Instabilidade de renda diante de choques climáticos: evidências do mercado de trabalho rural no Brasil.

Income instability under climate shocks: evidence from the rural labor market in Brazil

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Resumo: Condições climáticas adversas afetam diretamente as atividades econômicas nas áreas rurais e se refletem imediatamente nos rendimentos dos trabalhadores, gerando desvios entre os salários habituais e os efetivamente recebidos. Este artigo analisa a dinâmica desse desvio, identificando quais culturas e grupos socioeconômicos são mais afetados em condições climáticas adversas. Com foco nas áreas rurais do estado do Rio Grande do Sul, Brasil, uma das regiões mais expostas a choques climáticos no país, o estudo aplica estatísticas descritivas e técnicas de regressão a um conjunto de dados que abrange treze trimestres entre 2022 e 2025 (N = 29.838). Os resultados indicam que trabalhadores com níveis mais baixos de escolaridade, trabalhadores mais jovens, trabalhadores informais e aqueles envolvidos em atividades particularmente vulneráveis, como a produção de soja e a pecuária, estão mais expostos a flutuações significativas de renda durante períodos de maior instabilidade climática. Essas dinâmicas reforçam as desigualdades pré-existentes e ressaltam a urgência de políticas voltadas para mitigar perdas de renda e proteger os meios de subsistência rurais.
Palavras-chave: desvio de renda, choques climáticos, mercado de trabalho rural, vulnerabilidade econômica, agricultura.

Abstract: Adverse climate conditions directly affect economic activities in rural areas and are immediately reflected in workers' earnings, generating deviations between usual and effectively received wages. This article analyses the dynamics of this deviation by identifying which crops and socioeconomic groups are more affected under adverse climate conditions. Focusing on rural areas in the state of Rio Grande do Sul, Brazil, one of the regions most exposed to climate shocks in the country, the study applies descriptive statistics and regression techniques to a dataset covering thirteen quarters between 2022 and 2025 (N = 29,838). The results indicate that workers with lower levels of schooling, younger workers, informal workers, and those engaged in particularly vulnerable activities, such as soybean production and cattle farming, are more exposed to significant income fluctuations during periods of heightened climate instability. These dynamics reinforce pre-existing inequalities and underscore the urgency of policies aimed at mitigating income losses and protecting rural livelihoods.
Keywords: income deviation, climate shocks, rural labor market, economic vulnerability, agriculture.

1. Introduction

Rural labor markets are highly sensitive to environmental and economic fluctuations due to their dependence on natural conditions, high informality and productive heterogeneity.

Changes in agricultural output, extreme weather events and local economic disruptions directly affect employment and earnings, increasing income instability and socioeconomic vulnerability (Ellis, 2000; Machado, 2019; Santos, 2022; Costa and Pessoa, 2024).

A growing literature shows that climate variability and extreme events affect agricultural production, rural employment and food security. Droughts, floods and other shocks disrupt production, reduce labor demand and increase economic instability, with stronger impacts on vulnerable groups such as young, informal and family workers, who face limited protection and fewer opportunities to diversify income (Wheeler and von Braun, 2013; Milhorance, 2022; Wink Junior et al., 2024; Caleffi et al., 2024; Mueller and Quisumbing, 2011; Branco, 2021; Parida and Chowdhury, 2021).

Research has widely analysed climate shocks on production, poverty and employment, but less attention has been given to short-term income instability in rural labor markets. Thus, little is known about how environmental shocks affect the gap between expected and actual earnings. From a rural livelihoods perspective, such instability is a key vulnerability, as it limits households' ability to smooth consumption, sustain production and cope with adverse conditions.

This article addresses this gap by analysing income deviation in rural Rio Grande do Sul from 2022 Q1 to 2025 Q1, defined as the difference between expected and received income. By capturing discrepancies between expected and realised earnings, this measure reflects short-term income instability linked to shocks and production disruptions, serving as an indicator of economic vulnerability in rural contexts marked by climate uncertainty and seasonal labor dynamics.

The study analyses how income deviations vary across socioeconomic characteristics, occupational status and agricultural activities during periods of climate adversity. It is guided by three questions: how deviations differ across worker characteristics, how occupational status shapes income dynamics, and how agricultural activities relate to income deviations under climate instability.

Rio Grande do Sul is a relevant case due to recurring extreme events since 2022, including droughts, cyclones and the 2024 floods, which affected most municipalities and caused major economic losses. In regions highly dependent on agriculture and climate stability, such shocks disrupt income flows, employment and productive activities (World Bank, 2024; Rizzotto et al., 2024; Inter American Commission on Human Rights, 2025).

By focusing on gaps between habitual and effective income, this article offers a new perspective on income instability in rural labor markets and contributes to debates on rural

vulnerability and climate risks. It does so by introducing income deviation as a measure of short-term instability, providing evidence on how socioeconomic and occupational factors shape vulnerability, and highlighting how productive composition influences workers' exposure to environmental shocks across agricultural activities.

2. Literature Review

2.1. Climate shocks, agriculture and rural labor markets

Natural disasters increasingly threaten economic stability, especially in agriculture. Research shows that environmental shocks affect not only production but also employment, income and welfare, particularly in climate-dependent and fragile regions. Theoretically, these impacts reflect risk and vulnerability models, where shocks reduce labor productivity and demand, increasing income volatility and inequalities (Legg, 2021; Marengo et al., 2024; Jones et al., 2022; FAO, 2023).

Evidence from countries such as China and India shows that natural disasters have immediate and persistent impacts on rural economic stability, reducing agricultural employment and increasing poverty. These findings align with labor market risk literature, indicating that climate shocks affect both labor supply and demand, leading to seasonal unemployment, wage declines and greater informality (Zhao et al., 2022; Parida and Chowdhury, 2021).

Floods are particularly damaging to agriculture, causing major crop losses, productivity declines and job losses, which worsen rural poverty. Evidence from Italy, China and India shows that floods reduce wages and income, increasing vulnerability among small producers and widening inequalities. These effects align with models of incomplete markets, where credit constraints, lack of insurance and limited mobility amplify the impacts of shocks (Scorzini et al., 2021; Zhang and Wang, 2022; Guan et al., 2021; Parida and Chowdhury, 2021).

2.2. Evidence from developing countries and Brazil

In developing countries such as India, Bangladesh, Pakistan and Tanzania, floods have severe economic impacts, increasing rural unemployment and reducing agricultural wages, which worsen food insecurity and poverty. High informality and weak institutional protection limit households' ability to smooth income, reinforcing vulnerability and hindering recovery (Chowdhury et al., 2022; Jamshed et al., 2021; Ahmad and Afzal, 2021; Tiague, 2023).

In Brazil, studies show that extreme events increase rural poverty and agricultural unemployment, with worsening economic conditions, job losses and sharp income declines. These impacts exacerbate existing inequalities and raise socioeconomic vulnerability, consistent with frameworks linking shocks to fragile productive structures (Wink Junior et al., 2024; Rizzotto et al., 2024; Caleffi et al., 2024).

2.3. Heterogeneous impacts and research gap

Climate disasters show strong social heterogeneity, disproportionately affecting vulnerable groups such as women farmers, who face greater income losses and unemployment. Similar patterns occur in the United States and Tanzania, where small rural businesses are highly sensitive to flooding and experience prolonged recovery. These effects align with human capital and labor segmentation literature, indicating that less educated and precariously employed workers have lower adaptive capacity (Chowdhury et al., 2022; Sam et al., 2021; Sun et al., 2022; Tiague, 2023).

Young rural workers also constitute a particularly exposed group. Evidence from Bangladesh and Pakistan shows that floods affect their labor market insertion, increasing occupational turnover and reliance on informal and low paid jobs (Eskander et al., 2016). Lower accumulated experience and limited access to formal protection mechanisms increase the likelihood of income losses and occupational instability in disaster contexts, in line with life cycle models and human capital accumulation under risk (Mueller and Quisumbing, 2011).

Informal workers face similar vulnerabilities. Evidence indicates that floods reduce the availability of stable jobs and intensify economic insecurity among individuals already outside formal employment relationships, reinforcing vulnerability cycles and delaying post crisis recovery (Kirchberger, 2016). The combination of informality, limited social protection and direct dependence on agricultural productivity creates conditions of high exposure to environmental shocks, in which income volatility tends to be particularly pronounced.

Despite extensive research on disasters' effects on employment, income and poverty, less attention has been given to short-term gaps between expected and actual income and how they vary across socioeconomic groups, occupations and sectors. By introducing income deviation, this study addresses this gap and offers a new perspective on how climate shocks and productive structures shape income vulnerability in rural labor markets.

3. Methodology

3.1. Climate events in Rio Grande do Sul

The state of Rio Grande do Sul is located in southern Brazil, bordering Santa Catarina to the north, Argentina and Uruguay to the west, and the Atlantic Ocean to the east (Figure 1). With an area of approximately 281,000 km², it is the fifth largest state in the country and displays marked topographical diversity, ranging from plateaus and mountain ranges in the interior to coastal plains.

Figure 1. Geographical location of the state of Rio Grande do Sul, Brazil

Since 2022, Rio Grande do Sul has experienced a sequence of extreme climate events that have continuously affected its economic and social activities. In May 2022, the subtropical storm Yakecan generated winds exceeding 100 km per hour, damaging infrastructure, disrupting energy supply and affecting rural production in coastal and highland regions (INMET, 2022; Marengo et al., 2024). Between 2022 and early 2023, the state faced a severe drought associated with the La Niña phenomenon, resulting in substantial losses in soybean and corn production, with estimated declines between 30 and 50 per cent in some agricultural microregions (CONAB, 2023; Trentin, 2023). In 2023, extratropical cyclones, particularly in June and September, caused flash floods, landslides and widespread inundation, simultaneously affecting urban and rural areas (Marengo et al., 2024). In early 2025, a historic heat wave was recorded, with temperatures reaching record levels and contributing to agricultural productivity losses and water stress in already fragile crops (Pivetta, 2024). The recurrence of these events reflects the combined influence of global climate change and the vulnerability of production systems that are highly dependent on climate stability (Intergovernmental Panel on Climate Change IPCC, 2021).

The floods that occurred in 2024 constituted one of the largest climate disasters in recent Brazilian history, with large scale social and economic impacts. Approximately 2.4

million people were affected in 478 municipalities, resulting in 183 deaths and more than 442,000 displaced or homeless individuals, in addition to 388,732 damaged dwellings in 321 municipalities (Special Rapporteurship on Economic, Social, Cultural and Environmental Rights - REDESCA, 2025). Economic losses were estimated at R$ 88.9 billion (World Bank et al., 2024). Of this total, 69 per cent corresponded to losses in the productive sector, 21 per cent to social sectors, 8 per cent to infrastructure and 1.8 per cent to environmental damage (World Bank et al., 2024).

The impacts were particularly severe in vulnerable communities, including Indigenous peoples, quilombola communities and low income populations, who faced additional difficulties due to precarious infrastructure and limited access to basic services during and after the floods (REDESCA, 2025). Health conditions in flooded areas contributed to increases in infectious and dermatological diseases (Webber et al., 2024), as well as to the aggravation of psychological distress and mental health problems among affected populations.

Events of this magnitude have become more frequent and intense as a result of global warming and the limited adaptation of Brazilian cities and rural areas to new climate patterns. In the case of Rio Grande do Sul, the effects were aggravated by decades of unplanned urban expansion, insufficient drainage infrastructure and historical neglect of populations living in risk areas (Marengo et al., 2024). The disaster clearly revealed sociospatial inequalities, as peripheral territories characterised by high socioeconomic vulnerability and lack of basic infrastructure were the most severely affected (Caleffi et al., 2024).

The institutional response also revealed important limitations. Despite the mobilisation of resources and emergency efforts, public authorities displayed weaknesses in prevention, preparedness and social participation mechanisms. The absence of effective channels for listening to affected communities undermined the legitimacy of state actions, particularly with respect to priority setting and resource allocation (Dowbor et al., 2024). From a public policy perspective, Lima et al. (2016) and Verges and De Gois (2024) emphasise that the 2024 event exposed structural weaknesses in climate governance in Brazil. Insufficient intersectoral policies and weak coordination across levels of government reduced the capacity of the state to respond in a coordinated and effective manner to catastrophes and highlighted the discontinuity of programmes aimed at reducing climate related risks.

3.2. Hypotheses

This study tests three hypotheses regarding the determinants of income deviation under climate instability.

H1. Higher levels of schooling are associated with smaller income deviations during periods of climate instability. This hypothesis is grounded in the literature that identifies human capital as a central determinant of occupational stability and economic adaptation under risk (Mincer, 1974; Machado, 2019; Costa and Pessoa, 2024; Silva and Costa, 2021).

H2. Workers in formal employment exhibit smaller income deviations than informal, self-employed or family workers. This hypothesis follows from evidence that formalisation reduces exposure to shocks by ensuring greater regularity in payments and access to labor protection mechanisms (Souza and Neri, 2020; Moura and Barbosa Filho, 2022; IDB, 2024).

H3. Agricultural activities more exposed to climate risks exhibit larger income deviations during periods of environmental instability. This hypothesis is consistent with studies documenting the high sensitivity of crops such as soybean and tobacco and cattle farming to climate and sanitary events, in contrast to the relatively higher stability observed in rice production in the state (Tanure et al., 2020; Trentin, 2023; Scorzini et al., 2021; Embrapa, 2024).

3.3. Data

This study uses microdata from the Continuous National Household Sample Survey (PNADC) conducted by the Brazilian Institute of Geography and Statistics (IBGE), covering the period from the first quarter of 2022 to the first quarter of 2025. The choice of this time window aims to mitigate the influence of seasonal effects characteristic of agricultural activity, as working conditions and employment in rural areas exhibit systematic variation over the year due to production cycles. The analyzed sample consists of N = 29,838 individuals drawn from a specific subsample of the population residing in rural areas of the state of Rio Grande do Sul.

3.4. Variables

The dependent variable in this study is income deviation, defined as the self-reported difference between effective income and habitually received income. This indicator captures distortions in labor market functioning by reflecting deviations between expected and realized earnings, associated both with conjunctural shocks and with structural factors that limit the full utilization of labor. While habitual income represents the amount that workers usually receive or expect to receive regularly, effective income corresponds to the remuneration actually earned in the reference period (IBGE, 2025).

Income deviation is operationalized as the average percentage deviation, calculated as the difference between effective income and habitual income expressed as a proportion of habitual income. This definition allows comparison of the relative magnitude of income variations across individuals and over time, standardizing for heterogeneity in income levels. Negative values indicate that workers received less than usual on average, signaling income losses and higher economic vulnerability, whereas positive values reflect earnings above expectations, associated with periods of gain or relative stability under lower conjunctural instability.

The independent variables include a set of individual, occupational, productive and temporal characteristics selected based on the literature on wage inequality and rural labor market dynamics. In particular, demographic and human capital variables are considered, including sex, race, age and years of schooling, capturing systematic differences associated with gender and race as well as the effects of accumulated experience and formal qualifications (Barros et al., 2007; Ñopo, 2008; Mincer, 1974).

Additional variables characterise occupational status, distinguishing employees, self employed workers, employers and family workers, with employees as the reference category. Productive insertion is closely related to earnings levels, income stability and access to markets and protection mechanisms, aspects that are particularly relevant in rural areas, where self employment and family production units are predominant (Schneider, 2003; Grisa and Schneider, 2015; Del Grossi and Graziano da Silva, 2002).

With respect to productive activity, the set of independent variables includes indicators for the main agricultural and livestock chains in the region, such as rice, corn, tobacco, soybean, cassava, grape, cattle, swine and poultry production. These variables capture heterogeneity in economic returns across production systems, recognising structural differences in value added, price volatility and exposure to seasonality (CEPEA, 2023; Trentin, 2023; FAO, 2023).

Finally, temporal control variables are included through quarter and year dummies for the period 2022 to 2025 in order to capture macroeconomic variation and seasonal fluctuations in agricultural activity. Occupational controls based on the Brazilian Classification of Occupations (CBO) are also incorporated, absorbing unobserved heterogeneity related to task characteristics and workers' positions within the occupational structure and refining the analysis of the determinants of income deviation.

3.5. Empirical model

Descriptive statistics are first used to characterise the sample and identify preliminary patterns in the variables of interest. Subsequently, multiple linear regression techniques are employed to estimate the association between individual, occupational, productive and temporal characteristics and fluctuations in income deviation in the study region. The baseline empirical specification is given by Eq. (1):

$$IncomeDeviation_{it} = \alpha + \beta X_{it} + \gamma Z_{it} + \delta T_{t} + \theta O_{it} + \varepsilon_{it} \quad (1)$$

Note: where $IncomeDeviation_{it}$ denotes the percentage difference between effective income and habitual income of individual i in period t; X_{it} is the vector of individual characteristics including sex, race, age and schooling; Z_{it} corresponds to occupational and sectoral variables including occupational status and agricultural and livestock activities; T_{t} represents quarter year dummies controlling for seasonal and conjunctural effects; O_{i} denotes occupation dummies based on the Brazilian Classification of Occupations capturing occupation specific heterogeneity; and ε_{it} is the random error term.

It is important to note that the adopted approach does not aim to identify causal effects of climate adversity on income deviation. The model estimates conditional relationships and patterns of association between differences in habitual and effective income and periods characterised by climate instability, without exploiting exogenous variation or causal identification strategies. Accordingly, the results should be interpreted as descriptive and analytical evidence on the dynamics of income deviation under heightened climate uncertainty, rather than as estimates of direct causal effects.

4. Analysis and Discussion of the Results

4.1. Descriptive evidence on the dynamics of income deviation in rural labor markets

The data indicate the predominance of negative income deviations over almost the entire analysed period. In nearly all quarters, effective income remained below habitual income, indicating systematic income losses among rural workers in Rio Grande do Sul. The only episode of positive deviation occurs in the first quarter of 2023, when average earnings exceeded habitual expectations (Figure 1). In the remaining quarters, recurrent deterioration in income deviation is observed, with particularly pronounced declines in the fourth quarter of 2023 and the second quarter of 2024, when average deviations reached approximately minus eight per cent. These two periods concentrate the largest relative income losses observed in the sample.

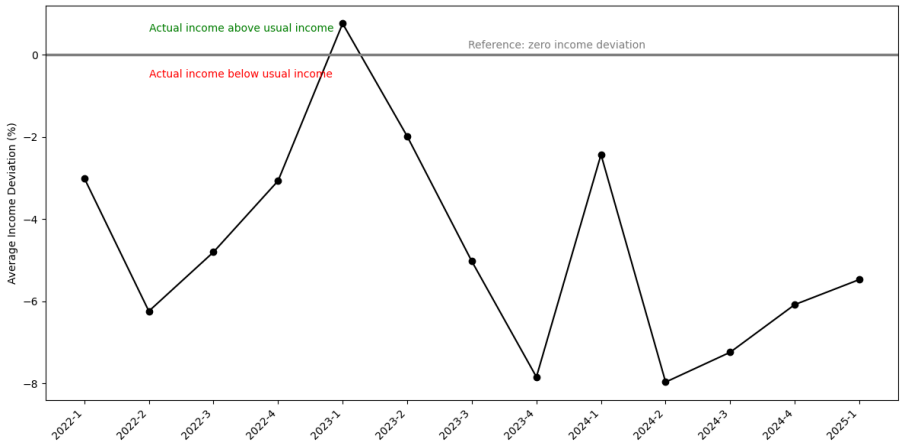

Figure 1. Average percentage income deviation in Rio Grande do Sul, 2022 Q1 to 2025 Q1.

Figure 2 presents the relationship between average percentage income deviation and selected socioeconomic characteristics. A positive association between schooling and income stability is observed. Individuals with lower levels of education exhibit systematically more negative deviations, whereas more educated workers tend to present deviations close to zero or positive. With respect to age, the distribution of income deviation appears relatively homogeneous across age groups. The analysis by sex and race reveals limited differences in the behaviour of income deviation. Men and women, as well as white and non white individuals, display broadly similar patterns over the analysed period.

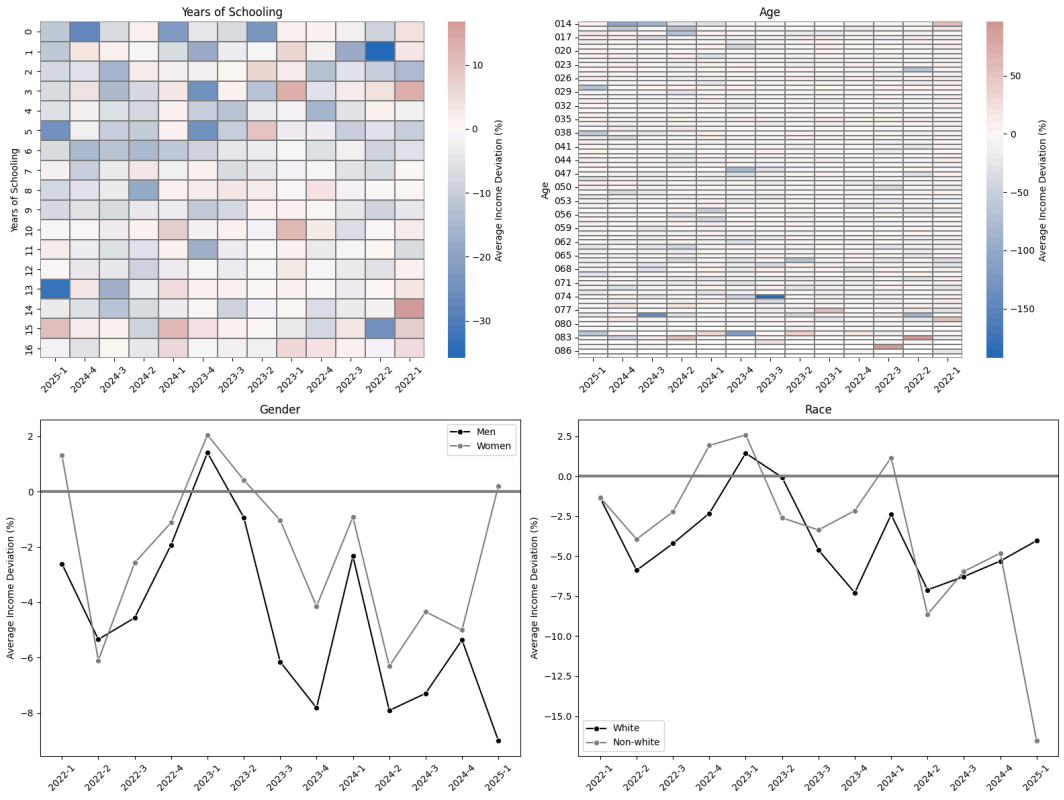

Figure 2. Average percentage income deviation in Rio Grande do Sul, by quarter, according to years of schooling, age, sex and race.

Figure 3 reports the behaviour of income deviation by occupational status, selected crops and livestock activities. Substantial differences emerge across occupational categories. Family workers display more volatile deviations, with sharp declines in some quarters, whereas formally employed workers exhibit greater relative stability. Among crops, rice presents positive deviations in several quarters, particularly in 2022 and 2024. Soybean and tobacco display higher volatility and episodes of strongly negative deviations. In livestock activities, cattle farming shows more negative deviations relative to other activities, while swine and poultry production exhibit smaller fluctuations.

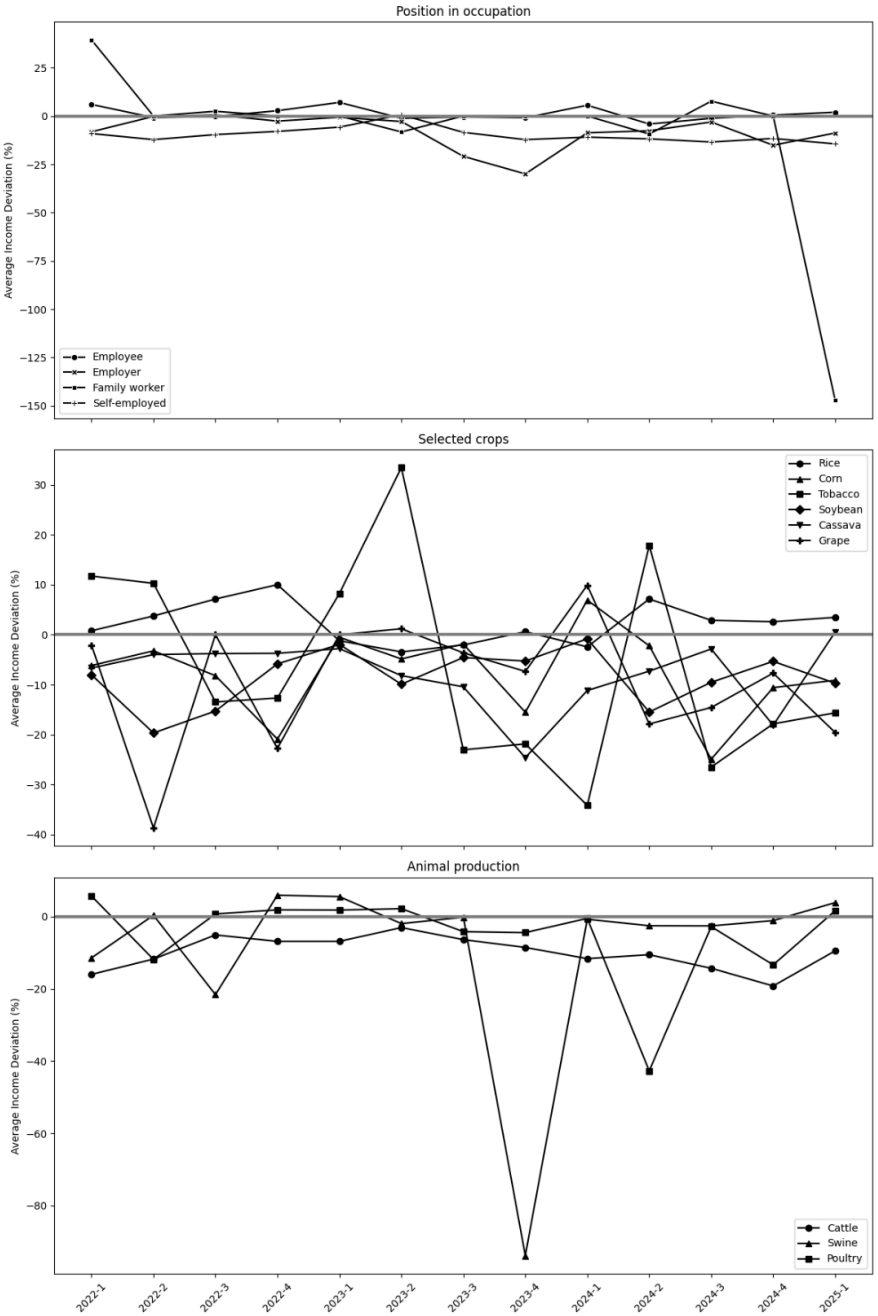

Figure 3. Average percentage income deviation in Rio Grande do Sul, by quarter, according to occupational status, selected crops and livestock activities.

4.2. Empirical evidence on the determinants of income deviation

Table 1 reports the results obtained from four alternative specifications that differ according to the progressive inclusion of controls for occupational status, sector of activity and occupational classification. Model 1 does not include occupational or sectoral controls. Model 2 incorporates controls for occupational status. Model 3 includes occupational status and occupation dummies based on the Brazilian Classification of Occupations. Model 4 simultaneously includes occupational status, sector of activity and occupation dummies. Across all specifications, the coefficients associated with sex and race do not display consistent statistical significance. In contrast, age and years of schooling are statistically significant in all models. In the fully specified model, each additional year of schooling is associated with an increase of approximately 0.35 percentage points in income deviation, indicating lower income vulnerability and greater capacity to preserve earnings during periods of instability.

The temporal dummies indicate a positive and statistically significant coefficient only in the first quarter of 2023, the only period in which average effective income exceeded habitual income. In the remaining quarters, coefficients are predominantly negative, with the largest magnitudes observed in the fourth quarter of 2023 and the second quarter of 2024, when relative income losses approach eight per cent. These results are consistent with the descriptive evidence and reflect the concentration of more severe income contractions in periods marked by heightened climate instability.

With respect to occupational status, self employed workers and employers present negative and statistically significant coefficients relative to the reference category, indicating systematically more unfavourable income deviations than those observed among formally employed workers. For family workers, although the coefficients suggest more negative deviations, the effects are not statistically significant in the most complete specification. Formally employed workers display systematically higher deviations and lower relative income volatility, consistent with greater institutional protection and more stable remuneration patterns.

Table 1. Regression analysis of percentage income deviation on explanatory variables.

	(1)	(2)	(3)	(4)
Sex (female)	1.2986	-0.1040	-0.2834	-0.4892
	(0.851)	(0.874)	(0.955)	(0.960)
Race (white)	-2.1508**	-0.1623	-0.3198	-0.2985
	(0.861)	(0.828)	(0.823)	(0.826)
Age	-0.0617**	0.0613**	0.0602**	0.0711**

	(1)	(2)	(3)	(4)
	(0.029)	(0.029)	(0.029)	(0.031)
Years of schooling	0.4363***	0.4026***	0.3083***	0.3489***
	(0.105)	(0.104)	(0.117)	(0.117)
Self employed		-10.3073***	-10.0315***	-10.0590***
		(2.728)	(2.799)	(2.787)
Employer		-11.0979***	-10.6022***	-10.7213***
		(0.839)	(0.809)	(0.800)
Family worker		-8.3299	-7.6446	-8.5657
		(6.680)	(6.711)	(6.776)
Rice				2.9003**
				(1.172)
Corn				-0.1261
				(1.151)
Tobacco				1.4486
				(2.942)
Soybean				-2.9184*
				(1.553)
Cassava				-0.6182
				(2.914)
Grape				-3.0739
				(4.011)
Cattle				-3.2075**
				(1.437)
Swine				-5.9604
				(6.118)
Poultry				0.7643
				(2.991)
2022-2	-3.3272*	-3.6122**	-3.6044**	-3.5864**
	(1.971)	(1.966)	(2.067)	(1.970)
2022-3	-1.9817	-2.3860*	-2.4265	-2.4364
	(1.618)	(1.610)	(1.610)	(1.6130)
2022-4	-0.2397	-0.8148	-0.8409	-0.8998
	(1.770)	(1.762)	(1.763)	(1.770)
2023-1	3.5977**	2.9692**	2.9889**	2.9449*
	(1.526)	(1.511)	(1.510)	(1.509)
2023-2	0.8787	0.4342*	0.4407	0.3364
	(1.573)	(1.567)	(1.567)	(1.563)
2023-3	-2.2604	-2.7940*	-2.8075*	-2.8261*
	(1.616)	(1.605)	(1.605)	(1.603)
2023-4	-5.0860**	-5.4445***	-5.4663**	-5.4983**
	(2.264)	(2.2620)	(2.264)	(2.249)
2024-1	0.2887	-0.0017	0.0302	-0.0582
	(2.076)	(2.0690)	(2.067)	(2.048)
2024-2	-5.3144**	-5.6765***	-5.6442**	-5.6581**
	(2.252)	(2.2510)	(2.250)	(2.2630)
2024-3	-4.5185**	-4.9450**	-4.9611**	-4.9602**
	(1.653)	(1.642)	(1.641)	(1.643)
2024-4	-3.3464	-3.7535*	-3.7464*	-3.7334*
	(2.118)	(2.115)	(2.115)	(2.111)
2025-1	-2.6327	-2.9686**	-3.0014	-3.0844
	(1.953)	(1.940)	(1.9400)	(1.940)
Intercept	-2.7392	-3.2106	-1.8458	-2.5063
	(2.293)	(2.274)	(3.204)	(3.281)
CBO controls	No	No	Yes	Yes
N	29.838	29.838	29.838	29.838

Notes: OLS regressions with White robust standard errors (HC0), reported in parentheses. The dependent variable is percentage income deviation. * p < 0.10, ** p < 0.05, *** p < 0.01. “CBO group included” indicates whether occupational controls were incorporated. Sector dummies (CNAE) and quarter year dummies are explicitly reported.

Regarding productive activities, rice cultivation exhibits positive and statistically significant coefficients in some specifications, suggesting greater income stability in this segment. In contrast, soybean production, and cattle farming display negative and statistically significant coefficients, indicating higher vulnerability to adverse conditions. Swine and poultry production present negative coefficients of smaller magnitude and lower statistical precision, pointing to more moderate income fluctuations in these activities.

4.3. Discussion

The results contribute to the understanding of the mechanisms through which climate shocks and structural characteristics are associated with the dynamics of income deviation in rural labor markets in Rio Grande do Sul. In line with the research questions proposed, the empirical evidence indicates that human capital, occupational status and productive composition constitute relevant dimensions for explaining heterogeneity in income vulnerability under conditions of climate instability.

With respect to human capital and life cycle dynamics, the results are consistent with Hypothesis 1. A positive and statistically robust association emerges between schooling and more favourable income deviations. More educated workers show a lower propensity to relative income losses, even in quarters characterised by heightened climate instability, suggesting a greater capacity to preserve earnings. This pattern is consistent with the literature emphasising the role of human capital in expanding access to more stable occupations and reducing exposure to productive seasonality and informality (Mincer, 1974; Machado, 2019; Costa and Pessoa, 2024). By diversifying income sources and facilitating occupational mobility, education appears as an important mechanism of economic resilience in rural areas.

Age also plays a relevant role in income stability. Older workers exhibit more favourable income deviations, whereas younger individuals show a higher propensity to relative losses. This result suggests that accumulated experience, consolidated social capital and greater insertion in stable occupations contribute to buffering the effects of adverse shocks. In contrast, the higher vulnerability observed among young workers reinforces the interpretation that early productive insertion often occurs under more precarious conditions and with limited access to protection mechanisms, in line with previous evidence for the Brazilian labor market (Moura and Barbosa Filho, 2022; IPEA, 2024).

The results also indicate the role of occupational status as a mechanism associated with income smoothing. Consistent with Hypothesis 2, workers in formal employment display

higher and less volatile income deviations than self employed workers and employers. This pattern suggests that formalisation functions as a form of protection against climate and market volatility by ensuring more regular payments and greater access to institutional protection mechanisms (Souza and Neri, 2020; Machado, 2019; Moura and Barbosa Filho, 2022).

Differences also emerge across productive activities. The results indicate substantial variation across production chains. Rice cultivation stands out as the most resilient activity, presenting more favourable income deviations in several quarters, including during critical periods. This performance suggests greater productive and institutional stability, possibly associated with adaptive management practices, stronger market organisation and the presence of more consolidated public support policies (Tanure et al., 2020; Embrapa, 2024). Differences in production systems and institutional arrangements across agricultural chains may also influence the capacity of producers and workers to absorb climatic shocks.

In contrast, soybean production, tobacco and cattle farming display greater sensitivity to climate and sanitary shocks, with pronounced income contractions in periods associated with floods and severe droughts. These results are consistent with the literature documenting the high exposure of these chains to climate risks, price volatility and recurrent production losses (Scorzini et al., 2021; Trentin, 2023; Caleffi et al., 2024). The evidence suggests that productive composition is an important determinant of income vulnerability because it shapes the degree of workers' exposure to environmental shocks. These differences also reflect the structure of rural livelihoods, in which workers' income stability depends not only on individual characteristics but also on the productive systems and institutional arrangements that shape rural labor markets.

The absence of statistically significant effects for sex and race indicates that, in the specific context analysed, climate shocks were associated with income losses across different demographic groups. This pattern suggests that during large scale disaster episodes income vulnerability may affect rural workers in a relatively widespread manner, even though structural inequalities in the Brazilian labor market remain present (IBGE, 2025; Costa and Pessoa, 2024).

5. Final remarks

This study analysed the dynamics of income deviation in rural areas of Rio Grande do Sul between 2022 and the first quarter of 2025, documenting how socioeconomic factors and climate shocks interacted to shape income fluctuations in a context of high structural

vulnerability. The results show that rural earnings were marked by recurrent losses relative to habitual income, with significant intensification in periods associated with floods and severe droughts, reflecting the fragility of rural livelihoods in the face of environmental and economic crises.

The empirical analysis indicates that schooling, age and occupational status constitute central determinants of income stability in rural labor markets. More educated and older workers displayed a lower propensity to relative income losses, whereas individuals inserted in informal, self employed or family occupations revealed higher exposure to economic volatility. These findings reinforce the role of formal education and employment formalisation as fundamental protection mechanisms against precariousness and the intensification of climate risks by expanding access to more stable occupations and institutional income smoothing instruments.

The study also documents substantial sectoral heterogeneity in responses to adverse shocks. Rice cultivation emerged as the most resilient production chain, presenting more favourable income deviations in several quarters and suggesting greater productive and institutional adaptive capacity. In contrast, soybean production, tobacco and cattle farming exhibited higher sensitivity to climate and market fluctuations, with pronounced income contractions in critical periods. These results indicate that productive composition plays a relevant role in determining economic vulnerability in rural areas.

From a public policy perspective, the findings point to the need for integrated strategies combining investment in human capital, strengthening of formal employment in rural areas and specific income protection instruments for more exposed sectors and groups. In a context of increasing intensification of extreme climate events, educational, labor and climate adaptation policies become complementary and essential to promote socioeconomic resilience and reduce the structural vulnerability of rural populations.

Among the limitations of the study, the use of observational data does not allow the identification of causal relationships between climate events, socioeconomic characteristics and income variation. In addition, the absence of qualitative information prevents capturing individual adaptation strategies, subjective perceptions of income loss and informal protection mechanisms. Future research could explore longitudinal designs, natural experiments or mixed methods approaches, incorporating qualitative evidence and exogenous variation associated with climate shocks to deepen the understanding of the underlying causal mechanisms.

This research contributes to the literature on income instability, climate vulnerability and rural development by introducing income deviation as an indicator sensitive to conjunctural fluctuations and environmental shocks. By highlighting the interaction between human capital, productive insertion and sectoral composition in shaping income stability, the study reinforces the importance of multidimensional approaches to promoting climate justice and sustainable rural development in southern Brazil.

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