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Assessment of rural credit in the Brazilian Amazon: role of the Northern Constitutional Financing Fund in rural development

Raysa Palheta Borges
Socioenvironmental and Water Resources Department, Federal Rural University of the Amazon (UFRA), Belém, Brazil

Wladimir Colman de Azevedo Junior
Department of Economics, Federal University of Mato Grosso (UFMT), Cuiaba, Brazil, and

Marcos Antônio Souza dos Santos and Marcos Rodrigues
Socioenvironmental and Water Resources Department, Federal Rural University of the Amazon (UFRA), Belém, Brazil

Abstract

Purpose – Resources provided by The Northern Brazilian Constitutional Financing Fund (FNO) aim to promote regional development to economically and socially backward regions through subsidized financial resources for economic activities, including agriculture. This study aims to determine whether rural credit and the FNO were able to produce structural changes in the distribution of financial resources and thus contribute to economic growth in Northern Brazilian municipalities.

Design/methodology/approach – This paper used inequality indexes and the Local Indicator of Spatial Association to verify the credit concentration and the spatial presence of clusters. To analyze the role of credit in promoting agricultural growth, this paper estimated an ordinary least squares regression with panel data for 450 municipalities during 1995–2017.

Findings – The results highlighted that rural credit, including the FNO, is essential to incentivizing agricultural production and increasing rural income. However, the financial resources are mostly captured by a small share of municipalities, spatially clustered in the expanding agricultural frontier of Pará, Tocantins and Rondônia states. Low-Low clusters are mainly present in the Western Amazonian region and are subject to structural and institutional constraints that reduce their demand for credit. The FNO resources proved insufficient to reduce financial inequality between Brazil's northern municipalities.

Originality/value – This study demonstrates that the FNO's policies are failing to reduce the concentration of financial resources in Amazonian agriculture. The results emphasize the importance of credit for development and, consequently, reducing inequality, which leads to a higher demand for financial resources by farmers. Implications include supporting economic agents with infrastructure and technical assistance, as well as improving farmers' access to the banking system.

Keywords Agricultural production, Cattle ranching, Concentration index, Panel data, Financial policy

Paper type Research paper

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1. Introduction

The Brazilian agricultural frontier has expanded rapidly over the Amazon since the 1960s through settlements incentivized by government policies (Coelho *et al.*, 2021; Fearnside, 2008; Maeda *et al.*, 2021). Infrastructure projects have made it easier to implement activities that focus on large-scale use of land and capital (Schielein *et al.*, 2021), such as agricultural commodities – mainly grains – and livestock (Vale *et al.*, 2019). To support Brazilian agriculture, including in the Amazon region, the "Official Rural Credit" provides financial resources with subsidized interest rates, allowing farmers to pay production costs and make investments, thus increasing household productivity and income (Leite *et al.*, 2023; Neves *et al.*, 2020).

Despite the agricultural growth in the Amazon, Brazilian territory is characterized by regional differences in terms of development, with more dynamic and wealthy areas in the South and Southeast, and the poorest and less developed areas mainly located in Northeast and Northern regions (Oliveira *et al.*, 2019). Created by the Brazilian constitution in the 1990s, the Constitutional Financing Funds are regulated by federal law n° 7827 / 1989; a percentage of federal taxes are allocated yearly to these funds as a source of credit to stimulate investment, generating employment and income (Macedo *et al.*, 2017). These funds aim to encourage the development of sustainable productive activities in rural and urban areas in the poorer regions, reducing the development gap between Brazilian regions.

The Northern Constitutional Financing Fund (FNO) [1] is intended to fund the seven states in Brazil's Northern region, which comprises the largest portion of the Brazilian Amazon, and is managed by public authorities –the Deliberative Council of the Superintendencies for the Development of the Amazon (SUDAM), the Ministry of Integration and Regional Development and the Banco da Amazônia S.A–. Part of the FNO's resources are directed to agricultural activities, complementing the "Official Rural Credit" through an application plan that is reviewed annually by the fund's management (Banco da Amazônia, 2023). Guidelines are drawn up to stimulate regional development considering that even within the Northern region there is significant heterogeneity between municipalities, prioritizing sustainable production systems.

The Northern region has the largest territorial extension in Brazil, low population density and precarious infrastructure, which make it difficult to attract private investment. The FNO, therefore, plays an important role in reducing regional inequalities, by funding investments in many sectors of the economy, such as agriculture, livestock, industry, commerce, services and infrastructure. Oliveira *et al.* (2019) demonstrated that the Brazilian Constitutional Financing Funds represent policies that are important to regional development, creating jobs and contributing to reducing regional inequalities. Souza *et al.* (2020) identified that technological progress in Brazilian agriculture is closely linked to rural credit and its institutional changes over time.

Despite being important mechanisms to reduce the regional development gap, the efficiency of the FNO and rural credit is related to its capacity to be widely distributed among municipalities in the Northern region, especially in agriculture, which is present throughout a wide range of activities in this region. While the FNO guidelines stimulate the distribution of credit throughout the entire Northern region, the actual allocation of resources is dependent on the individual decisions of credit borrowers (farmers). Some factors may reduce the willingness of farmers to obtain credit, such as the distance of the municipality from the commercial areas, the absence of bank branches, the lack of information about rural credit, the inexistence of technical assistance to elaborate agricultural projects (Moreira-Dantas *et al.*, 2023) and the divergencies (capital, land and available credit sources) between small and large farmers (Zeller and Schiesari, 2020).

Research on the distribution of FNO resources in rural areas is scarce. Some studies highlight the small share of the FNO destined to activities with high potential in the Amazon region, such as aquiculture (Araújo *et al.*, 2015), and a concentration of funds in cattle

ranching and in expanding grains production (Gumiero, 2023). To provide insights into the FNO allocation in the Northern region, the present study focuses on three key questions:

(1) Is rural credit concentrated in a few municipalities in the Northern region of Brazil?

(2) Is the FNO contributing to reducing rural credit concentration, particularly by directing resources to regions in less developed areas? and

(3) Does rural credit promote agricultural economic growth and rural income?

To answer these questions, we gathered data on rural credit (by source) for each municipality from the Brazilian Central Bank and rural data from the Brazilian Agricultural Census to determine whether rural credit and the FNO were able to produce structural changes in the distribution of financial resources and contribute to agricultural economic growth in the Northern region's municipalities.

2. Material and methods

2.1 Data

Our data is presented in Table 1 and covers 450 municipalities from the seven Northern states (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins), which represent more than 70% of Brazil's Legal Amazon. Data on official rural credit in Brazil was obtained from the Brazilian Central Bank. We divided the origins of the rural credit resources into two main groups: the FNO, which is funded by Federal taxes; other sources, which include all other credit sources, except for the FNO. Data on farm households, agricultural area, rural employment and agricultural production value were obtained from the 1995–1996, 2006 and 2017 Brazilian Agricultural Censuses. To analyze the period between the Censuses, we assumed a linear increase/decrease in the variables as a proxy. We also gathered data from the Agricultural Value Added to GDP and transformed to per capita to represent the mean rural income for each municipality. Variables in Brazilian currency were adjusted using the IGP-DI index from the Getúlio Vargas Foundation to the 2017 base rate.

2.2 Inequality measures

To assess the scale of inequality in the distribution of rural credit in Northern Brazil, focusing on the role of the FNO, we used the Gini coefficient and the Theil index (T). The agricultural area and the number of farmers are directly correlated with the demand for capital in rural production; therefore, we compared both indexes using three different weights:

Table 1. Variables and descriptive statistics (municipality level)

Variables	Unit	Mean	SD	Source
FNO	Brazilian currency (m)	1.84	4.85	Central Bank of Brazil (2023)
Other		3.89	9.55	
Contract	Count	217.47	396.32	
Varea	Hectares (thousand)	96.74	129.12	IBGE (1996), IBGE (2006), IBGE (2017)
Aarea		32.88	47.08	
Farms	Count	1102.89	1138.65	
Labor	Count	4043.53	4237.12	
APV	Brazilian currency (thousand)	1924.92	2096.18	
AGDPpc	Brazilian currency, per capita	57.96	83.73	IBGE (2023)
Bank	Count	1.81	7.10	Central Bank of Brazil (2023)

Source: Authors' own work

(1) equally distributed between municipalities;
(2) weighted by the municipality share in total agricultural area; and
(3) weighted by the municipality share in total number of farms.

The Gini coefficient (Bowles and Carlin, 2020; Cowell, 2011), which measures the extent of deviation from the perfect distribution of the resources is presented in the following equation [equation (1)]:

$$G = \frac{1}{2n^2\overline{x}} \sum_{i=1}^{n} \sum_{j=1}^{n} |x_i - x_j| \tag{1}$$

Where G is the value of the Gini coefficient; n is the sample size; x is the value of the variable of interest (rural credit by source) for each individual. The Gini coefficient ranges from a perfect distribution (with a value of zero), where all individuals share an equal amount of the variable x, to the opposite situation, where one individual holds all resources measured by x (G equal to one).

Our second measure of inequality is the Theil index (T), proposed by Henri Theil, and based on information theory. The index is equivalent to the concept of redundancy, which is the subtraction of the actual entropy of the variable x from the maximum possible value of the x entropy [equation (2)]:

$$T = \frac{1}{n} \sum_{i=1}^{n} \frac{x_i}{\overline{x}} ln \left(\frac{x_i}{\overline{x}} \right) \tag{2}$$

The lowest value of the T index is zero (perfect equality distribution of variable x), and its maximum value is given by ln n. One advantage of the T index is that it is decomposable according to groups and subgroups between individuals. Assuming m groups, the Theil index is decomposed [equation (3)] in between-group (T_b) and within-group inequality (T_w):

$$T = \sum_{k=1}^{m} w_k \, ln \left(\frac{w_k}{\pi_k} \right) + \sum_{k=1}^{m} w_k T_k = T_b + T_w \tag{3}$$

Where w_k is the share of group k in the total of variable x $\left(w_k = \frac{\sum_{j=1}^{n_k} x_j}{\sum_{i=1}^{n} x_i}\right)$; π_k the share of individuals in group k in the total population ($\pi_k = \frac{n_k}{N}$) and T_k is the Theil index [equation (2)] calculated for each group k. The groups were the states in Northern Brazil.

2.3 Spatial data analysis

Despite inequality measures providing insights into the degree of concentration of certain variables, regional and local diversities, particularly surrounding agriculture in the Amazon, can result in a certain degree of spatial dependence between neighboring municipalities. The spatial data analysis (SDA) method is used to identify the presence of geographical clusters, outliers and other forms of grouping according to the similarities between neighboring municipalities. The Global Moran I [equation (4)] analyzes all municipalities simultaneously to determine whether the analyzed variable has a random spatial distribution (Lloyd, 2010). A positive Moran's I is evidence of spatial autocorrelation, creating visible clusters of High-

High or Low-Low neighboring values for the analyzed variable. A negative Moran's I shows a pattern of High-Low or Low-High neighboring values (Xiong *et al.*, 2022):

$$I = \frac{n}{s_0}\left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} z_i z_j}{\sum_{i=1}^{n} z_i^2}\right) \tag{4}$$

Where w_{ij} is the weight assigned to municipality i in relation to its distance from municipality j; z_i is the difference between the observed value of the variable and its mean and s_0 is the sum of all w_{ij} weights. The weight matrix W was obtained using the queen methodology, in which any municipality that has at least one point in common with its neighborhood is assigned the value 1, whereas the others that do not have any surrounding border or point have a value of 0 (Silva *et al.*, 2022).

Even though Moran's I can indicate whether there is spatial autocorrelation or not, regional patterns and clusters can still be formed. The Local Indicator of Spatial Association (LISA) – or Local Moran's I – was proposed by Anselin (1995) to verify noteworthy spots of clusters [equation (5)]:

$$I_i = \frac{z_i}{m_2}\sum_{j=1}^{n} w_{ij} z_j \tag{5}$$

Where $m_2 = \sum_{i=1}^{n} z_i^2/n$. LISA values can be applied to a Moran scatterplot to identify four spatial autocorrelation patterns (clusters) between the municipality and its bordering neighbors: High-High; High-Low; Low-High; Low-Low.

2.4 Econometric approach

The economic factors of production – labor, capital and land – are essential components in agricultural development. In this manuscript we adopted the panel data ordinary least squares (OLS) econometric approach to examine how the agricultural production factors capital (rural credit, divided into FNO and other sources), land (vegetal and animal available land and number of farms) and labor (rural labor) influence the rural income growth [equation (6)] and agricultural value production [equation (7)] in Brazil's Northern municipalities. The panel data analyzes the period between 1995 and 2017, and we estimated the models with two different cross-sections: for the 449 Northern region municipalities and reducing the cross-sections to 20 by grouping municipalities according to Brazilian Northern mesoregions. All variables were logarithmically transformed to represent the coefficients as elasticities:

$$\begin{aligned}\ln AGDPpc_{it} = {} & \beta_1 + \beta_2 \ln FNO_{it} + \beta_2 \ln Other_{it} + \beta_3 \ln Varea_{it} \\ & + \beta_4 \ln Aarea_{it} + \beta_5 \ln Farms_{it} + \beta_5 \ln Labor_{it} + \epsilon_{it}\end{aligned} \tag{6}$$

$$\begin{aligned}\ln APV_{it} = {} & \beta_1 + \beta_2 \ln FNO_{it} + \beta_2 \ln Other_{it} + \beta_3 \ln Varea_{it} \\ & + \beta_4 \ln Aarea_{it} + \beta_5 \ln Farms_{it} + \beta_5 \ln Labor_{it} + \epsilon_{it}\end{aligned} \tag{7}$$

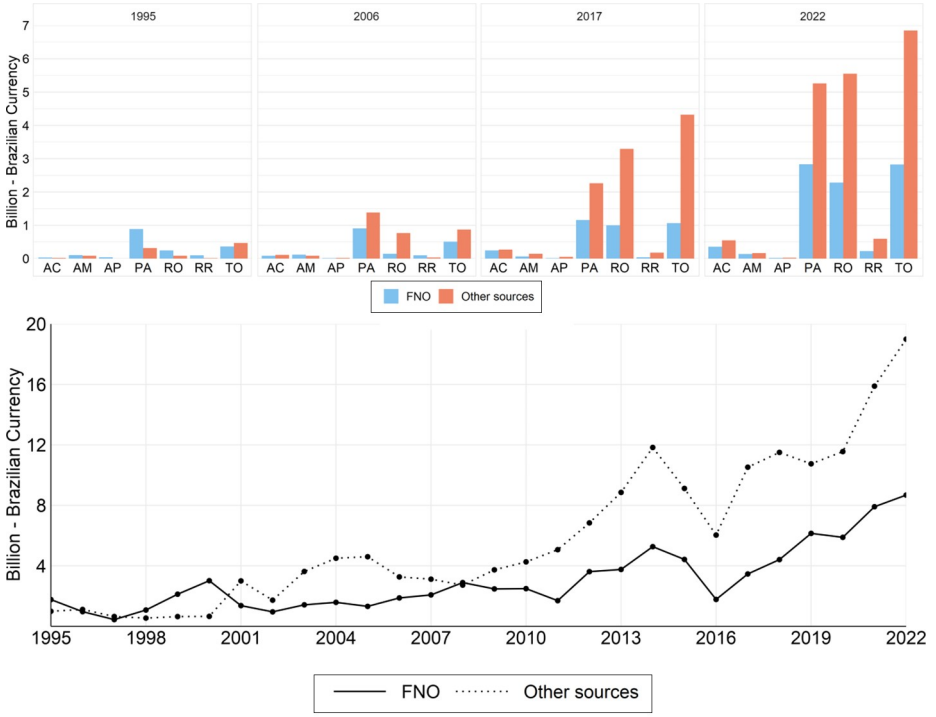
First, we checked if the time series were affected by their own past values through panel unit root tests to check the stationarity of variables at level –I(0)–, where the null hypothesis states that there is a unit root. There are several tests to check stationarity in panel data, including the Levin, Lin and Chu (LLC) test (Levin *et al.*, 2002), Im, Pesaran and Shin test

(IPS) (Im *et al.*, 2003), ADF – Fisher test (ADF) and PP-Fisher test (PP) (Choi, 2001). The credit variables (FNO and other sources) are potentially endogenous, because there may be flows to more productive regions and the increase in production also increases the demand for financial resources. We used two instrumental variables – number of bank branches in each municipality (*Bank*) and the number of credit contracts (*Contract*) – in our model to address the potential endogeneity of the credit variables. The panel OLS estimates compared the fixed effects model (FEM) with the random effects model (REM) using the Hausman test, under the null hypothesis that the estimators do not differ substantially and the alternative hypothesis where the FEM is preferred.

3. Results

3.1 Rural credit inequality measures

The total rural credit contracted by farmers in the Northern states rose from 2.76 bn in 1995 (in Brazilian reais) to 27.67 bn in 2022 (a mean increase of 8.91% per year). The FNO's resources grew less than other sources, going from 1.77 bn in 1995 to 8.68 bn (in Brazilian reais) in 2022. Despite the state of Pará having the largest share of rural credit between 1995



Notes: AC = Acre; AM = Amazonas; AP = Amapá; PA = Pará; RO = Rondônia; RR = Roraima; TO = Tocantins

Source: Elaborated by the authors with data from the Central Bank of Brazil (2023)

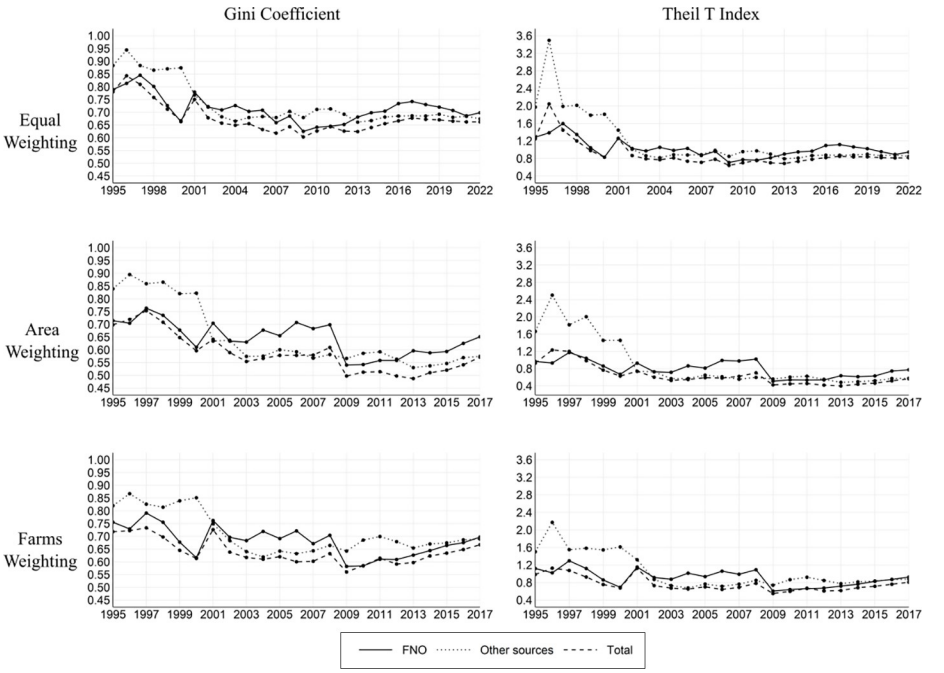
Figure 1. Evolution of rural credit by source in the Northern Brazilian states

and 2006, the state of Tocantins held the largest share from 2008, whereas Rondônia consolidated second place in total credit in 2014 (Figure 1). The relative share in total credit in the states of Acre, Amazonas, Amapá and Roraima fell from 14.21% in 1995–7.49% in 2022, showing some degree of concentration in the three most productive states.

The Northern region covers the largest area in Brazilian territory and presents technological and institutional heterogeneity in its municipalities, which impacts the local demand for rural credit. However, some agricultural productions have a naturally higher demand for credit, such as cattle ranching, which is prominent throughout the Northern region and captures the largest share of rural credit, and grains production, which requires large investments and high production costs. Cattle ranching and pasture accounted for 55.3% of all agricultural credit in Northern Brazil in 2017, followed by soybean and maize with 19.2% of total credit.

To measure how this heterogeneity impacts credit distribution, we measured the inequality in resource distribution with two concentration indexes. Considering the equal weighting in the distribution of credit between municipalities, the Gini coefficient and Theil Index evidence a deconcentrating tendency between 1995 and 2009, followed by a period (between 2010 and 2022) with slight growth and a subsequent fall in indexes, independently from the resource's origin (Figure 2).

Agricultural credit obtained by municipalities depends, regardless of policy objectives, on both agricultural area and number of farms in each municipality (number of credit borrowers). We gathered data from Brazilian Agricultural Censuses (1995, 2006 and 2017)



Source: Authors' own calculations

Figure 2. Evolution of Gini coefficient and Theil T index for rural credit in Northern Brazil

and assumed a linear increase/decrease in agricultural area and farms between intervals as proxy to the period. When weighting the inequality indexes in each municipality according to the share of available agricultural area and the share of farms, the concentration showed an overall decrease when compared to an equal distribution, as expected.

When weighting by the share of area, the index values were slightly lower than farms weighting, demonstrating that the available agricultural area is more highly correlated with obtaining financial resources. Another important aspect observed is that FNO resources were more greatly concentrated than other sources between 2001 and 2008, and between 2013 and 2017. Despite the reduction in indexes, the overall values in all cases demonstrate a tendency of concentration, with values closer to one in the Gini coefficient.

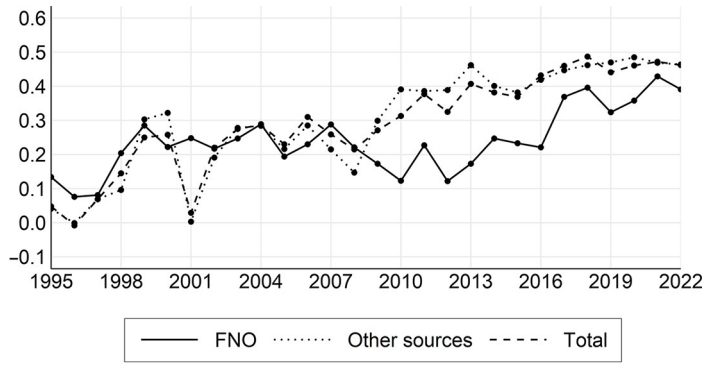
We decomposed the Theil T index between (T_b) and within (T_w) subgroups. Results for equally distributed weight showed that the FNO was widely concentrated within states, with the T_w ranging between 65.3% (minimum in 2016) and 89.4% (maximum in 2008). Other sources of rural credit also demonstrated major concentration within states, with the T_w explaining between 63.8% (minimum in 2006) and 87.9% of Theil T (maximum in 2012).

Area weighting showed lower concentration indexes than other weighting methods but did not indicate significant differences in the decomposition of the Theil T index, with T_w ranging from 68.9% to 95.7%. Farms weighting presented similar results with equal distribution in terms of concentration, and the Theil decomposition (T_w) of total credit explained between 81.5% and 95.7% of the Theil T index.

3.2 Spatial rural credit concentration

Although the Gini coefficient and Theil T demonstrated an initial tendency of reduction, this process reversed from 2013. Analyzing the FNO resources, if most of the Fund is directed at less developed municipalities – and is the cause of concentration –, its objective, to develop more socially and economically backward areas, can be partially fulfilled. To test this hypothesis, we also verified the spatial autocorrelation of rural credit using the Moran's I statistic (Figure 3). As with the inequality indexes, Moran's I statistic increased over time, meaning that despite the source, rural credit became more spatially concentrated. To determine the existence of important regional clusters, we estimated the LISA.

The LISA results showed that other sources of rural credit have more municipalities than the FNO that are significantly allocated into clusters (Table 2). In the High-High clusters, the



Source: Authors' own calculations

Figure 3. Moran's I statistic

Table 2. Classification of Northern Brazilian municipalities according to LISA results

Credit source	Cluster	1995	2006	2017	2022
FNO	High-High	19	23	28	29
	Low-Low	32	65	86	109
	Low-High	20	14	11	7
	High-Low	1	5	3	3
	Not significant	378	343	322	302
Other sources	High-High	9	37	70	62
	Low-Low	17	77	128	126
	Low-High	20	13	14	16
	High-Low	8	7	2	2
	Not significant	396	316	236	244

Source: Authors' own work

FNO resources showed less municipalities, rising from 19 to 29 between 1995 and 2022. The other sources increased from 9 to 62 municipalities in the same period. The Low-Low cluster exhibited a large increase in municipalities in both sources, reinforcing the spatial concentration of rural credit.

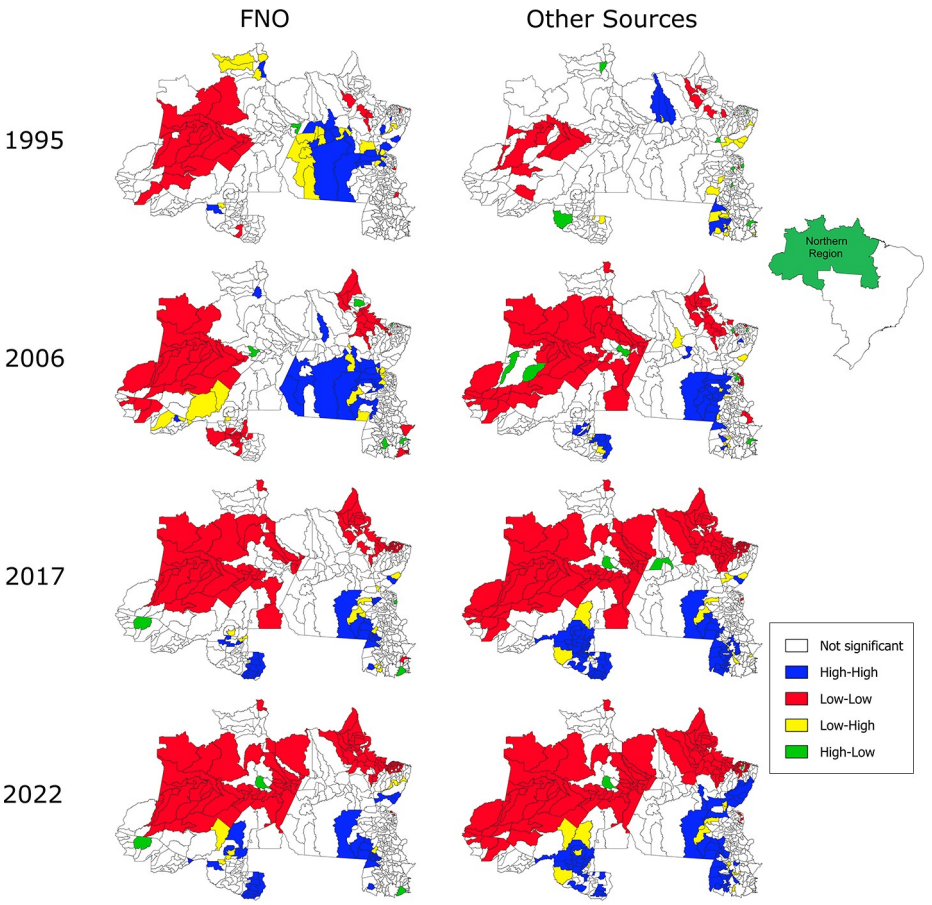
Analyzing the LISA results (Figure 4), both the FNO and other sources showed High-High municipalities concentrated in the southeast of the state of Pará between 1995 and 2006, with cattle ranching as the predominant activity. Over the years, the High-High cluster in Pará partially migrated to Tocantins and Rondônia. In 2006, 10 municipalities were in both the FNO and other sources High-High clusters, and these municipalities made up 12.03% of total credit. The number of municipalities in both High-High clusters increased to 22 municipalities in 2017 and 2022 (4.9% of Northern region municipalities), and this group obtained 20.85% and 17.93% of total credit in 2017 and 2022, respectively.

On the other hand, Low-Low clusters are clearly present in Acre, Amapá, Amazonas and in municipalities in the North of the Pará state, independent of the financial source. The area covering the Low-Low cluster increased substantially over the years, which also intersects some of the lesser developed regions in the Brazilian Amazon. High-Low municipalities are dispersed throughout the Northern region in the period analyzed, and Low-High municipalities mainly occurred near High-High spots.

Financial institutions intermediate the credit with farmers, and for the Northern region, particularly concerning FNO resources, the Banco da Amazônia S.A. is the main economic agent. Data from 2006 demonstrates that branches of the Banco da Amazônia S.A. were found in just 71 municipalities in the Northern region. After 10 years (December 2017), the number of municipalities with a Banco da Amazônia S.A branch had marginally increased to 89 (some municipalities may have more than one branch). The states of Roraima and Amapá have the lowest number of branches and municipalities, whereas Pará and Tocantins have the highest (Table 3), corroborating with the Low-Low clusters allocation.

3.3 Econometric model

The role of agriculture in the Brazilian economy can be extended to local development, as many regions are highly dependent on agricultural production. Consequently, rural credit plays an important role in incentivizing investments, increasing productivity and raising rural income. Our econometric approach aimed to investigate if the sources of rural credit, agricultural area, number of farms and rural employment affect the Agricultural Production



Source: Authors' own calculations

Figure 4. Clusters of rural credit in Northern Brazilian municipalities – LISA results

Value (*APV*) and the Agricultural Added Value to GDP per capita (*AGDPpc*). The panel unit root tests confirmed that the series are stationary in level (Table 4).

The panel models were estimated considering the municipalities as the cross-sections. We also grouped the municipalities in mesoregions to reduce the number of cross-sections in a second estimation. Comparing the REM with FEM models, the Hausman test failed to reject the null hypothesis – except at the municipality level for the *APV* dependent variable – and the REM was preferred in our analysis (Tables 5 and 6).

As expected, rural credit, independently from the source, showed a positive and significant coefficient, confirming its role in increasing agricultural production value. Table 5 reports that an increase of 1% in FNO and Other Sources of credit at the municipal level raises *APV* by 0.015% and 0.039%, respectively. At the mesoregion level, the elasticities are 0.031% and 0.060%, respectively, for FNO and other sources. When analyzing rural income

Table 3. Number of branches of Banco da Amazônia S.A. in the Northern Brazilian states

State	2006	2017	Municipalities
AC	8	9	22
AM	9	12	62
AP	2	3	16
PA	36	42	144
RO	8	14	52
RR	2	2	15
TO	12	17	139
Total	77	99	450

Source: Authors' own work with data from Central Bank of Brazil (2023)

(Table 6), the FNO resources showed a positive and significant effect in both cross-sections models – a 1% increase in FNO credit results in a 0.069% and 0.042% growth in Agricultural Added Value to GDP per capita for municipality and mesoregion respectively –, confirming the importance of this resource to develop rural areas in the Northern region. Nevertheless, other sources of rural credit coefficient are positive at the municipality level and negative when estimated to mesoregions.

The number of farms and vegetal production areas presented positive and significant effects in all cases, except for the municipality rural income model (coefficient not significant). Inversely, the animal production area presented a negative effect on rural income, with elasticities of −0.034% and −0.438%, respectively, for municipality and mesoregion. The results for the rural employees' variable are not significant in any model.

4. Discussion

4.1 Concentration of rural credit in Northern Brazil

In each municipality, the total credit obtained annually is the sum of the farmers' formalized contracts, which is influenced by several variables (e.g. willingness to obtain credit, production characteristics, distance from markets, presence of agency branches and technical assistance). An uneven distribution of rural credit to more developed regions is anticipated, considering the structural and institutional differences between municipalities in the region as well as over time, due to market volatility and activities shifting through the territory. However, considering the FNO program that prioritizes low-income areas, unequal distribution is expected in such locations and total rural credit distribution will be less unequal as a result of policy guidelines.

Our results confirmed that despite a trend of decreasing inequality indexes, credit remained concentrated in certain municipalities, particularly those in productive clusters. The reduction in concentration was mainly due to the expansion of agricultural activities, especially grains, into more municipalities in Tocantins, Rondônia and Southeast Pará, increasing the demand for financial resources rather than improving credit access for less favored municipalities. The inequality indexes also demonstrate that the concentration in the more productive clusters includes the FNO program, despite the opposite being expected due to the program prioritizing low-income regions. In the expanding agricultural frontier, High-High clusters were formed, largely concentrating on rural credit, which explains the rise in Moran's I statistics over time. The spatial influence of agricultural production is therefore important to understand the dynamics of credit concentration, as proved by Zhu *et al.* (2021).

Table 4. Panel unit root tests to check stationarity at level

Variable	Cross-section: municipality				Cross-section: mesoregion			
	LLC	IPS	ADF	PP	LLC	IPS	ADF	PP
APV	−12.51**	2.02	1585.00**	15762.40**	−3.66**	−0.89	52.06	159.21**
AGDPpc	−28.87**	−22.39**	2418.30**	2602.02**	−2.75**	−2.85**	63.91**	60.09*
FNO	−44.64**	−35.57**	3549.09**	3085.50**	−1.88*	−1.19	55.95*	64.90**
Other	−34.01**	−27.09**	2859.50**	2419.33**	−2.25**	−5.30**	102.28**	68.06**
Varea	−30.92**	−35.20**	7194.29**	12963.40**	−3.00**	−2.98**	70.29**	1194.44**
Aarea	−10.36**	4.18	1585.15**	6021.30**	−2.87**	0.10	39.84	118.99**
Farms	−11.93**	1.97	951.37	10037.50**	−1.88*	1.60	29.26	936.23**
Labor	−22.8**	−18.05**	2186.66**	2114.55**	−2.37**	−1.97*	70.61**	99.32**

Notes: ** = significant at 1%; * = significant at 5%
Source: Authors' own work

Table 5. Panel models estimation. Dependent: Agricultural Production Value (*APV*)

Cross-section		Municipality		Mesoregion	
Model		FEM	REM	FEM	REM
Variables	constant		4.673**		2.545**
Coefficients	*FNO*	0.006	0.015*	0.563	0.031*
	Other	0.048**	0.039**	−0.444	0.060**
	Varea	0.011	0.022**	0.082	0.136**
	Aarea	0.078**	0.074**	0.395	0.021
	Farms	0.677**	0.699**	2.017	0.765**
	Labor	−0.060**	−0.052	2.067	−0.008
R^2		0.370	0.417	0.008	0.851
F-statistic		5059.12**	6111.65**	9.059	2622.48**
Hausman test		38.115 **		0.704	

Notes: ** = significant at 1%; * = significant at 5%
Source: Authors' own work

Table 6. Panel models estimation. Dependent: Agricultural Added Value to GDP per capita (*AGDPpc*)

Cross-section		Municipality		Mesoregion	
Model		FEM	REM	FEM	REM
Variables	constant		7.221**		−3.285**
Coefficients	*FNO*	−0.094**	0.069**	−4.758	0.042*
	Other	0.124**	0.093**	4.306	−0.105**
	Varea	−0.055**	−0.036	1.095	0.316**
	Aarea	0.044**	−0.034**	−4.565	−0.438**
	Farms	−0.107	−0.027	−9.910	0.639**
	Labor	0.006	−0.009	−20.496	−0.065
R^2		0.451	0.485	0.024	0.304
F-statistic		79.469	107.702	0.042	245.615
Hausman test		2.630		0.100	

Notes: ** = significant at 1%; * = significant at 5%
Source: Authors' own work

A cattle ranching is the dominant agricultural activity in the Brazilian Amazon and is prevalent in most municipalities in the northern region. Despite their widespread presence, the largest cattle herds are concentrated in a small group of municipalities in Pará and Rondônia. Santos *et al.* (2017) identified traditional farming systems in Amazonian livestock, with extensive areas and low innovation levels, which still rely on capital for pasture and animal supplementation. Consequently, rural credit is directed at these economically influential locations with a high demand for financial resources, as observed in the High-High clusters in 1995 and 2006, corroborating the results of Sousa *et al.* (2020).

Moreover, High-High clusters with predominant cattle ranching include municipalities such as São Félix do Xingu, Porto Velho, Novo Progresso and Marabá, which have higher deforestation rates (Levy *et al.*, 2018). This aligns with the literature identifying cattle ranching as a primary driver of deforestation in the Amazon (Müller-Hansen *et al.*, 2019; Santos *et al.*, 2021). In this context, the FNO may directly fund unsustainable activities or

indirectly contribute via the "dragging effect" (Fearnside, 2001), exacerbating regional deforestation. However, as Assunção *et al.* (2020) noted, Brazilian institutions implemented changes post-2008 to reduce deforestation, including rural credit constraints that had a greater impact on cattle ranching than crop production. Therefore, future studies could analyze how credit impacts deforestation in High-High clusters.

The institutional change in credit may have contributed to the displacement of High-High clusters between 2006 and 2017, partially shifting from areas of cattle ranching to the expanding production of grains, mainly soybean and maize, in Rondônia (e.g., Vilhena, Corumbiara), Eastern Pará (e.g., Paragominas, Santana do Araguaia) and Tocantins, as part of the emerging group of MATOPIBA states (Araújo *et al.*, 2019). Grains have characteristics of economies of scale, with high costs of production and demand for investments (Cacho, 2016; Rodrigues and Campos, 2019), demanding more credit per area than cattle ranching and other regional activities. The inequality indexes showed lower values of concentration when weighted by the share of area, supporting the fact that municipalities with a large agricultural area (characteristic of cattle ranching and soybean production in Brazil's Amazon) demand higher volumes of credit, especially in High-High clusters.

4.2 Determinant factors of credit inequality in Low-Low clusters

The Low-Low clusters of rural credit increased in municipalities throughout the two decades analyzed and are mostly present in the less-developed areas within the Brazilian Amazon, especially in the states of Amapá, Acre, Amazonas, Roraima and Northern Pará. In such locations, the FNO credit can contribute to regional economic development, and increase income of rural families and farm productivity (Neves *et al.*, 2020). However, our results showed that this fund was unable to reduce inequalities in credit distribution.

Some structural and institutional factors are responsible for reducing the capacity to raise funds by municipalities in Low-Low clusters; first, the relative absence of a widely available banking system, in which many municipalities does not have a bank branch. Most notably is the absence of the *Banco da Amazônia S.A.*, which is not only the FNO's fund manager but also one of the principal banks to supply farmers with rural credit in Northern Brazil. Farmers in locations that are far from bank branches lack access to information and end up being excluded from the credit circuit. The presence of a bank branch increases access to credit and supports the development of economic activities, which, as demonstrated by Rebello *et al.* (2013), are limited in municipalities in Northern Brazil and contribute to credit inequality. Moreira-Dantas *et al.*'s (2023) results also demonstrated that the network of bank branches influences the microcredit of small farmers in the Brazilian Amazon. Therefore, developing alternative means to access the banking systems is essential to reducing the credit gap; this may include the use of communication technologies in these areas.

Second, the agricultural area is predominantly smaller in Low-Low clusters, where the large share of native forest in the territory, more protected lands (Herrera *et al.*, 2019) and low rates of deforestation limits the growth and expansion of agriculture. In addition to the lower availability of agricultural land, the predominance of activities with lower demand for capital when compared to those in High-High clusters impacts the demand for rural credit in the municipalities. In such locations, the existent activities should be enhanced through policies to add value to local production, either by industrial processing, or by reaching high value markets, as in the cases of açaí and cocoa (Braga *et al.*, 2023; Stabile *et al.*, 2020).

Another factor involves institutional constraints, such as excessive bad debt in some municipalities, leading to temporary credit suspensions, limited information available to farmers and the absence of formal requirements to formalize contracts (e.g. insufficient

assets to be pledged as collateral, farm compliance with legal titling and lack of knowledge or assistance to elaborate the technical project required by the bank). Such constraints have a greater impact on small farmers, who are (in terms of number of farms) more numerous than large farms in most Amazon municipalities (Ely *et al.*, 2019). Expanding the technical assistance network for small farmers is important to stimulate investment and develop sustainable systems through rural credit resources (Bragança *et al.*, 2022).

When the concentration indexes were weighted by the share of farms, the results confirmed that the increase in the number of farms is unrelated to a reduction in credit concentration. Stabile *et al.* (2020) argued that the absence of assistance, basic infrastructure and resources leads small farms to engage in inefficient markets and practices, where the low productivity is more frequently addressed by the increase in area – through deforestation – than by productive intensification; consequently, there is no significant increase in the demand for credit as the number of small farms increases.

By comparing the characteristics of the High-High clusters with those of the Low-Low clusters, the latter is unlikely to reduce inequality in rural credit in the short and medium term. According to Portugal (2017), municipalities in the state of Roraima were unable to absorb FNO resources planned in the period (2011–2015), due to a lack of demand, which is dependent on the technological, institutional and productive level of the farmers.

4.3 Rural credit, agricultural production and rural income

Brazilian rural credit is a policy that offers financial resources for agricultural activities throughout the national territory. The policy's objectives include stimulating rural investments; fund farmers' production costs; encourage sustainable production systems and increase the well-being of rural populations. In turn, one of the main objectives of the FNO is to fund less developed areas in the Northern Brazilian region. The panel data results confirm that the increase in credit allocation in municipalities and mesoregions is pivotal to developing agricultural production and rural income. Our findings align with Chen *et al.* (2021), who also used a panel data OLS estimation for Chinese farmers and found that financial resources positively contribute to rural income.

Results indicated that while expanding animal areas boosts agricultural production, it has a negative effect on rural income. This outcome is due to the inefficiency of cattle ranching in the Amazon, characterized by extensive systems with low animal density (Hamid *et al.*, 2023; Sparovek *et al.*, 2018). Initially, this increases the local economy but ultimately reduces regional output compared to more efficient production such as with grains. This inefficiency highlights the need for substantial credit policy reforms to support sustainable agriculture and more productive cattle farming practices.

For vegetal areas, all models showed positive coefficients, indicating that expanding cropping areas enhances agricultural productivity. Unlike livestock farming, vegetal production, especially soybeans, has the potential to make a greater contribution to poverty reduction (Weinhold *et al.*, 2013). However, concentrating financial resources in municipalities focused on crop and cattle production deviates from the FNO's goal of improving regional income distribution and exacerbates disparities between developed and underdeveloped areas in the Amazon (Campos and Santos, 2013), therefore limiting the policy effectiveness.

Because rural credit resources in a municipality result from individual farmer's decisions, regions with advanced agriculture and favorable conditions capture the most significant share, leading to higher agricultural production and rural income. Thus, the FNO resources can alter the economic dynamics in less developed regions. The policy, however, requires structural changes to encourage farmers in Low-Low clusters to seek credit. Policy measures

to boost credit demand in these areas include investing in logistics to enhance input and output flow, stimulating agroindustry to add value to local products, promoting sustainable production systems tailored to regional markets, improving farmer access to technical assistance to boost investments and labor productivity, and expanding the financial system using new communication technologies to reach more municipalities.

5. Conclusion

Official rural credit in Brazil is an important funding mechanism that contributes to agricultural production through investments and to finance production costs. Our results demonstrate that credit concentration indexes showed a decreasing tendency in the first period (between 1995 and 2009), followed by a period (between 2010 and 2022) with more stable distribution. This phenomenon occurred due to growth in agricultural activities in more municipalities of the agricultural frontier in Tocantins, Rondônia and Southern Pará, where the higher demand for financial resources in large scale crops and cattle ranching acted as a gravitational force to the flow of resources.

The High-High clusters have a greater capacity to support high value agriculture, thus concentrating the credit, whereas the Low-Low clusters, which are larger in area and number of municipalities, lack infrastructure, technology, and agricultural land, as well as presenting institutional constraints that reduce the demand for credit and consequently receive a small share of the FNO.

The panel data demonstrates that rural credit plays an important role in developing agricultural production and rural income, so the concentration of credit can result in a less efficient credit policy, especially regarding the FNO resources. However, our results showed that these resources are not properly contributing to reducing inequality in credit distribution and economic development between municipalities, because its flow is being captured by those municipalities and regions with consolidated large-scale agricultural production (such as soybean and cattle ranching).

Therefore, efforts to develop the Amazon and reduce regional disparities through the agricultural sector must include supplementary actions to expand access to credit by farmers and municipalities who currently lack certain conditions. Supporting the Low-Low municipalities with infrastructure in rural areas, technical assistance at the farm level, and increasing access to the banking system, particularly via new communication technologies, are all essential to economic agents, creating structural conditions to raise the demand for credit, and thus contributing to the generation of income in economically and socially backward areas. Future studies could focus on exploring how the clusters influence local economies, defining the determinants of credit concentration, as well as determining the decisions made by individuals (farmers) to obtain credit at a regional level.

Note

1. *Fundo Constitucional de Financiamento do Norte.*

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Corresponding author
Marcos Rodrigues can be contacted at: marcos.rodrigues.adm@gmail.com