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THE RELATIONSHIP BETWEEN INCOME AND DEFORESTATION IN BRAZIL: THE IMPACT OF BOLSA FAMILIA PROGRAM

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Absract

In order to contribute to the literature on the relationship between income and deforestation, this study investigates the impact of the Bolsa Familia program – one of the largest conditional cash transfer programs – on forest clearings. Using a difference-in-differences approach and an event study, we take advantage of a change in the program's allocation methodology for municipal quotas as an exogenous source. Our main findings show an increase in deforestation in both the Amazon and Cerrado biomes, with the Amazon being the main focus of clearings. Additional robustness exercises reinforce the initial results. In a complementary investigation into the mechanisms behind the main estimated impact, our evidence suggests an increase in pasture and crop areas in the Amazon, as well as a rise in cattle herd and soybean production in the Cerrado. Thus, our conclusion is that the enlargement of the Bolsa Familia program in Brazil has expanded agriculture and livestock, which, in turn, has led to an increase in deforestation.

Key-words: Bolsa Familia Program; Deforestation; Differences-in-differences; Event Study; Amazon; Cerrado.

JEL cod.: C23, H53, I38, Q50.

1 Introduction

Deforestation has been a concern in economic literature since the end of the 20th century, but recently, it has gained even more emphasis, especially in countries like Brazil, which shows negative changes in forest cover (FAO, 2020). Additionally, the country has the world's largest rainforest, the Amazon forest, which holds unique biodiversity and a large stock of stored carbon. The region also carries international relevance since it contributes to global climate regulation and South America's rainfall regime (Foley et al, 2007). Therefore, Brazil occupies a prominent place in the eyes of the international community when the subject is deforestation. Thus, studies that analyze the dynamics of forest clearing in the country are of great importance to avoid further damage.

Recently, literature investigating the effects of cash transfer programs on deforestation dynamics has emerged. Since many developing countries adopt this type of policy to address poverty, it is fundamental to know whether they have any impact on the environment, even if unintended. On one hand, cash transfers may increase the opportunity cost of leisure and, thus, discourage agricultural production (Alix-Garcia et al, 2013; Deininger & Minten, 2002). Alix-Garcia et al (2013) also argue that additional income may stimulate the adoption of more efficient technologies, reducing pressure on the loss of forest cover. On the other hand, the program might change the consumption pattern in the beneficiary households, increasing the demand for land-intensive products and encouraging deforestation by producers in an attempt to meet this new demand (Foster & Rosenzweig, 2013).

In Mexico, the cash transfer program ”Oportunidades” seemed to have increased deforestation due to a rise in recipient's demand for land-intensive goods, such as meat and milk (Alix-Garcia et al, 2013). Likewise, Gambia has also experienced an increase in the loss of forest cover as an effect of a community-oriented development program that allocated funds for rural villages in the country (Heß, Jaimovich & Schündeln, 2020). In contrast, Indonesia's conditional cash transfer program, ”Keluarga Harapan”, reduced forest cover loss by around 30%. The reduction in deforestation appears to be caused by a decrease in the consumption of goods originating from forest clearings, along with the substitution of deforestation as a form of insurance (Ferraro & Simorangkir, 2020).

In 2003, Brazil launched a conditional cash transfer (CCT) program called Bolsa Familia, which targeted families living in poverty and extreme poverty situations. The beneficiaries were required to fulfill several conditions to receive the benefit, such as attending prenatal consultations for pregnant women, participating in educational activities offered by the Brazilian Ministry of Health for lactating women, keeping children's vaccination records up to date, and maintaining minimum school attendance (MDS, 2013). The program achieved several socioeconomic impacts that, possibly, had indirect effects on deforestation. For example, there were positive impacts on education and school attendance (De Brauw et al, 2015; Cacciamali, Tatei & Batista, 2010; Sawyer, 2007), which makes it possible to argue that the awareness of the preservation of the environment may have increased among the beneficiaries. Besides, some studies also point to an increase in employment in the formal market and in the occupation rate for those who receive the benefit (Sawyer, 2007; Gerard, Naritomi & Silva, 2021; Hermeto, 2009), which may enable these individuals to stop turning to deforestation as a form of insurance and income supplement. However, the impact of the program on clearings is unknown since no study has tried to investigate this connection yet.

In light of recent investigations that have been gaining space in the literature and, so far, have produced ambiguous conclusions on the effects of cash transfer programs on deforestation, the lack of studies regarding Brazil draws attention. Especially since the country, in addition to having one of the largest rainforests, was also responsible for the implementation of one of the largest conditional cash transfer programs in the world. Thus, this study evaluates whether Bolsa Familia had a causal effect on deforestation and what direction this effect took. Particularly, it looks into the impact of the program's expansion that took place in 2009.

The analysis is carried out in a municipality-by-year panel dataset from 2006 to 2012. We use data on land cover from the MapBiomas initiative and administrative data on Bolsa Familia provided by the Brazilian Ministry of Citizenship. We combine this data with additional information at the municipal level to consider the potential confounding effects of agricultural prices and environmental policies on deforestation. Moreover, considering that the North and Northeast regions have a high coverage of aided families and that they cover the two most threatened biomes in the country, there is a concern about whether Bolsa Familia is adding to clearings in those areas. Because of that, we narrow the study to municipalities from the Amazon and Cerrado.

We conduct an event study and a difference-in-differences (DiD) research design to evaluate whether the program had an impact on forest cover. The method takes advantage of an exogenous change in the program's quotas. Due to budget constraints, not all eligible families get to receive the benefit. The total number of national slots is divided across municipalities based on poverty estimates. Then, each municipality is assigned a quota, which represents the maximum number of households that can benefit from the program in that municipality. Our empirical strategy is an application of the methodology used by Gerard, Naritomi, and Silva (2021) to measure the impact of Bolsa Familia on the local formal labor market. The authors used an expansion of quota attribution, due to changes in quota calculation, as an outlet to conduct a difference-in-difference approach.

Our main findings suggest that the expansion of Bolsa Familia had a positive and significant impact on deforestation in the Amazon and Cerrado biomes, but mostly in the Amazon. The effect seems to have been stronger in the immediate period after the expansion of the program. The results are corroborated by a series of robustness tests. In addition to reproducing our main specification with an alternative measure of deforestation, we also ran two more different specifications to further validate our results. In general, this set of findings confirms an increase in deforestation as a result of the program's expansion.

After identifying the main impact, we investigated its potential mechanisms. We followed the same strategy as before, conducting an event study for both pasture and crop areas and then robustness exercises. The evidence points to an increase in crop and pasture area, but mostly pasture, as well as cattle and soybean production as main channels. Thus, the results signal that deforestation escalated due to the expansion of agriculture and livestock.

This study outlines different features of the economic literature. First, it contributes to the wide literature relating income and deforestation. Only a few papers associate cash transfer programs and forest clearings (Alix-Garcia et al., 2013; Heß, Jaimovich, & Schündeln, 2020; Ferraro & Simorangkir, 2020). Usually, the relationship between economic growth and deforestation is explained by the Environmental Kuznets Curve (EKC) [1]. However, this line of research provides mixed evidence on the existence of an inverted U-shaped curve (Acemoglu & Robinson, 2002; Kaika & Zervas, 2013; Chiu, 2012; López-Feldam, 2014; Assa, 2021; Akbostance, Türüa-As-Ik, & Tunc, 2008). The only conclusion that seems to be unanimous is that income somehow affects

[1] The EKC states that there is an income level, characterized as a reversion point, in which income growth below this point deteriorates the quality of the environment, while income growth above it improves environmental quality. Hence, the curve also has an inverted U shape (Chen, Huang, & Lin, 2019; Kaika & Zervas, 2013)

deforestation.

The relationship between income and clearings is also extensively investigated in studies associating poverty and clearings (Deininger & Minten, 1999). Yet, in contrast, many papers indicate that higher levels of income are actually associated with deforestation (Zwane, 2007; Elburz, Çubukçu, & Nijkamp, 2019), which once again produces ambiguous conclusions.

Furthermore, authors have also explored the effects of credit on forest cover. Rural credit has a positive impact on clearings in the Amazon (Hargrave & Kis-Katos, 2013), and as Assunção et al (2020) show, reducing the availability of this type of credit decreases deforestation rates. However, credit destined for infrastructure does not seem to be a significant driver of deforestation dynamics in Brazil (Pfaff, 1999).

Nevertheless, funding from Payment for Environmental Services (PES) programs[2] has reduced deforestation in Uganda, Mexico, and Costa Rica (Jayachandran et al, 2017; Alix-Garcia, Shapiro, & Sims, 2012; Sills et al., 2008). Although Jayachandran (2013) points out that the success of PES incentives "depends on the time profile of forest owners' opportunity costs." This means that, in Brazil, for example, the incentives may not be enough to compensate for the gains from cutting trees, given that agriculture and livestock are the main cause of deforestation.

Therefore, this study adds to this broad literature by demonstrating that in Brazil, additional income destined for the poorest households increases forest clearings. Specifically, it focuses not only on the Amazon rainforest but also on the Cerrado biome, which is not usually a subject of research in publications despite its importance for the country's biodiversity. More importantly, it contributes to the ongoing discussion of the effects of cash transfer programs on forest cover by providing evidence for a well-known conditional program. Moreover, the results also contribute to the literature on the mechanisms by which income can interfere in deforestation, particularly in countries similar to Brazil, where agriculture has significant economic relevance.

Finally, this study speaks to the literature on the effects of Bolsa Familia. So far, the program has proved to be effective in improving healthcare indicators (De Brauw et al., 2012; Campello & Neri, 2013; Rasella, 2013), reducing acute malnutrition (Duarte, Sampaio & Sampaio, 2009; Pinto, 2010; Cotta et al., 2011; Oliveira et al., 2011), and raising school attendance and grade progression (Cac-

[2]Income transfers conditional on environmental conservation.

ciamali, Tatei & Batista, 2010; De Brauw et al., 2015). Additionally, despite negative comments, Bolsa Familia does not encourage beneficiary fertility (Alves & Cavenaghi, 2015; Rocha, 2018) nor discourages employment (Sawyer, 2007; Gerard, Naritomi & Silva, 2021; Hermeto, 2009). Our results point to an unintended positive impact of the program on deforestation, emphasizing the need for poverty alleviation programs to be complemented by environmental regulations. Thus, this study can also contribute to the debate about public policy design, especially cash transfer policies, since it became pronounced the importance of the sustainability aspect of public policies nowadays.

2 Institutional Context

2.1 Bolsa Familia Program

The Bolsa Familia is a conditional cash transfer program managed by the Ministry of Social Development. Originating in 2003 during President Lula's first term, the program symbolized the unification of the Federal Government's income transfer actions. Before its creation, there were similar policies that worked independently. In addition to promoting poverty and hunger alleviation for several Brazilian families, it was also designed to better monitor health care and education services. Mostly, Bolsa Familia aimed to rupture the intergenerational cycle of poverty reproduction (Brazil, 2004; Ortiz & Camargo, 2016; Campello, 2013; Paiva, Falcão & Bartholo, 2013).

According to Brazilian law nº 10.836/2004, which effectively created the Bolsa Familia program (BF), the benefits were separated into basic and variable. The basic benefit was destined for families with children living in extreme poverty; that is, households with a monthly income per capita of up to approximately US$18[3]. Meanwhile, the variable portion of the benefit was directed to poor families whose per capita income was from US$18 to approximately US$36[4], and extreme poor

[3]In the November 2021 dollar exchange rate
[4]In the November 2021 dollar exchange rate

family units with pregnant women, nursing mothers[5], children, and/or teenagers in its composition[6]. Bolsa Familia gave a new dimension to the existing system by enlarging social protection coverage to the poor population of working age[7] (Brazil, 2004; Ministry of Citizenship, 2021).

Given that investment in human capital came into focus within the debate of social protection and not just the guarantee of access to basic services, enrolled families were required to meet certain requirements in return for the continuity of the benefit. Pregnant women should attend prenatal consultations, while breastfeeding mothers should participate in educational activities offered by the Ministry of Health. On top of that, it was necessary to keep the vaccination record of children aged 0 to 7 years old updated and ensure a minimum school attendance of children and adolescents. Also, socio-educational actions were requested for children in child labor situations. If these requirements were met, enrolled families earned a basic aid of US$18 and an additional US$8.8 for each child in the household[8] [9] (Duarte, Sampaio & Sampaio, 2009; MDS, 2013).

Bolsa Familia does not use any proxy means test formula for beneficiary selection. Its eligibility is determined by self-reported family income and composition, as noted by Soares (2011), making it the only CCT program in Latin America to do so. To become eligible, families should be registered in the Cadastro Único para Programas Sociais (CadÚnico), a portal for government social programs that allows the identification of low-income families based on household information such as residence characteristics, education, work situation, and income. Additionally, families must keep their registration information up to date on the portal for the benefit to remain valid, according to Soares (2011) and the Ministry of Citizenship (2021). Gerard, Naritomi, and Silva (2021) point out that although family information is self-reported, a member of the family, preferably a woman over the age of 16, is responsible for providing truthful information about the household. Furthermore, strategies, such as audits, are employed to prevent incorrect reporting.

Although the program was planned at the federal level, it was operated in a decentralized manner

[5]Mothers who are breastfeeding their child up to six months old are considered nursing mothers if breast milk is the baby's main food (Brazil, 2004)

[6]Since 2003, there have been changes in the income ranges that define the condition of poverty and extreme poverty. However, the definition presented here is from 2021, according to the Ministry of Citizenship.

[7]Before the BF, the universal social protection system was mainly characterized by only benefits for those who lost their productive capacity (Paiva, Falcão & Bartholo, 2013)

[8]There is also an additional amount of US$10.25 for each adolescent in the family

[9]In the November 2021 dollar exchange rate

and relied on shared efforts from state and municipal administrations. Due to government budget constraints, not all eligible families received the benefit, and selection took place at the municipal level, where each municipality held a quota. The quota represented the maximum number of households that could receive the aid, and in cases where the number of eligible families exceeded the quota, priority was given to family units with the lowest per capita income and the highest number of children aged between 0 and 17 years old per household, according to De Brauw et al (2015).

Recently, the Bolsa Familia benefit values increased during the beginning of President Lula's third term. Each family now receives at least approximately US$114 as a basic benefit and an additional US$28 per child up to 6 years old. In addition, the per capita income limits that define poverty and extreme poverty situations have risen. Extreme poverty is now defined as families with a monthly per capita income equal to or less than US$20, while poor families have a monthly per capita income between US$20.01 and US$40[10]. This significant increase in benefits makes it even more relevant to study the effects of the program on forest cover, as a larger benefit can result in a more significant impact.

Along with being the largest Brazilian social program and one of the largest income transfer programs in the world, Bolsa Familia is also known for its significant success (De Brauw et al, 2015; De Sousa Camelo, Tavares & Saiani, 2009). Regarding vaccination campaigns, Bolsa Familia had a positive impact on the number of children vaccinated. Due to the prerequisite of keeping children's vaccinations up to date, the program expanded coverage of DTP and polio immunizations[11] and caused the number of children never vaccinated to fall (De Brauw et al, 2012; Campello & Neri, 2013, Rasella, 2013).

Furthermore, the program was effective in reducing child mortality, particularly deaths related to diarrhea. In addition to reducing hospitalization rates in children under five years old for both general and specific causes, the program also increased prenatal consultations (Rasella, 2013).

Bolsa Familia was successful in addressing malnutrition as well, especially in children. Along with being responsible for changing the diet of enrolled families and increasing the consumption of foods that did not undergo industrial processing, the program had a positive impact on food security

[10] In the exchange rate of late March, 2023

[11] DTP vaccination is indicated to prevent diphtheria, tetanus, and whooping cough, while polio prevents poliomyelitis, all contagious and dangerous diseases that affect the childhood stage

(Duarte, Sampaio & Sampaio, 2009; Pinto, 2010; Cotta et al, 2011; Oliveira et al, 2011; Sperandio et al, 2017). The policy also helped increase the proportion of children who were exclusively breastfed, reducing acute malnutrition among newborns and infants (Campello & Neri, 2013).

Moreover, it seems Bolsa Familia's school attendance requirements successfully impacted beneficiaries' education. Not only did the children's attendance increase, but grade progression improved as well, particularly for girls. Additionally, BF also had a reducing effect on the school dropout of recipients. Nevertheless, the findings show that older kids who benefited did not attend school exclusively, as the program also increased the incidence of child labor (Cacciamali, Tatei & Batista, 2010; De Brauw et al, 2015; Sawyer, 2007).

Nonetheless, despite the beneficial effects of Bolsa Familia on inequality and its many determinants, the program was and still is the target of excessive criticism. Seeing that the program had a pro-natalist design[12], there were issues raised regarding whether its effect, in practice, would be too pro-natalist (Rocha, 2018; Alves & Cavenaghi, 2015; Simões & Soares, 2012). However, studies have shown that this is not the case. The variable benefit destined for each additional child did not seem to compensate for the decision to have more children. Also, the probability of a beneficiary having a child once enrolled in BF is low. Therefore, the program does not show a significant effect on the fertility of the beneficiaries (Cavenaghi, 2015; Alves & Cavenaghi, 2015; Rocha, 2018).

A second criticism leveled at the program is associated with what De Oliveira (2009) calls the "laziness effect". Supposedly, the income transfer offered to the poorest strata of the population could lead to inertia on the part of families and a reduction in job offers. Furthermore, there could also be a depreciation of human capital, undermining one of the program's objectives

Anyhow, Bolsa Familia seems to have increased participation in the labor market by individuals benefited, particularly when it comes to people who did not receive any type of government assistance. The impact in the local labor market associated with BF is positive, as well as the effect on employment and job search (Sawyer, 2007; Naritomi & Silva, 2021; Hermeto, 2009).

Lastly, the program also had a beneficial influence on female empowerment. The power of women's decision-making concerning the use of contraceptives improved, in addition to decisions related to household expenses and children's health and education. Meanwhile, Bolsa Familia was

[12]The more children in the household, the greater the final benefit received

associated with greater time availability for mothers to work as well (Tavares, 2010; De Brauw et al, 2012).

The vast literature makes it clear that Bolsa Familia increased the welfare of its grantees, which probably translated into benefits for the country as a whole. Still, the effects on the environment, an essential aspect of the economy nowadays, are yet little studied. Although there are no studies referring to Brazil yet, income transfer programs in countries such as Mexico, Gambia, and Indonesia have already been subjects of impact assessments (Alix-Garcia et al, 2013; Heß, Jaimovich & Scündeln, 2020; Ferraro & Simorangkir, 2020). Hence, by evaluating the impact of the program's expansion in 2009 on the loss of forest cover, this study takes advantage of the lack of studies addressing the impact of Bolsa Familia on environmental indicators and the ambiguous possibilities that known effects might manifest to contribute to the literature, both on the effects of Bolsa Familia and on the relationship between income and deforestation.

2.2 Deforestation

Environmental conservation is a crucial element of long-term economic development, and this knowledge has brought studies and public policies to the forefront of the literature. The deterioration of pollution, greenhouse gas emissions, and deforestation has led to harmful consequences for the world's population. In addition to contributing to climate change, these actions have negative effects on biodiversity and ecosystem services, such as erosion and a decline in air and water quality. Moreover, they contribute to changes in regional precipitation patterns and reduce soil fertility (Trigueiro, Nabout & Tessarolo, 2020).

The decrease in global forest areas has mainly occurred as a result of fires, tree cutting for commercial purposes, or natural phenomena. Rapid population growth and increasing consumption are primary factors that induce land use changes worldwide by creating economic opportunities in areas close to forests. Therefore, economic agents have benefited from the removal of trees for various uses, such as a source of energy, housing construction, and making land available for agriculture. Brazil is no exception to this trend, as its extensive and diverse geography includes six ecological zones with vast biodiversity for both fauna and flora. Furthermore, the country's abundant land represents great agricultural potential. According to Austin et al (2017), Brazil is one of four tropical countries with the largest deforested areas, making it a target of surveillance regarding deforestation (Assunção et al, 2017; Arraes, Mariano & Simonassi, 2012; Garcia et al, 2017).

The Amazon is Brazil's most well-known biome as it includes the Amazon rainforest, which holds the largest reserve of tropical wood globally. The region's biodiversity is unique and contributes to its recognition as a Natural Heritage of Humanity. Additionally, one cannot overlook the significance of the region for indigenous communities, as some groups have made the Amazon their home for thousands of years, accumulating vast knowledge about the forest over time (MMA, 2023).

Due to its spatial distribution within Brazilian territory, the Amazon remained preserved for a long time. As the cities near the coast were the most important for the country's pioneering economic activities, the forest only began to be noticed when the focus of activities shifted to the peripheral regions of the country. This is the case, for example, of the creation of SUDENE (Northeast Development Superintendence) and the construction of Brasilia, symbolizing a new perception of the national space and the attractiveness of regions not considered central (Becker, 1974).

In contrast, the Cerrado has been a target of deforestation since the occupation of the Brazilian Midwest, mostly due to its potential for grain cultivation and livestock. The Cerrado is considered the second-largest Brazilian biome and holds different types of physiognomies, such as grassland, savannah, and forest formations, which guarantees great ecological diversity to the region (Arruda, Pereira Junior & Koulikoff, 2014; MMA, 2023). In addition, the biome is important for the local communities that use Cerrado products for subsistence, especially craftsmanship.

However, despite its importance, the biome has been neglected while attention (mainly international) turns solely to the Amazon rainforest. Currently, the Cerrado is considered one of the most threatened biomes on the planet. Until 2018, about half of the primary natural vegetation (49.4%) had already been suppressed. Most of these areas are currently occupied by planted pastures and annual crops (Kink & Machado, 2005; MMA, 2023; Strassburg et al, 2017).

In that regard, both of the largest Brazilian biomes are endangered by deforestation. The causes are mainly economic. Initially, as Hargrave & Kis-Katos (2013) point out, the first studies related to deforestation in the Amazon corresponded to the first stages of the occupation process in the region, and indicate that the drivers of deforestation were population growth, infrastructure development (roads, in particular), and livestock.

Currently, the motivations behind forest clearing have not changed significantly. Pfaff's (1999) land-use model also suggests that road paving in municipalities and neighboring counties, as well as independent infrastructure development projects, contribute to further deforestation. Livestock influence on the loss of forest cover is also corroborated by Fearnside (2006). The author argues that cattle pasture is the dominant land use in deforested areas, not only in areas of large commercial cattle ranches but also in smallholder farmers. Although pasture expansion seems to be responsible for most of the deforestation in the Amazon, croplands also have their share of responsibility. The spread of large-scale mechanized agriculture has changed the dynamics of forest clearings in southern Amazon, since soy production has recently been responsible for the deforestation process in the region (Macedo et al, 2012; Morton et al, 2006).

Moreover, another driver of clearings, especially in the Amazon biome, is the land market, marked by fragile property rights. The prospect of capital gain accruing from the purchase and sale of land is attractive and leads to a search for land ownership. However, land clearing is the main way of guaranteeing property rights, even if it is done illegally. The process is divided into two: illegal land grab by *grileiros* and the establishment of property rights. Ultimately, the potential profit to be obtained from cattle ranching is the underlying motivating force (Sant'anna & Young, 2010; Alston, Libecap & Mueller, 2000; Margulis, 2004).

Likewise, economic reasons are also the motivation behind forest conversion in the Cerrado. Initially, the construction of Brazil's capital, Brasília, was the main factor leading to Cerrado clearings. Because of that, land speculation and infrastructure advances were also deforestation drivers. Recently, Trigueiro, Nabout & Tessarolo (2020) showed that the density of roads can still increase deforestation in some parts of the biome. Nonetheless, pasture and agriculture are yet the biggest motivations for deforestation in the region (Sano et al, 2010).

More than 35% of the Cerrado has been replaced by pasture areas, and, although the biome has open vegetation physiognomies, unlike the Amazon rainforest, fire remains the main tool for managing or expanding the agriculture frontier. Until 2011, the expansion of pasture areas accounted for approximately 48% of the vegetation loss (Garcia et al, 2017; Garcia & Ballester, 2016). On top of that, seeing as Brazil became a major player in the global market for commodity soybean, the country has expanded further its soy production. That led to forest conversion for cropland and infrastructure to transport the products to markets. Because of the role Brazil plays in the market, there were even conversions of pasture areas to cropland to enlarge the soy industry (Nepstad et al, 2019). As Macedo et al (2012) point out, from 2001 to 2010, soybean production increased mostly due to cropland expansion into previously cleared pasture areas. According to the authors, during the period, cropland expansion for soybean production into forested areas fell, and most of the deforestation occurred due to pasture expansion. Thus, soybean production influences deforestation dynamics both directly, by the straight conversion of forests for soy cultivation, and indirectly, by replacing existing cattle pastures, which eventually will occupy other forested areas.

Having laid out the background of Cerrado and Amazon deforestation processes, it is important to point out that the North and Northeast Brazilian regions have high coverage of Bolsa Familia. In the year 2009, about 7.5 million people enrolled in the program were from these two regions, representing 60% of total coverage. Because the North and Northeast mostly cover the Amazon and Cerrado, it raises questions about whether the income transfer from Bolsa Familia has any impact on deforestation over the biomes. In this study, we address those questions. Additionally, we also seek to find the possible mechanisms leading to the impacts on forest cover.

It is not clear from the existing literature whether there should be an increase or decrease in deforestation, as there are mixed channels that can act in the process. On the production side, although frequently associated with big commercial farms, livestock as well as croplands can be essential in helping poor rural families escape the poverty trap. So, additional income can help these families not to deforest as a form of insurance (De Haan, 2001). Based on micro-foundation, higher wage (off-farm) rates are expected to reduce the probability of clearings due to a reduction in the expected profit and an increase in appreciation for non-timber uses of forests. Even though Bolsa Familia might not have induced an increase in off-farm wages, it could have raised the opportunity cost of leisure, dissuading on-farm production and reducing pressure on land in a similar way (Deininger & Minten, 2002; Alix-Garcia et al, 2013). In addition, income increases may also lead to upgrades in the technologies adopted and, in turn, improve agriculture production without the need for forest clearing (Shortle & Abler, 1999).

Meanwhile, on the consumption side, there are differing theories. According to Duroy (2005) and Foster and Rosenzweig (2003), environmental quality is considered a luxury good, which means it only becomes a concern when basic needs have been met. In that sense, Bolsa Familia might have decreased deforestation if it helped families meet their basic needs and increase their demand for environmental amenities. Foster and Rosenzweig (2003) also point out to the possibility of income growth leading to an increase in the demand for forest products. Nevertheless, that kind of response can only occur if demand for forest products rises faster than the demand for agricultural goods, which is not the case in a developing country like Brazil.

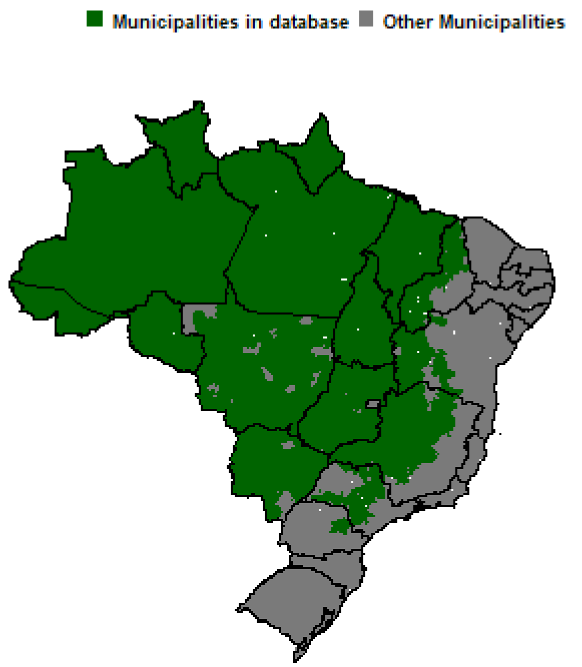
On the other hand, seeing as Bolsa Familia aids poor families, including those whose main economic activity is agriculture and livestock, the amount received by the families can fund the expansion of their production, which may increase the families' income. Although this may help families address the problem of poverty, it can also worsen deforestation, as expansion of production, especially in small businesses, translates itself into an expansion of crop and pasture areas. Moreover, if household units increase their demand for land-intensive agricultural goods (e.g. beef) due to income growth, deforestation would probably escalate (Alix-Garcia et al, 2013). This effect is more pronounced if inferior goods are relatively more land-efficient than normal goods. As Alix-Garcia et al (2012) point out: "as incomes increase, households would substitute consumption away from these inferior land-efficient goods (e.g. beans) to land-intensive normal goods (e.g. beef), thus expanding their 'ecological footprint'" (Alix-Garcia et al, 2013, pp.7). This trade might also occur due to malnutrition overcome, which can be achieved through animal food products. Even though plant-based diets can provide high-quality energy, protein, and micronutrients, their bio-availability is lower than in meat and milk (De Haan, 2001). In Brazil, the possibility of a rise in the demand for land-intensive goods is quite fair, seeing as in developing countries, meat has a high income elasticity (De Haan, 2001).

Considering our goal is to investigate the impact of the Bolsa Familia 2009 expansion on deforestation, we also look into possible mechanisms to check which of the hypotheses mentioned above apply to the Brazilian case.

3 Data

The analysis is based on a municipality-by-year panel dataset covering the period from 2006 to 2012. Figure 1 illustrates the main sample of the study, which is composed of 1848 municipalities within both the Amazon and Cerrado biomes. Two additional sub-samples are constituted from the Amazon and Cerrado separately, with 545 and 1415 municipalities, respectively.

Figure 1: Municipalities of the study samples



Note: The figure illustrates the study's main sample, which is composed of municipalities within both the Amazon and Cerrado biomes.

3.1 Data on Deforestation

The data on deforestation in Brazilian municipalities were collected through the MapBiomas project, which is based on satellite monitoring. The MapBiomas initiative was established in 2015 through collaboration between universities, NGOs, and technology companies, with the goal of creating a fast, reliable, and low-cost method to produce an annual time series of land cover and land use maps in Brazil. Since then, the collaborative network has produced annual mapping of land cover and land use, in addition to monitoring the country's water surface and fire scars. Along with publicly available georeferenced maps, the organization also provides statistics compiled through these geographic data (Projeto MapBiomas, 2022).

The deforestation data are constructed based on MapBiomas' forest land cover data, measured in hectares. Due to the heterogeneity of municipal areas, we use a normalized measure of deforestation to smooth out variations in municipality size. The structure of this measure follows the normalization in Assunção and Rocha (2019):

$$\mathbf{Deforest_{mt}} = \frac{\mathbf{AI_{mt}} - \overline{\mathbf{AI_m}}}{\mathbf{sd}(\mathbf{AI_m})}, \tag{1}$$

where *Deforest*$_{mt}$ is the normalized measure of annual deforestation for the municipality m in year t; AI_{mt} is the annual increment of deforestation[13] in municipality m in year t; $\overline{AI}_m$ is the average annual deforestation increment for the municipality m between the analysis period (2006-2012) and $sd(AI_m)$ is the standard deviation of the annual increment for the municipality m also in the period of analysis.

An alternative measure to smooth out deforestation is the inverse hyperbolic sine (IHS) measure, which is calculated as described in equation 2. The IHS measure is used in robustness exercises to test the validity of the findings.

$$\mathbf{IHS}(\mathbf{Deforestation})_{\mathbf{mt}} = \ln\left(\mathbf{x} + \sqrt{\mathbf{x^2+1}}\right), \tag{2}$$

where *IHS (Deforestation)*$_{mt}$ is the alternative measure of annual deforestation, for municipality m in year t and x is the annual increment.

3.2 Administrative Data

Data on Bolsa Familia were collected from two sources. The first source is the Brazilian Institute of Geography and Statistics (IBGE), which is responsible for providing demographic analysis and

[13] That is, the increment in year t of total deforestation for the sample period.

population studies in Brazil [14]. Data on social indicators and the 2000 Census were collected, as well as the total 2000 and 2006 municipal populations.

Additionally, data from Brazil's Ministry of Citizenship were collected. The main information used from this source was the actual municipal quotas of Bolsa Familia benefits for the years 2006 and 2009.

3.3 Controls

Data on deforestation and Bolsa Familia program were used to build the main variables in the analysis. However, subsidiary data were also used to build controls for the empirical model. The controls are mostly related to agriculture commodities prices and conservation policies, since both sets of controls are known to influence deforestation rates (Capistrano & Kiker, 1995; Angelsen & Kaimowitz, 1999; Assunção & Rocha, 2019; Arima et al, 2014).

Also provided by IBGE, we collected yearly data on Municipal GDP, and more importantly, Gross Added Value of Municipal Agriculture. We also used a series of livestock and crop prices as model controls. The construction of these indices followed the methodology described in Assunção et al (2015) and Assunção et al (2020). To structure these indices, which capture exogenous variations in the demand for agricultural commodities produced locally, we used agricultural prices in the state of Parana, as well as data from the Municipal Agricultural Survey (PAM, in Portuguese) and the Municipal Livestock Survey (PPM, also in Portuguese).

The first step in constructing the index is to weight the Parana time series prices with cross-section variation based on the local relevance of each product, including cassava, corn, rice, soybean, sugarcane, and cattle. For crops, this is done by dividing the municipal area planted for each crop by the area of the municipality. For cattle, the basis is the ratio between cattle heads and the municipal area. Next, product prices are combined into a single index using principal component analysis (PCA). PCA provides weights that best explain the variation in the dataset, resulting in a new variable called the first principal component, which includes the defining weights (Bro & Smilde, 2014).

[14] Its quantification, composition, structure and administrative political distribution, on top of demographic components such as fertility, mortality and internal migration (Oliveira & Simões, 2005).

Note that these controls are important as the prices of agricultural products and profit prospects in the sector are central to agricultural activity, which, in turn, in a country like Brazil, may be a determining factor for deforestation trends. Thus, ignoring them may introduce bias into our findings.

A set of controls regarding conservation policies was also implemented since they are considered to be determinants of deforestation in the literature. In this regard, a list provided by the Ministry of the Environment with information on Priority Municipalities is used to construct a dummy variable.[15]. Data were also collected on embargoes carried out by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA, in Portuguese) in respect of non-compliance with environmental regulations.

Lastly, following studies that show the potential of protected areas in reducing the loss of forest cover, information on whether municipalities have protected areas in their territories is also part of the study's database[16].

3.4 Other Outcome Variables

Furthermore, this paper intends to explore the possible mechanisms by which the program affects the environment. To do so, we gathered extra information from MapBiomas on Brazilian land cover – in particular, we use measures of pasture and crop areas. For the same previous reason, normalized and IHS measures are also calculated, as shown in equations 3 and 4.

$$\mathbf{NormArea_{mt}} = \frac{\mathbf{Area_{mt}} - \overline{\mathbf{Area}}_{\mathbf{m}}}{\mathbf{sd}(\mathbf{Area_{m}})}, \tag{3}$$

$$\mathbf{IHS}(\mathbf{Area})_{\mathbf{mt}} = \ln\left(\mathbf{x} + \sqrt{\mathbf{x^2 + 1}}\right), \tag{4}$$

where *Area Norm*$_{mt}$ is the normalized measure of either crop or pasture area in municipality m

[15]Priority Municipalities are municipalities included on a list established by the Ministry of the Environment, indicating the municipalities that need the most attention concerning their dynamics of recent deforestation (BRASIL, 2007).

[16]The data are available at `https://dados.gov.br/dataset/unidadesdeconservacao`.

in year t; $Area_{mt}$ is the annual area occupied by crop or pasture activity in municipality m in year t; $\overline{Area}_m$ is the average annual crop or pasture area for the municipality m between sample period (2006-2012) and $sd(Area_m)$ is the standard deviation; $IHS\ (Area)_{mt}$ is the alternative measure of either crop or pasture area, for municipality m in year t and x is the annual area in either activity.

Additional data from Brazilian surveys PAM and PPM, namely cattle heads and soybean production (in R$ value), are also used in this study. From IBGE, other components of the economy's Gross Added Value are collected. Besides agricultural added value, which is used as an outcome variable in some regression specifications, industry and services added value are also components of our database.

Table 1 summarizes the data described above in all three samples of analysis.

4 Empirical Strategy

In this study we evaluate Bolsa Familia program's impact on deforestation in the Brazilian Amazon and Cerrado biomes. To do so, we explore the timing of the 2009 program expansion due to changes in the methodology used to allocate municipal quotas, following Gerard, Naritomi and Silva (2021)'s approach. The methodological change in the BF provides a fitting source of exogenous variation for applying a differences-in-differences research design. Furthermore, we also used a differences-in-differences approach to investigate the mechanisms leading to the effects on deforestation.

4.1 Allocation of BF Quotas

As already mentioned, every year, a part of the eligible families is not entitled to the benefits due to federal budget restrictions. The federal budget sets the total number of slots available for beneficiaries. The total number, in turn, is divided by all Brazilian municipalities in the form of quotas, which represents the maximum number of families that can be attended by the program in

Table 1: Descriptive statistics

	Amazon and Cerrado biomes	Amazon	Cerrado
ΔQuota	0.0059	0.0072	0.0053
	(0.0293)	(0.0346)	(0.0269)
Deforestation	586.4361	1253.5044	386.7573
	(3125.4405)	(5218.4151)	(1741.6404)
Normalized Deforestation	-0.0393	-0.0628	-0.0333
	(0.9092)	(0.8872)	(0.9148)
IHS Deforestation	1.5841	1.9914	1.5525
	(6.2979)	(7.2338)	(5.9480)
Pasture Area	60722.5277	101397.4947	49839.8495
	(102117.4945)	(134504.7215)	(87500.9120)
Normalized Pasture Area	-0.0012	0.0867	-0.0293
	(0.8654)	(0.8514)	(0.8683)
IHS Pasture Area	10.4284	11.3208	10.1834
	(2.1256)	(1.6601)	(2.1892)
Crop Area	12557.2624	10584.0916	15523.6955
	(40418.1028)	(50316.0023)	(45038.1811)
Normalized Crop Area	0.1301	0.0949	0.1473
	(0.8585)	(0.9118)	(0.8352)
IHS Crop Area	6.2948	5.0617	6.7964
	(3.8054)	(3.2574)	(3.9045)
Cattle (log)	10.2286	10.4260	10.2237
	(1.5357)	(1.9214)	(1.3609)
Soybean Production (log)	9.2355	9.5376	9.2893
	(1.9944)	(2.2651)	(1.9641)
Agriculture Added Value (log)	9.7288	9.9283	9.6699
	(1.2940)	(1.0903)	(1.3593)
Industry Added Value (log)	8.9560	8.8762	8.9772
	(2.0181)	(1.7937)	(2.0808)
Services Added Value (log)	10.1099	10.0305	10.1424
	(1.6044)	(1.4756)	(1.6477)

Note: The table presents the means and standard deviations (in parentheses) for the main sample and two sub-samples.

that location. The quotas allocated to each municipality are based on poverty estimates made by the IBGE, based on census data and sample surveys. Considering the program's coverage limitation, the use of quotas based on these specific estimates helps to better target households in greater need (Gerard, Naritomi, & Silva, 2021; Barros et al., 2008; Cutrim, 2019).

According to Gerard, Neritomi, and Silva (2021), the initial total number of slots was set in the year 2003, even before the program was launched, at 11.2 million. Then, in 2006, that number was revised and decreased slightly to 11.1 million. Until 2006, the program had not reached its national cap, mostly because in the first few years, beneficiaries of other welfare programs were still being transferred to BF, and municipalities were still registering new families in Cadastro Unico. In 2009, there was a significant increase in the number of slots, around 15%, to 13 million. The timing of the expansion coincides with changes in the methodology used to allocate municipal quotas (Gerard, Neritomi, & Silva, 2021).

The initial methodology for quotas attribution also dates back to 2003 and stayed the same, with slight modifications, until 2006. One of the elements used in the calculus was the number of poor families in each state, based on a "poverty line" established by micro-data from National Household Sample Survey (PNAD in Portuguese)[17] – which corresponds to half the minimum Brazilian wage per capita. Another element used was the number of households in each municipality with a total income of less than two minimum wages, based on Brazil's 2000 Census (Gerard, Naritomi, & Silva, 2021).

Meanwhile, the calculation of 2006 quotas needed a minor update due to population growth of municipalities. Therefore, a component referring to such growth was included in the estimates (Gerard, Naritomi & Silva, 2021). The calculation of quota allocation for the years 2003 and 2006 follows the formulas presented, respectively, in equations 5 and 6:

$$\mathbf{Quota}_{\mathbf{ms}}^{\mathbf{2003}} = \frac{\mathbf{Poor}_{\mathbf{ms}}^{\mathbf{2000}}}{\sum_{\mathbf{K}\in\mathbf{s}} \mathbf{Poor}_{\mathbf{ks}}^{\mathbf{2000}}} \cdot \mathbf{Poor}_{\mathbf{s}}^{\mathbf{2001}} \tag{5}$$

[17]The 2001 PNAD was used to construct 2003 quotas, while the 2004 PNAD was used to calculate 2006 quotas, when there was a small revision in the methodology (Gerard, Naritomi, & Silva, 2021).

$$\mathbf{Quota_{ms}^{2006}} = \frac{\mathbf{Poor_{ms}^{2000}} \cdot \mathbf{n_{ms}^{[2000,2003]}}}{\sum_{\mathbf{K}\in\mathbf{s}}\left(\mathbf{Poor_{ks}^{2000}} \cdot \mathbf{n_{ks}^{[2000,2003]}}\right)} \cdot \mathbf{Poor_{s}^{2004}} \tag{6}$$

where $Quota_{ms}^{2003}$ and $Quota_{ms}^{2006}$ are the quotas for 2003 and 2006, respectively, for the municipality *m* in state *s*; $Poor_{ms}^{2000}$ is the number of families considered poor in the municipality *m* in the state *s*, based on the 2000 Census; $Poor_{s}^{2001}$ and $Poor_{s}^{2004}$ are the number of poor families in each state, according to PNAD 2001 and 2004, respectively; and $n_{ms}^{[2000,2003]}$ is an estimate of the population growth in each municipality between 2000 and 2003.

However, in 2009, a change in the methodology used in quota calculation was implemented. This change was carried out progressively between the second and fourth quarters of 2009. Fundamentally, one of the elements used in the methodology did not change significantly. IBGE continued to use PNAD to calculate the number of poor families in each state, but it started to be calculated using the PNAD 2006. However, the institute abandoned the use of the Census and replaced it with the use of poverty maps. The procedure was developed by a group of World Bank researchers (Gerard, Naritomi & Silva, 2021; Elbers, Lanjouw & Lanjouw, 2003).

In the World Bank researchers' opinion, although household surveys can be used to calculate distributional measures, ”at low levels of aggregation these samples are rarely representative or of sufficient size to yield statistically reliable estimates” (Elbers, Lanjouw & Lanjouw, 2003, pp. 355). They also believe that census data measure income and consumption poorly, even though they are of sufficient size to allow proper disaggregation. The authors created a method for poverty mapping that combines household survey income and expenditure data with population census data[18] (Elbers, Lanjouw & Lanjouw, 2003).

Accordingly, the Brazilian Institute developed a statistical model based on Elbers, Lanjouw, and Lanjouw's studies to predict the number of poor households that would exist in each municipality in the 2000 census based on prior data on municipal-level variables. To construct the poverty map, IBGE used information from the Household Budget Survey (POF, in Portuguese) about per

[18] According to the authors, the smaller but richer data is used to estimate the joint distribution of a household-level variable of interest *(y_h)* and a vector of covariates *(x_h)*. Then, by restricting the set of explanatory variables to those that can be linked to households in the census data, this estimated distribution can help generate the distribution of variable y_h for any sub-population in the larger sample. This, in turn, allows the construction of the conditional distribution of an indicator of poverty or inequality based on the distribution of y_h (Elbers, Lanjouw & Lanjouw, 2003).

capita household spending and imputed that information in the 2000 Census, enabling estimations of poverty and inequality measures. Then, the institute used the same model but with 2006 data to predict the number of poor families in each municipality in 2006 (Gerard, Naritomi & Silva, 2021; IBGE, 2008). Thus, the new quota calculation is presented in equation 7.

$$\mathbf{Quota_{ms}^{2009}} = \frac{\mathbf{\hat{Poor}_{ms}^{2006}}}{\sum_{\mathbf{K \in s}} \mathbf{\hat{Poor}_{ks}^{2006}}} \cdot \mathbf{1.18} \cdot \mathbf{Poor_{s}^{2006}} \tag{7}$$

where $Quota_{me}^{2009}$ is the municipal quota for 2009 in municipality *m* in state *s*; $\hat{Poor}_{ms}^{2006}$ is the predicted number of poor families in each municipality *m* and state *s* in 2006, according to the IBGE model; $Poor_{s}^{2006}$ is the number of poor families in each state in 2006 and $\sum_{K \in s} \hat{Poor}_{ks}^{2006}$ is the sum of the number of poor families in each municipality within each state in 2006.

Since it was not possible to access the IBGE forecast model that gives the exact number of quotas, in the present study, we use data on the number of families benefited by the program in 2009 as a proxy for the municipal quota. That is, the actual number of households assisted by Bolsa Familia, which is a close approximation to the numbers defined by the model.

It is worth noting, however, that the new methodology was short-lived. The poverty map was only used in 2009. In 2012, the IBGE had already returned to using census data to calculate quota allocations. However, this time, the information gathered was from the 2010 census (Gerard, Naritomi & Silva, 2021).

4.2 Research Design

In order to find out whether Bolsa Familia had any effect on Brazilian deforestation, an impact assessment is one of the most suiting approaches. In the present study, we use a quasi-experimental technique known as differences-in-difference along with an event study to conduct our impact evaluation.

However, to conduct this type of analysis for Bolsa Familia, the intervention in question needs to be an exogenous variation and the endogeneity present in determining the number of aided families in each municipality is an obstacle to that.

Fortunately, the procedure adopted by Gerard, Naritomi and Silva (2021), based on the methodological change of the BF program, provides a source of exogenous variation for applying a differences-in-differences approach. The change in the quotas calculation generated an expansion of the program and a variation in the number of new beneficiaries in some of the municipalities. This change did not depend, for example, on govern policies or inclinations and much less on whether a municipality deserved a bigger quota then the other. The expansion of Bolsa Familia occurred simply due to a change in the formulas used to calculate quotas, since the previous methodology was viewed as flawed. This, in turn, provides a unique opportunity for the construction of the analysis.

The authors calculated the difference between the actual 2009 quotas and the "counterfactual quotas" (i.e., the 2009 quotas if they were calculated with the initial methodology) to assign control and treatment groups. The counterfactual quotas were estimated as shown in Equation 8:

$$\mathbf{CountQuota_{ms}^{2009}} = \frac{\mathbf{Poor_{ms}^{2000} \cdot n_{ms}^{[2000,2006]}}}{\sum_{\mathbf{K \in s}} \left(\mathbf{Poor_{ks}^{2000} \cdot n_{ks}^{[2000,2006]}} \right)} \cdot \mathbf{1.18 \cdot Poor_{s}^{2006}} \tag{8}$$

where $CountQuota_{ms}^{2009}$ is the counterfactual quota for 2009 in the municipality *m* in the state *s*; $n_{ms}^{[2000,2006]}$ is an estimate of population growth in each municipality between 2000 and 2006 and the state-level constant, $1.18.Poor_{s}^{2006}$, is simply the sum of the 2009 quotas across the municipalities in each state.

Then, the authors created a variable of relative change of 2009 quotas.

$$\mathbf{\Delta Quota_{ms}^{2009}} = \frac{\mathbf{Quota_{ms}^{2009} - CountQuota_{ms}^{2009}}}{\mathbf{Pop_{ms}^{2006}}} \tag{9}$$

where $\Delta Quota_{ms}^{2009}$ is the relative change variable of the quotas and Pop_{me}^{2006} corresponds to the population of the municipality in 2006.

When analyzing the distribution of the variable $\Delta Quota_{ms}^{2009}$, Gerard, Naritomi, and Silva (2021) showed that no beneficiary was forced to leave the program and that there was a significant increase in the number of beneficiaries in the top 50% municipalities in the distribution of the relative difference. Therefore, the reform increased the number of beneficiaries in some municipalities but not in others. In their analysis, the municipal units that had an increase are part of the treatment group, while the remaining municipalities are part of the control group.

Although we based our empirical strategy on their approach, we made some modifications to better suit our analysis. Instead of dividing our sample into treatment and control groups, we chose to use $\Delta Quota_{ms}^{2009}$ linearly[19]. Additionally, Gerard, Naritomi, and Silva (2021) conducted a study with national coverage, whereas our study focuses solely on the Amazon and Cerrado biomes.

We conducted an event study that involves creating dummies indicating the time before and after the expansion from 2006 to 2012 (except for the year 2009) and interacting them with $\Delta Quota_{ms}^{2009}$. The event study is considered an extension of the differences-in-differences (DiD) approach, aimed at testing whether the policy change had an effect on the outcome before it actually occurred. The presence of pre-trends is judged as a sign of endogeneity (Freyaldenhoven, Hansen, & Shapiro, 2019).

Our main specification of the model, based on the modifications mentioned above, is expressed in equation 10:

$$\boldsymbol{Var_{m,s,t} = \alpha_m + \theta_t + \lambda_{st} + \sum_{p \neq 2009} \beta_p \Delta Quota_{ms}^{2009} \times (Year_{ms} \in p) + \sum_{k} X_{m,e,t} + \varepsilon_{m,e,t},} \tag{10}$$

where $Var_{m,s,t}$ represents one of the variables ($IHS_{m,t}$ or $Deforest_{m,t}$) for the municipalities *m* of the state *s* in the period *t*; α_m and θ_t are, respectively, municipality and year fixed effects; λ_{st} represents state-specific linear trends; $Year_{ms}$ is a dummy indicating the periods in p = (2006, 2007, 2008, 2010, 2011, 2012); *k = (1,2,3,...,K)* is the number of control variables and $X_{m,s,t}$ is the vector of controls. The specification also includes two-way clustering for municipalities and for an interaction between micro-region and year. The inclusion of clusters is important to estimate robust standard errors in order to avoid autocorrelation between error terms – errors within the same municipality over time and between municipalities in each microregion in each period of time.

Further, we conducted a series of robustness tests to check the validity of our findings. Firstly,

[19] Later in the study, the samples are divided between control and treatment, but only as a form of conducting a robustness check.

we ran a difference-in-difference model with the main variable being an interaction between a dummy $Post2010_{ms}$ indicating periods before or after the expansion and $\Delta Quota_{ms}^{2009}$. Note that the dummy refers to the year 2010 because the change in methodology occurred along the second and fourth quarter of 2009, and therefore the effects on deforestation may not be as clear using that year as the division. We also applied this same specification to an alternative sample that employs PRODES data from the National Institute for Space Research (INPE) for the Amazon biome. Lastly, we employed a model similar to Gerard, Naritomi, and Silva (2021)'s main specification, using the $\Delta Quota_{ms}^{2009}$ distribution to construct a dummy indicating whether a municipality is part of the treatment or control group. Following Gerard, Naritomi, and Silva (2021), municipalities in the top 50% of the $\Delta Quota_{ms}^{2009}$ distribution form the treatment group, while the remaining 50% form the control group. We then interacted the dummy with $Post2010_{ms}$. The two specifications implemented in the robustness exercises are shown below:

$$\mathbf{Var_{m,s,t}} = \alpha_{\mathbf{m}} + \theta_{\mathbf{t}} + \lambda_{\mathbf{st}} + \beta \mathbf{\Delta Quota_{ms}^{2009}} \times \mathbf{Pos2010_m} + \sum_{\mathbf{k}}^{\mathbf{K}} \mathbf{X_{m,s,t}} + \varepsilon_{\mathbf{m,s,t}} \tag{11}$$

$$\mathbf{Var_{m,s,t}} = \alpha_{\mathbf{m}} + \theta_{\mathbf{t}} + \lambda_{\mathbf{st}} + \beta \mathbf{Treat_{m,s}} \times \mathbf{Pos2010_m} + \sum_{\mathbf{k}}^{\mathbf{K}} \mathbf{X_{m,s,t}} + \varepsilon_{\mathbf{m,s,t}} \tag{12}$$

Note that, similar to the main specification, equations 11 and 12 also include municipality and year fixed effects, state-specific linear trends, and two-way cluster for municipalities and micro-region-year. All results are presented in the next section.

After exploring the impact of the Bolsa Familia program on deforestation, we investigated its potential mechanisms. As mentioned, there are mixed theories on how income can affect forest conversion. An increase in household income can either increase the opportunity cost of leisure, discouraging agricultural work, or it can allow technology improvements, enhancing the efficiency of agricultural activities, leading to a decline in deforestation. However, if Brazil has a high income elasticity for land-intensive agricultural goods, an increase in income can expand the demand for those goods and produce added pressure on forests (Da Haan, 2001; Alix-Garcia et al., 2012; Deininger & Minten, 2002; Shortle & Abler, 1999).

To test these hypotheses, we adopted a model equivalent to equation 10, but instead of using deforestation measures, we use measures of pasture and crop areas, since these are potential mechanisms for the effect of the Bolsa Familia program. Moreover, since pasture and crop areas might carry heterogeneity due to municipality size, we used two alternative measures (equations 3 and 4) rather than the area itself. The only modification to the specification is that agriculture gross added value is not included in the control vector, as it is also an outcome variable in the mechanisms analysis.

Along with the main results, we also run robustness exercises to check the validity of our results with respect to channels leading to the main impact. Likewise, we run specifications similar to equations 11 and 12, minus agriculture gross added value as a model control. In addition, cattle heads and soybean production (in value), agriculture, industry, and services added values (all in log) are outcome variables as well. All results are displayed in section 6.

5 Results

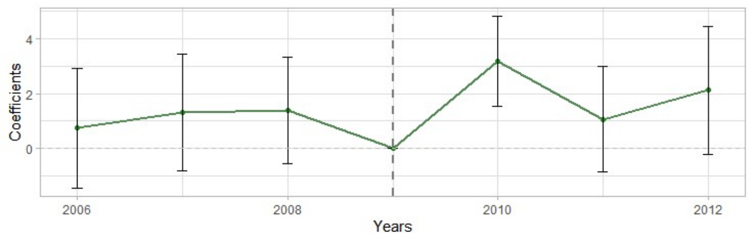
5.1 Impact on Deforestation

Figure 2 plots the estimated coefficients for the effect of Bolsa Familia expansion on forest clearing based on the event study presented in equation 10. The deforestation measure is the normalized measure indicated in equation 1. On the vertical axis are the estimated impacts of BF on deforestation, while on the horizontal axis are the periods before and after the change in the quota calculation methodology (pre and post periods are separated by the dashed grey line).

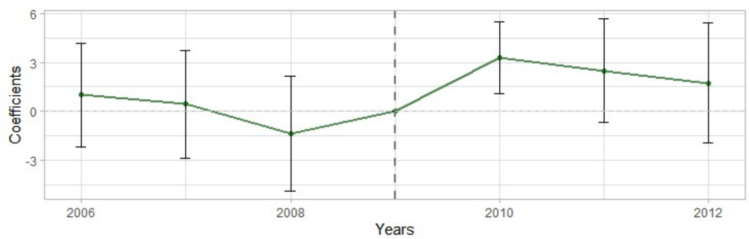
Results indicate, in general, a positive effect of Bolsa Familia expansion on deforestation. That is, the change in quota allocation methodology seems to have increased forest clearings in municipalities with higher quotas. All three samples present upward jumps right after the methodology change in 2009. Furthermore, in the Amazon biome the impact appears to be more pronounced, considering the descending trend in the period pre 2009. Therefore, it can be argued that exposure to Bolsa Familia, when enlarged, may lead to greater forest clearing.

Figure 2: Bolsa Familia's effects on deforestation

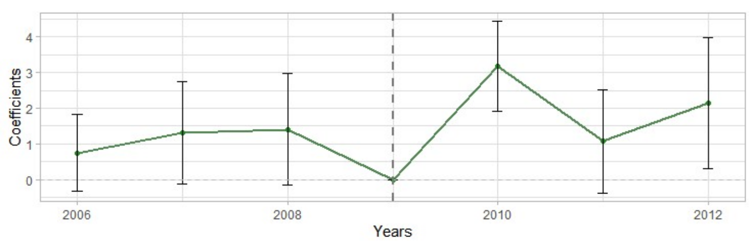
(a) Amazon and Cerrado biomes



(b) Amazon



(c) Cerrado



Note: The graph reports the estimated impact of Bolsa Familia on the normalized deforestation measure before and after the methodological change in the program in the Amazon and Cerrado biomes. The green dots represent the estimated average effects specific to the sample years, while the whiskers represent 95% confidence intervals.

All estimates shown are statistically significant at a 0.05 significance-level. That is, there is a 5% chance that we argue in favor of a positive effect in deforestation that, in fact, does not exist. Particularly, for the Amazon, the estimates are statistically significant at a 0.01 significance level. Quantitatively, for 2010, when the effect seems to be more concentrated, a point estimate of 3.168 suggests that an one standard deviation increase in ΔQuota leads to a 0.11 standard deviation increase in municipal deforestation[20]. Moreover, at the end of the sample period, an increase of one standard deviation in municipal quotas seems to have caused an increase of 0.07 standard deviations, indicating a decreasing effect of the methodological change over time.

[20]Considering the standard deviation of ΔQuota in Amazon's sample is 0.0347

5.2 Robustness checks

To test the validity of our results, figure 3 presents an event study using the inverse hyperbolic sine as the primary variable to determine whether the choice of normalization in our first measure has influenced our main findings. The most significant estimates are observed in 2010, shortly after the methodological change. The results generally show similar trends, albeit milder, to those in Figure 2, supporting our initial findings of a positive effect from Bolsa Familia. This exercise also demonstrates that the normalization formula chosen for deforestation is not biasing our original results.

Table 2 shows the estimates for a second set of robustness exercises. We run both a difference-in-differences model using $\Delta Quota_{ms}^{2009}$ linearly, as shown in equation 11, and a model using $Treat_{m,s}$, as indicated in equation 12.

We observe positive and sizable estimates across most specifications, with only three of them not being statistically significant. The estimates are significant at least at 10%. Together, the evidence supports the initial findings, suggesting a rise in forest clearings after the 2009 methodological adjustment. Once more, the Amazon shows a predominant effect in both Mapbiomas and PRODES samples. For the MAPBIOMAS sample, the table reports an estimate of 2.497 at a 0.01 significance level, while for the PRODES sample, the estimate is smaller and less significant – 1.587 at a 0.1 significance level.

Overall, the results indicate a significant impact of Bolsa Familia on deforestation. This suggests that CCT programs can have a meaningful impact on environmental quality, in this case, in a harmful way. However, it is important to point out that forest conservation was never the primary goal of Bolsa Familia and, therefore, in that sense, the program did not fail. The project was launched during a period when the concern regarding hunger was highlighted, and it may have overshadowed concerns about the environment throughout its formulation. Still, the evidence cautions that policymakers should complement poverty alleviation programs with environmental regulation to mitigate the unintended consequences of such programs.

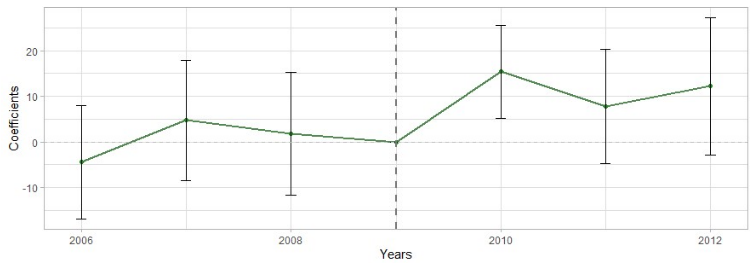
Table 2: Bolsa Familia's effects on deforestation: robustness checks

	MAPBIOMAS						*PRODES*
	Amazon and Cerrado biomes		**Amazon**		**Cerrado**		**Amazon**
	Normalized Deforestation						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ΔQuota*Post 2010	1.273*		2.497***		0.638		1.587*
	(0.675)		(0.842)		(0.916)		(0.919)
Treated*Post 2010		0.052		0.115*		0.038	
		(0.043)		(0.066)		(0.051)	
Priority Municipalities	−0.621***	−0.614***	−0.596***	−0.583***	−0.225	−0.226	−0.298***
	(0.106)	(0.107)	(0.106)	(0.106)	(0.230)	(0.230)	(0.087)
Protected Areas	−0.152	−0.155	0.102	0.104	−0.217	−0.218	0.073
	(0.137)	(0.137)	(0.203)	(0.198)	(0.179)	(0.179)	(0.249)
Embargoes$_{(t-1)}$	−0.006	−0.006	−0.017	−0.016	0.026	0.026	−0.004
	(0.012)	(0.012)	(0.013)	(0.013)	(0.019)	(0.019)	(0.010)
Crop Index$_{(t-1)}$	−0.0001	−0.0001	−0.00002	−0.00001	−0.00005	−0.00005	0.001***
	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Cattle Index$_{(t-1)}$	−0.011***	−0.011***	−0.009*	−0.008*	−0.011**	−0.011**	0.016***
	(0.003)	(0.003)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)
Agriculture Added Value$_{(t-1)}$	0.00000	0.00000	−0.00000	−0.00000	0.00000*	0.00000*	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)

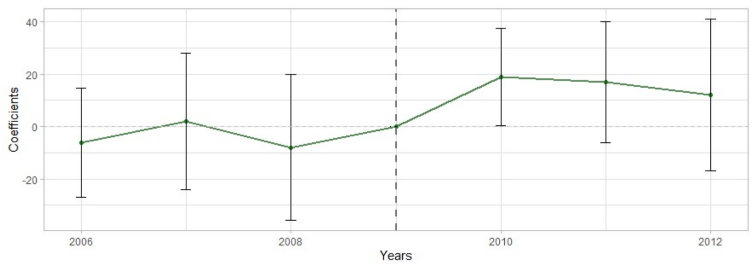
Notes: The table includes four samples of study: three MAPBIOMAS samples and the PRODES sample for the Amazon biome. All columns include municipal and year fixed effects, as well as state-specific linear trends. Robust standard errors are clustered at the municipality and micro-region-year level. The estimates in columns (1), (3), (5), (7), and (8) are based on a difference-in-difference approach using $\Delta Quota_{ms}^{2009}$, while columns (2), (4), and (6) are based on a difference-in-difference approach using $Treat_{m,s}$. Significance: *p<0.1; **p<0.05; ***p<0.01

Figure 3: Bolsa Familia's effects on deforestation: alternative measure

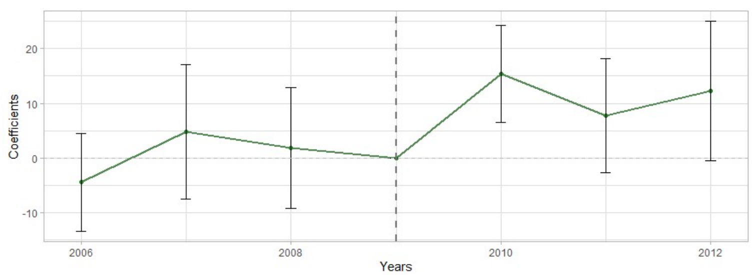
(a) Amazon and Cerrado biomes



(b) Amazon



(c) Cerrado



Note: The graphs report the estimated impact of Bolsa Familia on the inverse of hyperbolic sine measure, before and after the methodological change in the program in the Amazon and Cerrado biomes. The green dots represent the estimated average effects specific to each year in the sample, whereas the whiskers represent 95% confidence intervals.

6 Mechanisms

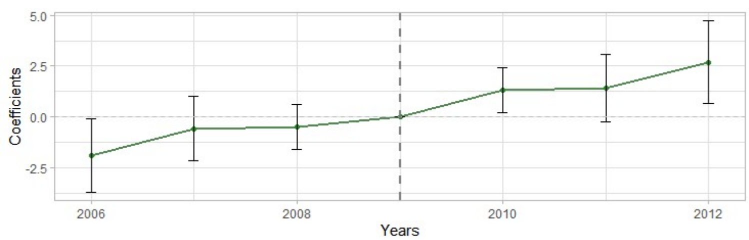
In order to better contribute to the discussion on designing poverty alleviation programs that do not cause additional damage to the environment, it is important to take into account how the impacts on the environment are mediated through markets. The results of our investigation regarding the mechanisms behind the positive effect of the BF program on deforestation can be seen below.

6.1 Pasture Area Expansion

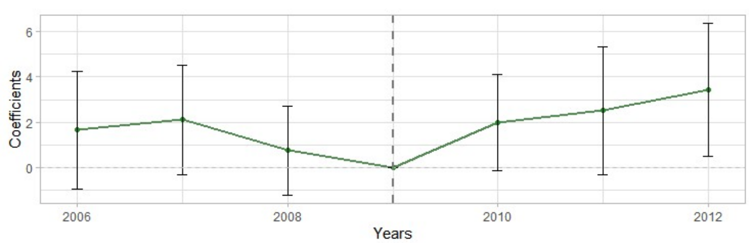
Since the literature points to pasture and croplands being the ultimate motivation behind the loss of forest cover, it seems reasonable to investigate whether those types of land use were also affected by the Bolsa Familia expansion. First, we ran the event study model presented in equation 10 using a measure of normalized pasture area (equation 3) as $Var_{m,s,t}$. Figure 4 reports the results.

Figure 4: Bolsa Familia's effects on pasture area

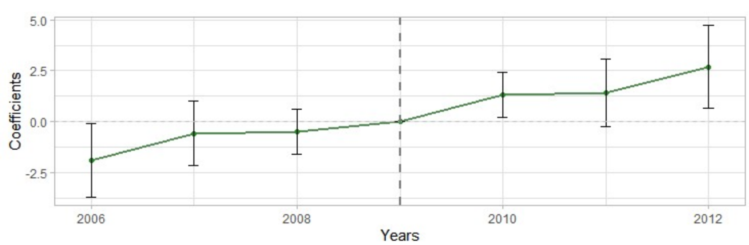
(a) Amazon and Cerrado biomes



(b) Amazon



(c) Cerrado



Note: The graphs show the estimated impact of the Bolsa Familia program on the normalized pasture area measure, before and after the methodological change in the program, in the Amazon and Cerrado biomes. The green dots represent the estimated average effects specific to the sample years, while the whiskers represent the 95% confidence intervals.

Figure 4 shows increasing trends in pasture areas after the expansion of the Bolsa Familia program. In the Cerrado biome, this effect is more noticeable in 2012, with an estimated coefficient close to 2. However, the results for the biome are not statistically significant. In contrast, the Amazon biome shows differing trends in the pre and post expansion periods, which suggest an increase in lands destined for livestock caused by the Bolsa Familia program. These results, in turn, are statistically significant at the 0.1 significance level (with the estimate for the year 2012 being significant at the 0.05 significance level).

We also conducted two additional tests to check the validity of our findings. Analogous to the main results, we ran a difference-in-differences approach using $Treat_{m,s}$ and $\Delta Quota^{2009}_{ms}$. Tables 3 and 4 present the results.

Table 3: Bolsa Familia's effects on pasture area: robustness checks

	Amazon and Cerrado biomes	**Amazon**	**Cerrado**
	Normalized Pasture Area		
	(1)	(2)	(3)
ΔQuota*Post 2010	2.533***	1.511	2.667***
	(0.826)	(1.024)	(1.017)

Notes: The table reports estimates for the coefficient of the interaction of $\Delta Quota^{2009}_{ms}$ and *Post2010*, referring to the specification in equation 11. The table includes the three main samples. All columns include municipal and year fixed effects, as well as state-specific linear trends. Robust standard errors are clustered at the municipality and micro-region-year level.

The evidence in Table 3, which reports estimates for the DiD with $\Delta Quota^{2009}_{ms}$, is slightly controversial in relation to Figure 4. It shows a positive and significant effect for the Cerrado biome and, although positive, a non-significant effect for the Amazon. However, the specification may not be capturing a significant effect as there was a reduction in pasture in the period prior to the methodological change. Meanwhile, Table 4 corroborates our findings from Figure 4, mainly for the Amazon biome. We observe an impact of 0.159 at a 0.05 significance level using the normalized measure. On the other hand, for the Cerrado, the impact based on this approach seems to be negative, although not significant.

Overall, it can be argued that Bolsa Familia led to an increase in the area of pasture in the Amazon. Anyhow, the results still need to be read with caution, considering the mixed results from Table 3 and 4.

Table 4: Bolsa Familia's effects on pasture area: robustness checks

	Amazon and Cerrado biomes	Amazon	Cerrado
	Normalized Pasture Area		
	(1)	(2)	(3)
Treat*Post 2010	0.036	0.159**	−0.005
	(0.045)	(0.081)	(0.051)

Notes: The table reports estimates for the coefficient of the interaction of $Treat_{ms}$ and *Post2010* referring to specification in equation 11. The table includes the three main samples. All columns include municipal and year fixed effects, as well as state-specific linear. Robust standard errors are clustered at the municipality and micro-region-year level.

6.2 Crop Area Expansion

As croplands seems to grow at the same rate, or even faster, than livestock areas in the Amazon, but mostly in Cerrado (Börner & Wunder, 2008; Nepstad et al, 2019), we perform an investigation regarding crop areas much similar to the previous exercises.

Figure 5 reports the event study results. For the Amazon biome, figure 5 (b) shows positive effect of the program on croplands, especially considering the descending trend pre 2009. At the same time, for Cerrado, the Bolsa Familia effect appears to kick in only in 2012, set out in the jump on figure 5 (c) at the end of our period analysis.

On further econometric exercises, presented in table 5[21], we observe a positive and significant impact only for the Amazon, in both specifications, at least at 0.05 significance-level. For Cerrado, the estimates are not statistically significant, even though positives.

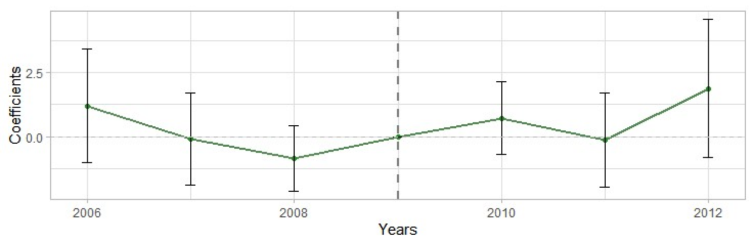
Altogether, the results point to an increase in crop areas in the Amazon biome. That is, clearings due to Bolsa Familia are being driven by an increase in both crop and pasture areas. Although the literature does not point out to an increase in grain production as a consequence of income rise, the literature of integrated crop-livestock systems (ICLS) might provide some insights.

Although specialization has been the main goal of agricultural enterprises, the system in which the rotation between grain cultivation and pasture is used presents itself as an alternative to making agricultural and livestock activities together economically viable. The integration reduces the risk of

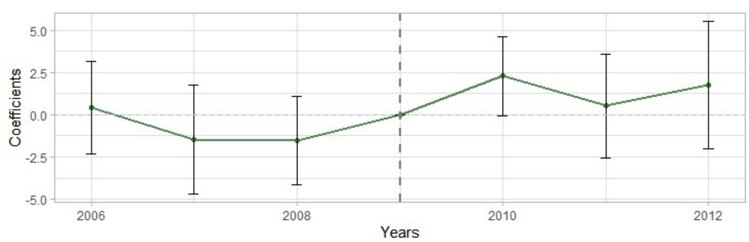
[21] The table presents the results of a difference-in-difference approach using $\Delta Quota_{ms}$ linearly and $Treat_{ms}$.

Figure 5: Bolsa Familia's effects on crop area

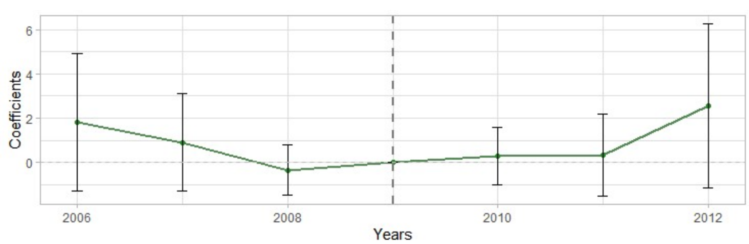
(a) Amazon and Cerrado biomes



(b) Amazon



(c) Cerrado



Notes: The table includes three main samples. All columns include municipal and year fixed effects, as well as state-specific linear trends. Robust standard errors are clustered at the municipality and micro-region-year level.

Table 5: Bolsa Familia's effects on crop area: robustness checks

	Amazônia + Cerrado	Amazônia	Cerrado
	Normalized Crop Area		
	(1)	(2)	(3)
ΔQuota*Post 2010	0.755	2.146**	0.478
	(0.721)	(0.898)	(1.015)

	Amazon and Cerrado biomes	Amazon	Cerrado
	Normalized Crop Area		
	(1)	(2)	(3)
Treated*Post 2010	0.033	0.195***	0.003
	(0.049)	(0.074)	(0.059)

Notes: The table includes the three main samples. All columns include municipal and year fixed effects, as well as state-specific linear trends. Robust standard errors are clustered at the municipality and micro-region-year level.

losses occurring in exclusively agricultural activities, enhancing crop production and farm economy. In Brazil, ICLS are generally implemented in the form of an annual rotation of the most profitable crops followed by grass cover crops grazed by cattle. This form of integration increases land-use efficiency and farm profitability, on top of allowing income diversification for farmers (De Albuquerque Nunes et al., 2021; Carvalho, 2013; Hilimire, 2011).

With that in mind, it can be argued that an expansion of beef cattle production may increase soybean production due to the enhanced profitability of integrated systems. Furthermore, soybean is used as animal feed, so an increase in animal-derived protein demand needs to be met with an increase in soybean production (Dei, 2011).

6.3 Other Variables

Two additional exercises were conducted to further investigate the channels that could have led to an increase in forest clearings. The first one, whose results are presented in Table 6, is a difference-in-difference with $\Delta Quota_{ms}$ in linear form with cattle herd (heads) and soybean production (in value), both in log, as outcome variables.

Table 6: Bolsa Familia's effects on cattle herd and soybean production

	Amazon and Cerrado biomes		**Amazon**		**Cerrado**	
	Cattle	Soybean Production	Cattle	Soybean Production	Cattle	Soybean Production
	(1)	(2)	(3)	(4)	(5)	(6)
ΔQuota*Post 2010	0.288*	1.771*	0.371	0.856	0.237*	2.039**
	(0.148)	(0.923)	(0.343)	(2.095)	(0.137)	(0.907)

Notes: The table includes the three main samples. All columns include municipal and year fixed effects, as well as state-specific linear trends. Robust standard errors are clustered at the municipality and micro-region-year level.

The results indicate an increase in both total livestock and soybean production in Cerrado and the combined Cerrado and Amazon, endorsing our findings for pasture area in the biomes. In the Amazon alone, although we find positive estimates (0.371 for the cattle variable and 0.856 for soybean production), they are not significant. The results reported in table 6 may appear conflicting, considering that in Cerrado, the expansion of crop areas does not seem to be driving clearings substantially. However, soybean production may be increasing deforestation indirectly by advancing on existing pasture areas, resulting in additional deforestation in the process of relocating livestock activity.

Lastly, the final test we conduct is, again, a difference-in-differences approach using $\Delta Quota_{ms}$ linearly, but with Agriculture, Industry, and Services gross added value as outcome variables instead. Table 7 presents the results

We detect a positive and significant impact on agricultural added value in the region formed by the Amazon and Cerrado biomes, as well as in Cerrado alone, which corroborates our results on pasture and crop areas. Furthermore, Bolsa Familia also appears to have increased the added value for services in the Amazon.

In short, the set of tests carried out indicates that the mechanisms behind the growth in deforestation due to Bolsa Familia are commercially motivated. It is likely that with the increase in income, families sought a more nutrient-rich diet, increasing their demand for land-intensive products (e.g., meat and milk). In turn, this increase in demand has generated an increase in livestock

Table 7: Bolsa Familia's effects on components of Added Value

	Amazon and Cerrado biomes		
	Agriculture Added Value	Industry Added Value	Services Added Value
	(1)	(2)	(3)
ΔQuota*Post 2010	0.595**	0.023	0.125
	(0.295)	(0.295)	(0.081)

	Amazon		
	Agriculture Added Value	Industry Added Value	Services Added Value
	(1)	(2)	(3)
ΔQuota*Post 2010	0.465	0.171	0.543*
	(0.456)	(0.534)	(0.301)

	Cerrado		
	Agriculture Added Value	Industry Added Value	Services Added Value
	(1)	(2)	(3)
ΔQuota*Post 2010	0.660*	−0.015	−0.121
	(0.352)	(0.434)	(0.178)

Notes: The table includes the three main samples. All columns include municipal and year fixed effects, as well as state-specific linear trends. Robust standard errors are clustered at the municipality and micro-region-year level.

farming, which occurs mostly through illegal land grabbing and burning of native vegetation. Another explanation is that rural families simply expanded their business with the additional income from Bolsa Familia, seeking larger profits.

Throughout the study, it became clear that the effects were stronger in the Amazon, which is not surprising given that, due to its immensity and late occupation, the biome still has a large amount of standing forest.

7 Conclusion

In this study, we evaluated the impact of the Brazilian Bolsa Familia program on deforestation. Specifically, we examined the impact of the CCT program's 2009 expansion, caused by a change in the methodology for allocating municipal quotas, on forest clearings in Brazil's most endangered biomes, the Amazon and Cerrado.

We took advantage of gaps in the literature, both on Bolsa Familia and on the relationship between cash transfer programs and deforestation. Although the literature on Bolsa Familia is broad and mostly reports the program's success on health, education, and labor market indicators, it rarely addresses the effects on environmental measures, much less on forest clearings. Additionally, there are still few studies linking income transfer programs and deforestation in the literature, and none of them are specifically directed at Brazil.

Our main specification was based on an event study design and included municipal and year effects, state-specific trends, and two-way clusters. We provided evidence indicating that the expansion helped increase clearings in the two regions. The results suggest that the impact was larger in the Amazon. Furthermore, we presented robustness tests that confirmed a positive and significant effect on forest clearings in the two biomes.

Having explored the impact on deforestation, it remained to investigate the possible mechanisms responsible for the acceleration of forest cover loss. The literature presents mixed theories on the environmental consequences of an income increase. On one hand, it points to the possibility of a reduction in deforestation due to an increase in the opportunity cost of leisure and/or due to the employment of better technologies that offer more efficiency in agricultural activity. In addition, it is also possible that an increase in income can raise the demand for environmental amenities if basic needs are met. On the other hand, an increase in income can expand the demand for land-intensive goods that can address malnutrition issues or encourage production expansion to help families earn more.

Seeing how our findings reveal a positive effect, we looked for reasons that induced pressure on forest cover. To do so, we examined whether Bolsa Familia had an impact on croplands and livestock. We observed evidence of an expansion in both crop and pasture areas in the Amazon, partially confirmed by robustness exercises. Apart from that, we also found a positive impact on cattle herd, soybean production, and added value for agriculture in Cerrado. Both sets of results suggest that there was an enlargement in agriculture and livestock activities.

In light of the climate change context, the results are concerning. Considering that environmental degradation can be an unintended side effect of poverty alleviation programs, and that CCT programs have been widely used throughout the developing world, this study draws attention to the need to design and implement programs that aim not only at poverty reduction but also at the conservation of the environment.

Note, however, that this paper has no intention of criticizing the Bolsa Familia program (or similar ones). It is just a fair warning about a harmful consequence, even if purposeless, that can be avoided through different designs of public policies. That is, policies that include environmental regulations in their formulations.

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