addition to this introduction, this study consists of four sections. The second section presents the literature review. The third section presents the methodology used. The fourth section presents the analysis and discussion of the results. And the fifth section presents the work's concluding remarks.

2. Literature review

2.1. Rural credit and its importance for Brazilian family farming

Over the past few decades, rural credit has established itself as one of the main public policy instruments aimed at agricultural development in Brazil. Since the creation of the Na-tional Rural Credit System (SNCR) in 1965, the policy's main objective has been to finance productive activities in rural areas, facilitate access to technologies, and contribute to in-creased productivity (Amaral & Bacha, 2025). Although these principles guided the system, its initial operation proved highly concentrated. The greatest beneficiaries were producers with greater economic capacity, located in the country's most developed regions, which, conse-quently, accentuated regional and social inequalities in rural areas (Araújo, 2011).

Beginning in 1990, the Brazilian state underwent a reconfiguration of agricultural poli-cies, reducing the direct state presence in financing the sector and opening it up to private par-ticipation (Buainain et al., 2014; Ramos & Martha Junior, 2010). In this new scenario, small farmers, already historically marginalized, began to face even greater difficulties in accessing the financial resources necessary to finance and invest in their activities. It was in this context of structural exclusion that the need to create a program focused exclusively on family farm-ing became clear (Bianchini, 2015; Ramos & Martha Júnior, 2010; Schneider, 2003).

In this context, in early 1996, small farmers began to receive greater assistance with ru-ral credit through the creation of the National Program for Strengthening Family Farming (Pronaf). The proposal arose from a growing social demand for policies to combat rural pov-erty and was driven by a joint study conducted by the Food and Agriculture Organization of the United Nations (FAO) and the National Institute for Colonization and Agrarian Reform (INCRA). This research highlighted the economic importance of family farming, revealing its relevance in food production and land use in the country, in addition to demonstrating the need for public policies that promote its productive inclusion (Belik, 2015; Schneider, 2010).

In Brazil, family farming is an essential segment from both an economic and social per-spective. According to the Family Farming Law (No. 11,326/2006), a family farmer is one who develops activities in rural areas under family management, primarily using family labor, in an area of up to four fiscal modules, and whose family income comes predominantly from activities carried out on the farm itself (BRASIL, 2021). According to the 2017 Agricultural Census, approximately 76.8% of Brazilian agricultural establishments were classified as fami-ly-owned (Brazilian Institute of Geography and Statistics - IBGE, 2017).

This universe, however, is marked by strong heterogeneity, with the South, Southeast, and Central-West regions concentrating the most capitalized, technologically advanced, and organized family farmers, while the North and Northeast are home to the majority of produc-ers with less access to credit, less education, and greater economic vulnerability (Besley, 1994; Bianchini, 2015; Mattei, 2014; Souza et al., 2013). This regional and structural diversity poses challenges to the formulation of public policies that are both broad and tailored to the reality of the different producer profiles.

Since its inception, Pronaf has undergone significant restructuring to address the diver-sity of Brazilian family farming. Beginning in 1999, the Central Bank of Brazil began classify-ing program beneficiaries into different groups based on annual gross family income, allowing for better adaptation of financing lines to producers' needs. This division included groups A, B, C, D, A/C, and E, which were adjusted over time according to the harvest plan (Schneider et al., 2004).

Group A was intended for farmers settled under agrarian reform and beneficiaries of the National Land Credit Program. Group B, in turn, was targeted at farmers with an annual gross family income of up to R$2,000, targeting the most impoverished segment of family farming, often living in extreme poverty (Schneider et al., 2004).

Groups C and D were targeted at farmers in transition, with annual gross family in-comes ranging from R$2,000 to R$14,000 (Group C) and between R$14,000 and R$40,000 (Group D), representing producers with increasing levels of capitalization. Group A/C was created in 2000 to serve farmers who first took out credit through Group A and subsequently began taking out financing (Schneider et al., 2004).

During the 2004-2005 period, the Harvest Plan established Group E, corresponding to the expanded reproduction level. However, starting with the 2008-2009 Harvest Plan, the groups known as C, D, and E were replaced by Group V. This group began to include the most capitalized family farmers, who do not fit the conditions of the other groups, but who still maintain the productive profile of family farming (Del Grossi et al., 2019; Wesz Junior, 2010)

Access to Pronaf requires farmers to have a Declaration of Eligibility for Pronaf (DAP), an instrument that was replaced by the National Registry of Family Farming (CAF) (BRASIL, 2017). Among the best-known lines are Pronaf Custeio, aimed at the acquisition of inputs and maintenance of production, Pronaf Investimento, aimed at the acquisition of ma-chinery and equipment, and also Pronaf B, characterized as a oriented productive microcredit, focused on lower-income farmers (Bianchini, 2015).

Despite the progress achieved, the distribution of Pronaf resources remains uneven. Studies such as those by Alves et al. (2025), Aquino et al. (2014), Araújo et al. (2020), Bianchini (2015), Machado et al. (2022), Mattei (2014) and Souza et al. (2013) indicate that credit agreements are concentrated mainly in the southern region of the country, where family farmers have a greater degree of social organization, access to cooperatives, and improved infrastructure. In contrast, the authors point out that farmers in the Northeast face historical obstacles to accessing the program, including the absence of bank branches, low institutional reach, and rigid access criteria.

This inequality within Pronaf's target audience reveals a paradox: although the program was created to promote social justice in rural areas, it has not yet managed to serve the most vulnerable farmers with the same effectiveness. This does not mean the program has failed. On the contrary, as Mattei (2005) points out, in less than a decade since its creation, Pronaf has become a benchmark among financing policies for the family farming sector. However, data and local experiences show that there is still a long way to go to ensure that rural credit fully fulfills its role of productive inclusion.

Therefore, understanding the functioning, scope and limitations of Pronaf, with atten-tion to regional and social disparities in access, is essential to improving this public policy.

2.2. Summary of soybean production in Brazil

Soybeans play a central role in Brazilian agricultural dynamics and are the country's main agricultural commodity, both in terms of cultivated area and production value, account-ing for a significant portion of agribusiness exports. This expansion has been fueled by factors such as public policies, technological advances, and the adaptation of cultivars to tropical conditions, as well as growing demand in the international market, especially from China (CONAB, 2021; Hirakuri et al., 2014).

In recent years, Brazil has established itself as the world's largest soybean producer, with more than 154 million tons harvested in the 2022/2023 harvest (CONAB, 2023b). The crop is present in all regions, but is particularly significant in the Central-West, Southeast, and South regions. The states of Paraná and Rio Grande do Sul, in this context, occupy prominent positions not only for the volume produced but also for the significant presence of family farmers who cultivate the oilseed (IBGE, 2017; Liszbinski et al., 2021).

The Paraná states remains among the states with the highest soybean productivity, benefiting from consolidated technical and institutional networks, and becoming the second largest soybean producer in the country, with a production of more than 21 million tons in 2022. Rio Grande do Sul presented a production of around 13 million tons in the same period (CONAB, 2023a).

According to the latest Agricultural Census of 2017, Rio Grande do Sul registered the largest number of family-owned soybean-producing farms in the country, with over 95,000, followed by Paraná with over 84,000 (IBGE, 2017). On many of these farms, soybeans occu-py a significant portion of the cultivated area and constitute the basis of the family's annual income (Liszbinski et al., 2021).

The soybean production on small properties faces economic limitations. Bazotti et al. (2017) found that, in units with fewer hectares of production, the crop tends to have narrow or even negative financial margins due to high costs and low production scale. Economic via-bility, in these cases, is often compromised, although producers remain in the activity. One reason for this is the ease of marketing and access to rural credit through the National Program for Strengthening Family Farming (Pronaf), which reduces entry costs and mitigates some of the production risks.

According to a study by Wesz Junior & Bueno (2008), soybeans continue to be cul-tivated in the Missões region of Rio Grande do Sul, even in low-profit situations. This is large-ly due to financing from Pronaf, which covers most of the production costs for family farm-ers. The data showed that, in this region, over 80% of the program's financing contracts are for soybeans, and 63% of producers say they would not plant without this financial support.

Access to Pronaf not only makes soybean cultivation viable but also offers protection mechanisms, such as Proagro Mais, an agricultural insurance program designed to cover losses in the event of adverse weather conditions. Even so, dependence on credit and low produc-tion scale keep farmers vulnerable to market fluctuations and adverse conditions, which can lead to recurring debt and difficulty in maintaining cultivation without new annual financing arrangements (Wesz Junior & Bueno, 2008).

It is important to highlight that, despite its national scope, Pronaf presents a strong re-gional concentration. Most of the contracts and credit volume are in the South, Southeast, and Central-West regions, where family farmers have better structural conditions, greater social organization, and access to banking services. In contrast, regions such as the North and North-east, which concentrate a significant portion of the most vulnerable family farmers, still face limited access to the program, as shown in the literature by Aquino et al. (2014), Bianchini (2015), and Mattei (2014). This unequal distribution of credit reveals one of the main chal-lenges faced by public policy: increasing its effectiveness in areas with greater socioeconomic and productive deprivation.

Therefore, the persistence of soybean production on small rural properties cannot be in-terpreted solely as a sign of productive success, but rather as a complex combination of fac-tors, such as ease of product distribution, institutional presence, regional agricultural culture, and the availability of financing. However, when cultivated on a very small scale, without qualified technical assistance or diversification strategies, it can limit families' income options and generate excessive dependence on credit.

Family farming plays an important role in soybean production, especially in the southern states, where the presence of cooperatives and market presence favor its continued existence. Even so, its economic sustainability depends on policies that, in addition to credit, promote access to innovation, training, and commercial stability. Therefore, assessing the impacts of access to Pronaf in this context is essential to understanding which measures have actually contributed to strengthening family soybean production and which limitations still need to be addressed.

3. Methodology

3.1. Empirical strategy

This study aims to estimate the effects of credit coverage from the National Program for Strengthening Family Farming (Pronaf) on soybean production in municipalities in the states of Paraná and Rio Grande do Sul, based on data from 2022. The empirical strategy adopted considers that municipalities are exposed to different levels of intensity of access to rural credit via Pronaf, represented by a continuous treatment variable, the Pronaf coverage rate.

This variable is constructed as the ratio between the number of producers who accessed Pronaf and the total number of soybean-producing establishments in each municipality. Because it is a continuous and proportional variable, ranging from zero to one, a nonparametric approach was chosen, based on the Generalized Propensity Score (GPS), as proposed by Hirano & Imbens (2004) and operationalized by Guardabascio & Ventura (2014), to estimate the causal effects of continuous treatment on the outcome variable, which is the quantity of soybean produced in the municipalities analyzed. The closer to unity, the greater the coverage of family farms within the municipality that accessed Pronaf credit. Therefore, the treatment effect may vary depending on the level of treatment.

The GPS method allows estimating the dose-response function between different levels of credit access and the variable of interest, controlling for observable characteristics that may simultaneously influence credit access and agricultural production. This approach is especially useful for addressing potential nonlinearity in the treatment effect and avoiding biases resulting from the omission of observed covariates.

The Generalized Propensity Score (GPS) methodology consists of three main steps:

a) Generalized Propensity Score (GPS) Estimation:

In the first step, the generalized propensity score R is estimated using a regression model of the continuous treatment variable on a vector of covariates X. According to Guardabascio & Ventura (2014), since the treatment variable T[0,1] is a fraction, the Bernoulli Quasi-Maximum Likelihood (QML) function with logit specification is applied. The maximized likelihood function is given by:

$$l_i(\beta) \equiv T_i \, log \, log \, \{F(\beta' X_i)\} + (1 - T_i) \, log \, log \, \{1 - F(\beta' X_i)\} \quad (1)$$

where F(·) is the cumulative logistic function, xi represents the vector of covariates for municipality i, and ti is the observed level of treatment.

The generalized propensity score for each unit is obtained by the conditional expectation:

$$\hat{R}_i = E[T_i \mid X_i] = F[\hat{\beta}' X_i] \quad (2)$$

This step also includes balancing tests of covariates between the different treatment levels, as described by Guardabascio e Ventura (2014)[2].

b) Estimation of the conditional dose-response function:

[2] The covariate balancing test was conducted according to the methodology described by Guardabascio and Ventura (2014), who proposes a five-step procedure. In this analysis, the treatment variable was divided into four intensity bands (k = 4), and the estimated propensity score values were segmented into five intervals (nq = 5) within each group, in order to verify the homogeneity of the covariates between the defined strata.

In the second step, the conditional expectation of the outcome variable, Y_i, in this case, the quantity of soybeans produced, is estimated as a flexible function of the treatment level, T_i, and the estimated score, $\hat{R}_i$, using a second-order polynomial approximation:

$$\varphi\{E(Y_i|T_i, R_i)\} = \alpha_0 + \alpha_1 T_i + \alpha_2 T_i^2 + \alpha_3 R_i + \alpha_4 R_i^2 + \alpha_5 T_i R_i \quad (3)$$

where $\varphi(.)$ is the identity function, assuming linearity between the parameters and the conditional expectation.

c) Estimation of the mean dose-response function:

Finally, the mean dose-response function is calculated by averaging the estimated regression function for different treatment levels:

$$E[\hat{Y}_i(t)] = \frac{1}{N}\sum_{i=1}^{N}[\hat{\alpha}_0 + \hat{\alpha}_1 T_i + \hat{\alpha}_2 T_i^2 + \hat{\alpha}_3 \hat{R}_i + \hat{\alpha}_4 \hat{R}_i^2 + \hat{\alpha}_5 T_i \hat{R}_i] \quad (4)$$

where N represents the number of observations (municipalities), the parameters $\hat{\alpha}$ are obtained in the second stage and $\hat{R}$ is the predicted value of the conditional treatment density at different treatment levels.

Based on this empirical strategy, the dose-response function associated with different levels of coverage of access to rural credit via Pronaf was estimated, in order to evaluate its effects on the quantity of soybean produced in the municipalities of Paraná and Rio Grande do Sul in 2022.

3.2. Data

The information used in this study comes from public databases at the municipal level. The analysis period is 2022, chosen because it represents the last year with consolidated in-formation on access to credit via Pronaf, as well as data on agricultural production and climate variables. The variables used refer exclusively to the universe of family farmers who had ac-cess to Pronaf in 2022, based on the criteria established by Law No. 11,326/2006 and the classifications adopted by the Brazilian Institute of Geography and Statistics (IBGE) and the Ministry of Agrarian Development and Family Farming (MDA)

The treatment variable, Pronaf coverage rate, was constructed as the ratio between the number of producers who accessed Pronaf in 2022 and the total number of soybean-producing establishments in the municipality. Information on soybean-producing establishments was ex-tracted from the 2017 Agricultural Census, while data on Pronaf access were obtained from the Ministry of Agrarian Development and Family Farming (MDA). The construction of this variable allowed us to represent the intensity of access to rural credit in the municipalities ana-lyzed, continuously and proportionally, with values between zero and one.

The dependent variable of the study is the quantity of soybean produced (in tons), ob-tained through the Municipal Agricultural Survey (PAM), available in the IBGE Automatic Recovery System (SIDRA). This variable represents the main economic outcome on which the effect of the treatment variable is estimated.

The vector of observable covariates X, used to calculate the generalized propensity score, includes production and climate information for the municipalities. The variables used were the harvested soybean area, obtained through the Municipal Agricultural Survey (PAM), available in the IBGE Automatic Recovery System (SIDRA), temperature and rainfall ob-tained from the National Institute of Meteorology (INMET), and the total number of family farmers registered to receive Pronaf, represented by the Declaration of Eligibility for the Na-tional Program to Strengthen Family Farming (DAP), obtained through the Ministry of Agrar-ian Development and Family Farming (MDA).

All of these variables were weighted relative to the total number of establishments in the municipalities, adopting the methodology employed by studies such as those by Helfand et al. (2015) and Sobreira et al. (2024), which treat municipalities as representative production units based on municipal averages. This procedure seeks to ensure comparability between mu-nicipalities and mitigate distortions associated with the heterogeneity of individual units.

Thus, this set of variables allows us to capture the main structural and conjunctural di-mensions that influence both access to Pronaf credit and productive results, ensuring the ro-bustness of the generalized propensity score model adopted in this study.

4. Results

4.1. Descriptive statistics

Before evaluating the dose-response functions of access to Pronaf on soybean produc-tion, it is important to understand the context in which these family farmers operate. Evaluat-ing the descriptive statistics in Table 1 for the 321 municipalities in Paraná and the 364 munic-ipalities in Rio Grande do Sul that accessed Pronaf in 2022, we observe some significant dif-ferences, both in the production profile and in the structural conditions of each region.

When analyzing average soybean production, Paraná stands out, with approximately 40,000 tons per municipality, while Rio Grande do Sul has an average of slightly more than 25,000 tons, which confirms the presence of highly productive municipalities and others with much more modest performance. Paraná also had the largest harvested area, with an average of 17,175 hectares per municipality, while Rio Grande do Sul averaged around 16,799 hec-tares. Therefore, these results demonstrate that the scale of production varies greatly among municipalities.

Regarding structure, one striking statistic was the average number of active Pronaf El-igibility Declarations (DAP). In Paraná, the average was around 41 per municipality. In Rio Grande do Sul, this number more than doubled, reaching 104. This may indicate a stronger presence of family farming in the state, at least in terms of formalization and Pronaf participa-tion. However, when comparing this data with production and harvested area, it becomes clear that greater formalization does not always translate into a larger production scale.

From a climatic perspective, the results showed that conditions vary, as expected. Pa-raná had an average annual temperature of 21.2°C, while Rio Grande do Sul was slightly cooler, averaging 19.9°C. Regarding rainfall, the situation is reversed, with 1,712 mm in Rio Grande do Sul versus 1,467 mm in Paraná. Although these differences may seem small, they can significantly impact soybean productivity, especially in regions with less irrigation infra-structure.

Given this context, the results showed that the two states have distinct profiles. Paraná stood out for its production scale and more robust average results. While Rio Grande do Sul had a higher density of formalized family farmers, it had a lower average production. These contrasts reinforce the importance of analyzing the effects of Pronaf credit with attention to regional specificities.

Table 1. *Descriptive Statistics*

Descriptive Statistic – Paraná State				
Variable	Maen	D E	Mín	Máx
Production (ton.)	40.688,5	49.199,4	255	379.780
harvested area (ha)	17.175,3	14.931,6	360	100.700
PRainfall (mm)	1.467	234	1.000	1.829
Temperature (°C)	21,2	2,1	16,4	25,3
Actives DAP	41	45	0	372
Descriptive Statistic - Rio Grande do Sul State				
Variable	Maen	D E	Mín	Máx
Production (ton.)	25.307,7	34.592,9	80	255.850
Harvested ares (ha)	16.799,5	22.473,5	50	150.500
Rainfall (mm)	1.712	202	1.192	2.091
Temperature (°C)	19,9	1,2	16,4	22,3
Actives DAP	104	114	4	1.592

Note: Prepared by the authors.

In the following subsection, estimates of the estimated effects of access to Pronaf on soybean production in the municipalities of Paraná and Rio Grande do Sul are discussed, based on the application of the Generalized Propensity Score (GPS) method.

4.2. Dose-response function estimation

The treatment variable corresponds to the Pronaf coverage rate, measured as the per-centage of soybean producers with access to program credit in 2022. Because this is a contin-uous variable, an approach is adopted that allows estimating the effects of the treatment across different levels of intensity, as suggested by Hirano & Imbens (2004) and operation-alized by Guardabascio & Ventura (2014).

The generalized propensity score estimation was conducted using a generalized linear model with a logit link function and binomial distribution. This model allows estimating, for each municipality, the conditional probability of observing a given level of treatment, given observable characteristics such as harvested area, number of active DAPs, temperature, and rainfall.

The model results indicated a significant statistical fit in both states. In Paraná, the de-viance/df value was 0.2338, and the AIC was around 1.02. In Rio Grande do Sul, the indices were slightly better, resulting in 0.1643 for the deviance/df and 0.96 for the AIC. These re-sults suggest that the scores were well-evaluated, allowing them to be applied to estimate causal effects with greater reliability.

Regarding the Generalized Propensity Score (GPS) distributions, both states showed positive skewness. In Paraná, the values ranged from 0.3569 to 0.7762, with a mean of 0.4937 and an skewness of 0.90. In Rio Grande do Sul, scores ranged from 0.2431 to 0.9866, with a mean of 0.4689 and a skewness of 1.18. These variations are essential for capturing the mar-ginal effects of credit across different coverage levels, providing a robust basis for analyzing the dose-response function.

The quality of the Generalized Propensity Score (GPS) estimation was assessed based on covariate balancing tests. In both Paraná and Rio Grande do Sul, the treatment variable (Pronaf coverage rate) was divided into four groups (k = 4) and the propensity score values into five subgroups (nq = 5). In both states, conditional mean difference tests indicated that the covariate balancing property was met at the 1% significance level, according to the Guardabascio & Ventura (2014) criterion.

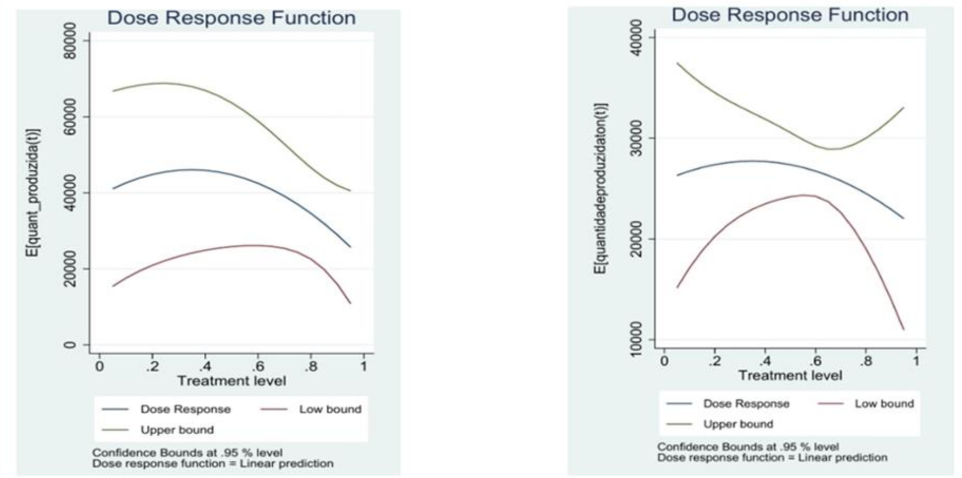
Although some variables showed marginal differences in certain groups, the overall evidence indicates that the GPS was effective in approximating the comparison groups, allow-ing the estimation of the average causal effect of the treatment.

The estimated dose-response functions for both states exhibited an inverted U-shaped pattern. Soybean production increases as the Pronaf coverage rate increases, reaching a peak around 0.4 to 0.5 coverage. After this point, the effects begin to diminish. This pattern indi-cates that credit exerts a stronger impact when it reaches an intermediate coverage level, pos-sibly related to an optimal combination of access to financing and productive response capaci-ty. Above this point, additional returns appear to be reduced, which may signal saturation or inefficiencies in credit use at very high levels (Figure 1).

These results corroborate evidence from more recent studies on the topic, such as those by Alves et al. (2025), Araújo & Vieira Filho (2018), Cruz (2023), and Machado et al. (2022), who found that Pronaf needs to be adjusted due to its limitations and promote broad-er technical assistance to farmers who access credit, so that the program is more efficient in the country.

Furthermore, the distribution of the treatment variable reinforces this interpretation. In Paraná, the coverage rate had a mean of 0.4937, a standard deviation of 0.2358, slightly nega-tive skewness (-0.1469), and a kurtosis of 2.23. Meanwhile, in Rio Grande do Sul, the mean was 0.4689, with a standard deviation of 0.2236, skewness of 0.2022, and kurtosis of 2.47. These values suggest that most municipalities have a moderate propensity to access Pro-naf, with variations that allow us to observe effects across the entire distribution.

The Generalized Propensity Score (GPS) modeling was conducted using logistic re-gression, a structure suitable for binary variables and integrated with the generalized linear model. Indicators such as deviance, AIC, and BIC presented satisfactory values, reinforcing the adequacy of the predictive model. Among the main factors associated with access to Pro-naf, the most prominent were harvested area, the number of active DAPs, and rainfall. These factors help explain why some municipalities access more program resources than others. On the other hand, the temperature variable showed a negative association, suggesting that specif-ic climatic conditions may limit the reach of rural credit, whether due to productive or struc-tural factors.



(A) Dose-response effect in Paraná **(B) Dose-response effect in Rio Grande do Sul**

Figure 1. *Dose-Response Effects in Paraná and Rio Grande do Sul*
Note: Prepared by the authors.

The analysis of dose-response effects showed that increased Pronaf coverage is associ-ated with higher levels of soybean production in the municipalities of Paraná and Rio Grande do Sul. The effects are more intense at intermediate coverage levels, stabilizing at higher levels. This indicates that, as credit reaches a greater number of farmers, there is a significant boost in production, although marginal gains diminish after a certain point.

Therefore, the results obtained in this analysis reinforce the hypothesis that access to rural credit via Pronaf can play a significant role in the intensification of agricultural produc-tion, especially among soybean producers in the states of Paraná and Rio Grande do Sul. The inverted U-shape observed in the dose-response functions suggests that there is an optimal point of credit coverage, at which the positive effects on production are most intense. Beyond this point, marginal returns begin to diminish, which may indicate some structural limitations or challenges in the efficient use of resources.

In this context, although there are differences between states, the consistency in stand-ards reinforces the importance of policies that not only expand access to credit but also offer technical and strategic support so that this credit is transformed into real productivity. This evidence points to the need for a closer look at the quality of Pronaf use, especially in contexts where access is already high but productive gains are beginning to slow.

These results are consistent with the findings of the study by Barros et al. (2024), who analyzed municipalities in Northeast Brazil using the Generalized Propensity Score (GPS) method and found that increasing rural credit coverage can generate positive and significant effects on family farming productive variables. Therefore, these results indicate that expand-ing the reach of Pronaf can generate concrete gains in family farming production, even in re-gions with a high level of technological advancement.

Expanding the program's coverage, combined with complementary support strategies, can make the policy more effective for the productive inclusion of family farmers in produc-tion chains such as soybeans.

5. Conclusions

The results presented in this study reinforce the relevance of rural credit as a tool to stimulate agricultural production, especially in the context of family farming. When analyzing the impacts of access to Pronaf on the quantity of soybean production in the municipalities of Paraná and Rio Grande do Sul, a significant relationship was observed between the level of credit coverage and production results, although this relationship was not linear.

The dose-response functions indicated an inverted U-shaped pattern, with the impact of Pronaf on soybean production increasing as access to credit increases, until reaching an in-termediate level. Beyond this point, the positive effects begin to diminish. This suggests that there is an optimal coverage point, at which resources are used more efficiently and the pro-ductive response is more intense. Above this level, returns tend to decline, possibly due to limitations in production management, saturation of credit utilization capacity, or the lack of technical support proportional to the volume financed.

These results reinforce that expanding access to credit is not enough; it is also neces-sary to improve its application and coordinate Pronaf with other public policies, such as ongoing technical assistance, rural extension, market access, and infrastructure investments. Credit, when used alone, has a limited effect, but when well-structured and adapted to local condi-tions, it can become an important catalyst for rural development.

Furthermore, the regional differences observed in this analysis were also crucial in as-sessing the effects of access to Pronaf. The results demonstrated that Paraná stood out in terms of production scale, while Rio Grande do Sul had a higher density of formalized family farmers. These contrasts reinforce the importance of public policies tailored to the realities of each region, recognizing and respecting their productive, structural, and social specificities.

Despite the contributions of this study, some limitations should be acknowledged. The analysis was conducted using aggregated data at the municipal level, which, while useful for capturing regional patterns, can obscure important dynamics occurring at the individual estab-lishment level. Furthermore, the model did not consider qualitative aspects of credit, such as the type of credit line contracted, the amount actually accessed by the producer, or the availa-bility of technical assistance, factors that can strongly influence the results. Another limitation is the lack of control for specific cyclical shocks in 2022, such as extreme weather events, which may have impacted soybean production in some municipalities.

Given these limitations, future studies can advance our understanding of this topic by adopting microdata at the establishment or producer level, allowing for more refined analyses. It would also be pertinent to investigate the interaction between access to credit and other factors, such as technology employed, type of technical assistance received, and marketing methods. Impact assessments in different cultures and less-served regions, such as the North and Northeast, can also contribute to a more comprehensive and equitable view of the scope of Pronaf.

In summary, this study offers empirical evidence that Pronaf can boost soybean pro-duction in family farming, but that its effects depend on the context, local structure and, above all, on integrated management of public policies, and that access to the program is a challenge in this scenario.

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Validation	X	X	X	X
Formal analysis	X	X	X	X
Investigation	X	X	X	
Resources	X	X	X	X
Data curation	X	X		
Writing –original draft	X			
Writing –review & editing	X	X	X	X
Visualization	X	X	X	X
Supervision	X	X	X	X
Project administration	X	X	X	
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