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WIDER Working Paper 2022/175

The unintended long-run impacts of agro-terrorism in Brazil

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December 2022

United Nations University World Institute for Development Economics Research
wider.unu.edu

Abstract: This paper studies the unintended long-run effects of a permanent agricultural shock led by agro-terrorism in Brazil on the education and labour market. We explore the witches' broom outbreak in cocoa farms in the world's second most important cocoa production region until 1989, the southeast of Bahia state in the northeast of Brazil. Although the introduction of the disease had political motivations, it had unintended effects on poor people's lives. To assess the impact of the witches' broom disease, we leverage information about people born in municipalities affected and not affected by the disease and explore the difference in educational attainments between cohorts older and younger than 18 years old at the time of the witches' broom outbreak. The main results show that the witches' broom outbreak negatively impacted the long-term education and earnings of individuals living in affected municipalities. We show a piece of evidence that the increase in child labour may drive our results. The negative effects on young cohorts are consistent with the known relation between child labour and cocoa production and the literature about the long-term effects of economic shocks.

Key words: witches' broom, Brazil, education, wages

JEL classification: N36, O12, O15

Acknowledgements: We thank Arnab Basu, Daniel Araújo, Daniel da Mata, Edson Severnini, Matti Mitrunen, Nancy Chau, Patricia Justino, Robson Tigre, Kalle Hirvonen, and participants of online conferences and seminars for critics and suggestions.

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This study has been prepared within the UNU-WIDER project Institutional legacies of violent conflict.

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ISSN 1798-7237 ISBN 978-92-9267-308-6

https://doi.org/10.35188/UNU-WIDER/2022/308-6

Typescript prepared by Siméon Rapin.

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The Institute is funded through income from an endowment fund with additional contributions to its work programme from Finland and Sweden, as well as earmarked contributions for specific projects from a variety of donors.

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1 Introduction

Terrorism and cyber-terrorism are well-known concepts and are part of many governments' and international organizations' agendas. Surprisingly, however, the deliberated action of differing attacks against crops, or agro-terrorism, has received much less attention from scholars and governments. In short, it is defined as 'the deliberate introduction of an animal or plant disease/pest to generate fear, causing economic loss, or undermining social stability' (USDA OIG 2018). Therefore, even though the act of agro-terrorism does not threaten people's lives directly, it may affect different aspects of the households, pushing many individuals to unemployment and reducing food security. It is a potentially more dangerous (Foxell 2001) threat to agriculture than the standard temporary shocks such as droughts, price fluctuations, floods, and diseases that have been largely studied in economic literature (Baker et al. 2019; Kruger 2007; Padrón and Burger 2015; Carrillo 2020; Ager et al. 2020). Nevertheless, it has been used over the last 50 years to promote political agendas, intimidate a target population, or extort firms, individuals, and governments. Biological agents or direct attacks targeting crops and livestock were used during the Cold War, and are still being used by terrorist groups[1] and governments.[2]

This paper studies the long-run effects of a significant agro-terrorism event in cocoa production in Brazil on education and the labour market. We explore the witches' broom outbreak in cocoa farms in the world's second most important cocoa production region until 1989, the southeast of Bahia state in the northeast of Brazil. By 1985, this region produced 80% of Brazilian and 62% of Latin American cocoa (IOCC 1993). The witches' broom is one of the most dangerous diseases to cocoa production. It is difficult to identify because of the incubation period. The disease is observable when the cocoa trees produce a particular type of mushroom (see Appendix A), which can spread quickly and fast through the wind. Once the cocoa tree is infected, there is no cure, and the cocoa fruits will be destroyed. There was no proper management at the time of the outbreak, and the infected trees were burned. Data and historical documents report that cocoa production reduced by 80% in the first ten years after the disease, pushing almost 250,000 workers to unemployment.

The context of the witches' broom in Bahia is particularly appealing to study the long-run impacts of agro-terrorism for several reasons. First, the municipalities affected by the witches' broom disease had a high dependency on cocoa production. At that time, cocoa was the second most exported product from the Bahia state. In the average affected municipality, cocoa production corresponded to 44% of total agriculture production, reaching more than 80% in some municipalities. This high dependency made the region very vulnerable, since a negative shock to cocoa production automatically converts into a strong shock on the total income of the municipality. Also, Bahia state has about 15 million inhabitants, comprising an area almost the size of France. It is the most important economy of the nine states in Northeast Brazil. Still, a high share of its working population has no jobs or work without any formal contract, and it has the highest percentage of the population receiving the cash transfer programme *Bolsa Família*, targeting the poorest families in Brazil. Despite nothing having been proved about the responsibility and the real motivations, the consensus is that the fungus spread was criminal and intentional (L. B. Rocha 2006). Based on the spatial pattern of the infections and the coincidental timing of the first two infections (two different and 100km apart focus sites, both located in the centre of the cocoa region), Pereira et al. (1996) concluded that the disease was criminally introduced. In addition, a Brazilian federal police investigation in 2006 also suggested that the disease introduction was criminal.

[1] See the case of Boko Haram in Nigeria as an example. https://adf-magazine.com/2016/10/when-food-is-a-weapon/.

[2] See the cases of Palestinian operations to contaminate eggs: Ungerer and Rogers (2006).

To assess the impact of the witches' broom disease, we leverage information about people born in municipalities affected and not affected by the disease and explore the difference in educational attainments between cohorts older and younger than 18 years old at the time of the witches' broom outbreak, which varies between 1990 and 1992 depending on the city. We then estimate a difference-in-differences model. The underlying hypothesis is that cohorts older than 18 had taken most of their educational decisions, while younger cohorts still needed to make many choices. It is a reasonable assumption because Brazil's expected age to graduate from high school is 17. Besides, the region's offer of college, university, or vocational education was minimal at the time of the outbreak. Then, we should not expect any difference in educational results between individuals in affected and not affected regions. We use the 2000 and 2010 Brazilian demographic censuses coupled with historical information about the timing and severity of the crisis in each city. Our sample contains seven million individuals who live in one of the nine states of the Brazilian northeast. Our sample is restricted to those born after the witches' broom outbreak and are less than 65 years old at each demographic census.

The main results show that the witches' broom outbreak negatively affected the education and income of individuals living in affected municipalities. People below 18 years old living in municipalities affected by the witches' broom disease have 2.8% less probability of having a high school degree, 3.2% less probability of having elementary school, and wages 4.8% lower. Those effects are greater for individuals between 0 and 12 years old at the time of the witches' broom outbreak. We also show that the impacts are higher in municipalities with a higher dependency on cocoa production before the witches' broom outbreak. We do that by splitting the sample between municipalities above and below the median of the cocoa dependency range, measured as the share of cocoa in the total agricultural production. The effects on high school achievement and wages increase to, respectively, 3.2% and 8.5%. We also provide evidence that the effects do not differ by gender and sex, following the empirical strategy proposed by Clay et al. (2020).

We also provide many robustness checks. Since the outbreak occurred in a staggered fashion between 1990 and 1992, we also used the estimator proposed by Sun and Abraham (2021), showing that the differences in treatment timing do not bias our results. The robustness section shows that other idiosyncratic shocks at the municipality level or concurrent shocks at the same time as the outbreak are unlikely to explain our results.

A natural step after presenting these results is to ask about the mechanism behind them. We provide evidence that the witches' broom outbreak led to a fall in the GDP per capita and affected municipalities' household incomes, as documented in the literature, pushing the southeast of Bahia to a recession. We estimate an event-study regression of the interaction of year dummies with a treatment indicator, where the treatment is being affected by the witches' broom outbreak, and the outcome is the share of children working compared to the total population of children in the municipality.[3] The result suggests that there was an increase in child labour by 2.5 percentage points in 2000 and 2010 in affected regions compared to non-affected regions.

Our results are consistent with the luxury axiom in the multi-equilibrium model developed by Basu and Van (1998), where parents choose not to send their children to work when incomes are sufficiently high, and the opposite occurs when the incomes are low. They also assume that adult and child labour are (not perfect) substitutes, which is in line with Walker (2007). Therefore, shocks change the opportunity cost of schooling, and children are forced to work to help the family income (Baker et al. 2019). The empirical evidence using Brazilian data supports the model's conclusions. Soares et al. (2012) provide an empirical test of the Basu model for the Brazilian context, showing that higher household wealth

[3] According to the Brazilian statute of children and teenagers, any kind of work is strictly prohibited for people younger than 14 years old in Brazil. See Estatuto Brasileiro da Crianca e do Adolescente - ECA. Law 8.069/1990. http://www.planalto.gov.br/ccivil_03/leis/L8069.htm.

is associated with lower child labour and higher schooling. De Carvalho Filho (2012) showed that families that became eligible to receive rural pensions in Brazil have a lower probability of sending their children to work. Duryea et al. (2007) found that when a head of the Brazilian household lost the job, the probability of having children working increases. There are also empirical evidence from coffee shocks showing that child labour increases during economic booms (Kruger 2007; Carrillo 2020). This points out that the relation between shocks and child labour may depend on the specificities of the labour demand and offer (Manacorda and Rosati 2011).

In addition to the fact that the witches' broom outbreak had occurred in an impoverished area, from 1987 to 1994, Brazil faced the worst inflationary period in its history, with the total annual inflation rate achieving 107,492.07% between February 1986 and November 1989. The inflation rate was controlled only with a pool of macroeconomic policies in 1994, which introduced the current currency, the Real. Therefore, during the witches' broom outbreak, most of the credit markets in the country were nonexistent, and most of the households had no savings. Furthermore, cocoa production makes intensive use of low-skilled workers, which reduces their mobility to other activities in case of crisis. Households cannot borrow and save pre- and during crises in an environment of incomplete (or lack of) capital markets and insurance (Jensen 2000). Because of their parents' volatile income, reducing children's educational investment is a survival strategy. Beegle et al. (2006) and Bandara et al. (2015) show that access to a bank account mitigates the effect of weather shocks on child labour in Tanzania, for example.

This paper makes three contributions to the literature. First, we are the first paper to estimate the causal impact of the witches' broom on educational and labour market outcomes. This novel contribution shows the unintended effects of a deliberated event to impact landlords, but which affected a higher share of the poor population in the region. Even though many cases of pathogens, such as Foot-and-Mouth-Disease, rinderpest, wheat stem rust, and African swine fever, in agriculture production may have been deliberately introduced, identifying it as an agro-terrorism event is not straightforward. Therefore, we are the first study to provide causal evidence of the potentially destructive impact of those events on welfare (Seebeck 2007; Ungerer and Rogers 2006). Second, we add to the literature on short- and long-run agricultural shocks, but we are the first to explore the effect of an agro-terrorism event with permanent effects on production. Most of this literature focus on the boll weevil disease in the US Cotton Belt (Baker et al. 2019; Ager et al. 2020), coffee shock prices in Latin America (Padrón and Burger 2015; Carrillo 2020; Kruger 2007), desert locust in African countries (Le and Nguyen 2022), or on the impact of climate events, such as droughts (R. Rocha and Soares 2015) and floods (Maccini and Yang 2009). The main difference is that those are temporary shocks, natural shocks, which significantly differ from the witches' broom characteristics, a disease that lasted for at least ten years and was deliberately introduced by human action. Third, we contribute to the literature that relates economic shocks in the agricultural sector to child labour (Kruger 2007; Cogneau and Jedwab 2012). Despite the literature suggesting a positive relation, most papers cannot empirically prove it (Baker et al. 2019). Besides that, we contribute to the literature on child labour and agricultural shocks in Brazil (Soares et al. 2012).

2 Background

Bahia—a large-sized state with about 15 million inhabitants and whose territory is about the size of France—is one of the poorest states in Brazil.[4] Bahia's labour market has a large share of informal jobs, low-educated workers, and high unemployment rates. According to the 2010 population census, informal jobs represented half of the total employment, and half of the workers had at most eight years

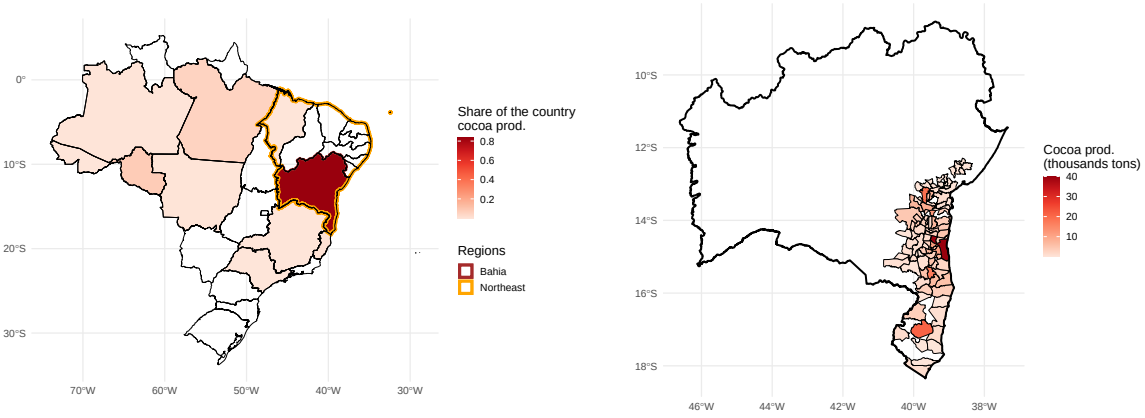
[4] Brazil is a three-tiered federation with 26 states, a federal district, and 5,571 municipalities. Bahia state has 417 municipalities.

of educational attainment.[5] In 2019, Bahia had the second-highest unemployment rate in Brazil—17% against the national rate of 11%.

Between 1961 and 1985, Brazil was one of the three biggest global cocoa producers. In 1985, the Brazilian production was about 448,577 tons of cocoa, representing 70.5% of Côte d'Ivoire's production, the biggest producer in the world. The share of Bahia state in the national production was approximately 86%. The southeast of Bahia state concentrated the cocoa production in Brazil until 1990. Figure 1 shows the map of Bahia state and highlights the municipalities with cocoa production, most known as the Ilhéus-Itabuna microregion. A considerable number of studies, technical reports, and books described the importance of cocoa production for the region, associating cocoa with the development of agribusiness, investments in infrastructure, and development of local human capital (Gomes and Pires 2015; CEPLAC 2009).

The cocoa production in the region was characterized by large farms owned by a few elite families, which led to very high inequality in the region. Besides, it became a monoculture because of the high prices of cocoa and the inequality in land ownership. Therefore, the region was highly dependent on it, with very low diversification in income generation. Even the development of city services depended on the cocoa economy, with the elite members being the main clients.

Figure 1: Spatial distribution of cocoa production in Brazil and Bahia - 1988



(a) All states (b) Bahia

Source: authors' illustration based on Ipeadata.

Witches' broom

In May 1989 the Ilhéus-Itabuna microregion fate started to change with the first discovery of the *Miniliophtora perniciosa* in the Uruçuca municipality. In October 1989, Camacan city also reported the presence of the disease. The disease discovered had no technical confirmation yet—it happened only in 1990. It had affected almost all municipalities with cocoa production by 1992. Figure 2 shows each city with official reports of witches' broom disease in Bahia state. Because witches' broom is one of the most dangerous diseases for cocoa production, many studies try to develop technical procedures to deal with it (IOCC 1993; Medeiros et al. 2010; Lisboa et al. 2020; Scarpari et al. 2005; Fioravanti and Velho 2011). A remarkable difference from the extensive literature about agricultural shocks is that while price and weather shocks are temporary, witches' broom was permanent. Appendix Figure A4 shows the number of infected cocoa fruits per year. At the start of the outbreak in Bahia, there was very little knowledge

[5] In 2010, the share of informal workers—defined as those not contributing to social security—was 35.4% in Brazil and 49.4% in Bahia.

about how to fight the disease, with the main recommendation being to cut and burn sick trees. It led to the destruction of farms and families' sources of income.

This recommendation was proven wrong, but there is still no specific cure or management for the witches' broom. The treatment is evaluated case by case based on the local climate and cocoa genetics. These characteristics implied that the peak of contaminated cocoa fruits was in 2000/01 (CEPLAC 2009), ten years after the outbreak. The high level of infected fruits persisted until new agricultural practices started to be implemented, including the use of more resistant genetically improved cocoa species (Medeiros et al. 2010). In addition, it is essential to point out that there was no programme created by the governments of the municipalities, the state, or the federal level to support the affected families.

At the time of the disease outbreak, the principal explanation for the disease was bio-crime conducted by cocoa producers' competitors in the Amazon forest and Côte d'Ivoire. Caldas and Perz (2013) provide an extensive narrative and relate different facts to argue that the event was agro-terrorism. The main event was a federal police investigation that interviewed Luiz Henrique Franco Timoteo, a member of the Democratic Labour Party (PDT). He confirmed that he partnered with the other four members of the PDT[6] that worked at the CEPLAC, the agency in the Ministry of Agriculture responsible for cocoa studies and technical assistance. He reported that they decided to contaminate the cocoa production monoculture to destroy the power of the cocoa landlord elites to increase the left-wing candidate support in the presidential elections. Besides, reducing their power would also benefit other candidates in the municipal elections in subsequent years.[7]

Brazil was facing the re-democratization period, and there was a tight dispute in the 1989 electoral campaign between the candidates Fernando Color de Melo (right-wing) and Luis Inácio Lula da Silva (left-wing). Besides, some years after the presidential election, Brazil also had municipal elections. Therefore, affecting the landlords, economic power would translate into less political power for the elites, increasing the chances of political groups not being connected with the military allies in the region. Despite nothing having been proved about those responsible and the real motivations, the consensus is that the fungus spread was criminal and intentional (L. B. Rocha 2006). Based on the spatial pattern of the infections and the coincidental timing of the first two infections (two different and 100km apart focus sites, both located in the centre of the cocoa region), Pereira et al. (1996) concluded that the disease was criminally introduced. Finally, it is essential to point out that there is no evidence that the disease introduction had the goal of affecting human capital accumulation in the cocoa region. The available evidence suggests that the target was the political power of cocoa's landlords.

Because of the witches' broom, cocoa production reduced from 448,577 tons in 1985 to only 96,000 tons in 1999. The Ilhéus-Itabuna microregion had the highest level of unemployment in its history, with 250,000 rural workers losing their jobs and the average cocoa revenue reducing from US$600 million/year to US$200 million/year (CEPLAC 2009). Figure 3 shows the production of cocoa through time. Cocoa production has had a negative trend since 1985 when cocoa prices started to fall. However, it became steeper after the witches' broom outbreak, with the lower production levels in 2000, the peak year of cocoa-infected products (CEPLAC 2009).

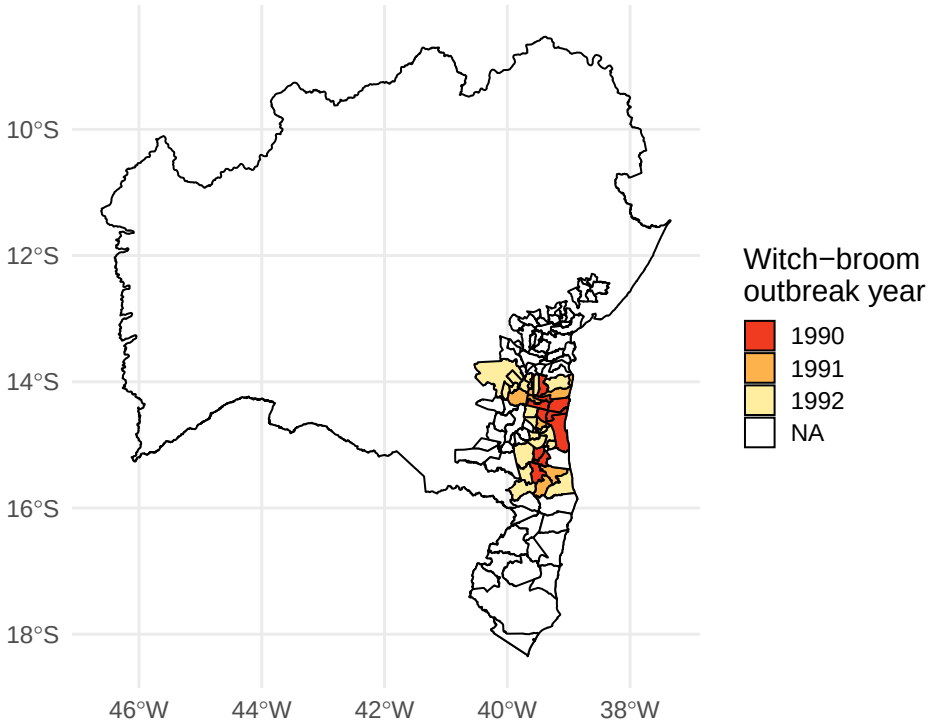
Panel (a) of Figure 4 shows that while the GDP in municipalities exposed to the witches' broom fell between 1985 and 1995, it stayed the same in the other municipalities. Panel (b) shows that the fall in the GDP per capita in the period is much higher for childhood exposure municipalities. As mentioned

[6] It is important to point out that PDT is not Lula's political party. Lula is a member of the Workers' Party (PT).

[7] The militant and his crime partners used to work for CEPLAC, a public institution that provided technical assistance to cocoa production in Brazil. Therefore, they knew about cocoa diseases and their dissemination. In addition, to reinforce the history, it was made public that the owner of the first farm affected by the disease (*Conjunto Santana*) was the president of the Democratic Rural Union, a right-wing union supporting Color in the 1989 presidential election, and one of the landlords in the region.

before, from 1987 to 1994, Brazil faced the worst inflationary period in its history, with the total annual inflation rate achieving 107,492.07% between February 1986 and November 1989. Notwithstanding, there is a gap in the GDP data at the municipality level, with 1985 being the last year before the witches' broom outbreak and 1995 being the first year after the outbreak. Besides, we believe that the positive trend after 1995 is explained by the introduction of successful macroeconomic reforms and the new currency (Real) that controlled inflation in Brazil. Although these graphs strongly suggest the impact of the witches' broom disease, the GDP data at the municipality level before 2002 faces methodological problems,[8] and there is a gap between 1985 and 1995.

Figure 2: Witches' broom outbreak by municipalities and years

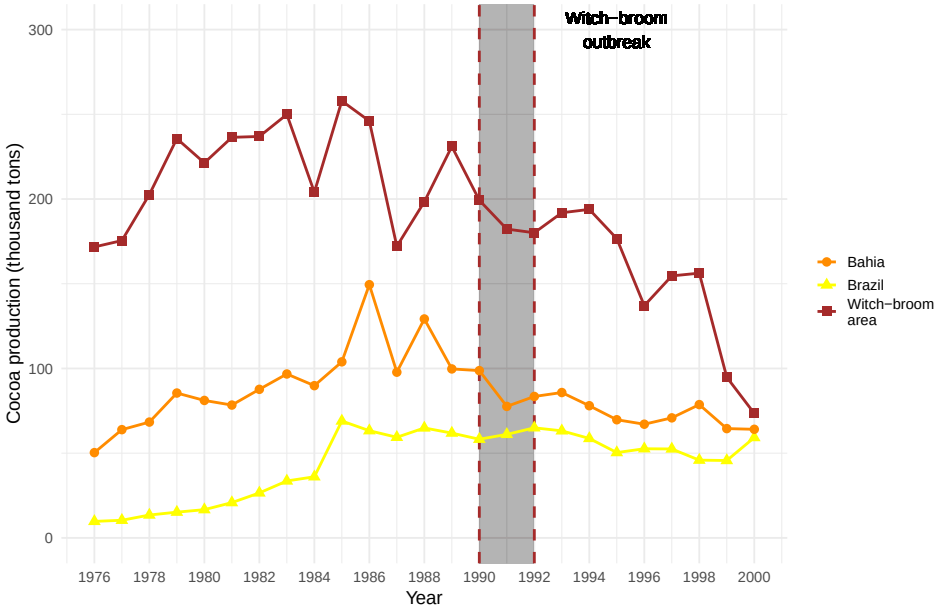


Note: the municipalities with the border lines and without any color are municipalities that had some cocoa production in 1989 but were not affected by the disease.

Source: authors' illustration based on Lisboa et al. (2020).

[8] Brazilian municipalities only started to calculate GDP using the same methodology in 2002, developed by the Brazilian Bureau of Statistics (IBGE). The municipality's GDP before 2002 was recovered through a methodology developed by Reis et al. (2005). Another important limitation is that the series before and after 1990 are calculated using different methodologies. Therefore, because of measurement errors, it is not recommended to use it for estimation procedures.

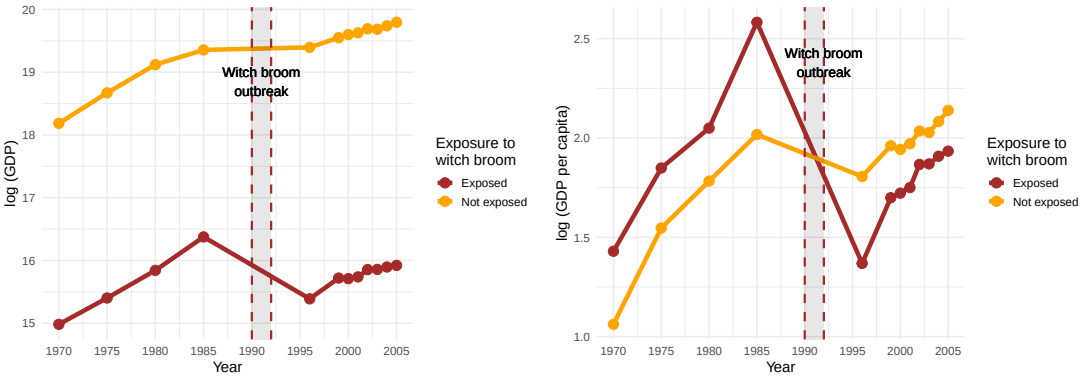
Figure 3: Trends in cocoa production 1986 to 2000



Note: the orange line represents the Bahia net of witches' broom municipalities production, the red line the witches' broom municipalities production, and the yellow line Brazil net of Bahia production.

Source: authors' elaboration based on Ipeadata.

Figure 4: GDP and GDP per capita by regions exposed and not exposed to witches' broom



(a) GDP (b) GDP per capita

Note: this figure shows the evolution of the municipality GDP (panel (a)), and municipality GDP per capita (panel (b)) between treated (affected by the witches' broom) and control municipalities (northeast municipalities excluding the ones affected by witches' broom).

Source: authors' calculations based on Ipeadata.

Finally, the witches' broom disease has two important features for our study. The first one is that there is an incubation period between the disease inoculation and the signals that make it possible to identify sick trees. Only after the incubation period can the sick trees be identified because of the appearance of very specific mushrooms. The second is that there is no specific cure or preventive manipulation to prevent the disease development and dissemination (Alves et al. 2006; Scarpari et al. 2005). The sick trees with the disease in the initial stage are difficult to spot, and if the mushrooms are not correctly destroyed, they can disseminate the disease to other trees after small pieces of it are taken by the wind and land in another tree. Appendix Figures A1, A2, and A3 illustrate a healthy cocoa fruit, a fruit contaminated with witches' broom, and the witches' broom mushroom that indicates that the tree is contaminated with the disease.

3 Data and empirical strategy

3.1 Data

To assess the long-run effects of the witches' broom outbreak, we use the 2000 and 2010 waves of the Brazilian census. The census has detailed information on education and labour market outcomes, like occupation and wages. Since the 2000 and 2010 censuses do not ask individuals the municipality of birth, we only keep in the sample individuals that declared to be born in the municipality of residence and use this information as a proxy to the municipality of residence at the time of the shock. We only consider municipalities in the northeast region and exclude from the sample individuals more than 65 years old. To improve the comparability of age cohorts, we restrict the sample to individuals from 0 to 35 years old at the time of the witches' broom outbreak. For municipalities not affected by the witches' broom, we consider the individuals with 0 to 35 years by 1990, the first year of the disease. Finally, the witches' broom outbreak dates for each municipality were collected using data from Pereira et al. (1996).

3.2 Empirical strategy

We are interested in the effect of the witches' broom disease outbreak on the probability of completing elementary and high school education and on wages in the long run. Our empirical strategy exploits variations in the location and time of the outbreak at the municipal level in Brazil.[9] Thus, first, we estimate the equation 1 that generalizes the difference-in-differences framework exploiting the differential timing of the year of the witches' broom outbreak across municipalities. The unit of analysis is the individual. We are comparing individuals above and below 18 years old at the time of the outbreak living in affected and not affected municipalities. The estimated parameters must be interpreted as an intention to treat effect because not everyone in the treated municipalities was directly affected by the shock.

$$Y_{im} = \beta WB_{im} * A_{age\leq 18} + \tau A_{age\leq 18} + \gamma X_i + \rho_m + a_{2010} + _{im} \tag{1}$$

X_i is a vector of socioeconomic characteristics, such as gender, race, and ρ_m is a municipality fixed effect that controls for unobserved determinants of long-run outcomes across municipalities. Y_{im} is the outcome that will assume a value equal to 1 if the individual completed elementary education or high school. Y_{im} will also represent the logarithm of the individual earnings. The key parameter is β_i, which summarizes the magnitude of the witches' broom (WB) impact. A negative and significant estimate would suggest that exposure to witches' broom disease leads to a reduction in education or earnings. In addition, equation 2 is an event-study version of the previous equation to examine the witches' broom disease impacts on education and wages by comparing adjacent birth cohorts. In this case, individuals are grouped in eight cohorts WB_c, and we add a cohort fixed effect θ_c.

The cohorts below 18 years old living in municipalities affected by the witches' broom outbreak are the treated group because they did not finish their schooling decisions, while the cohorts above 18 years old at the time of the outbreak are the control group because they had already taken most of their educational decisions. The interpretation of these estimates assumes that individuals between 19 and 35 years when the witches' broom happened in their municipality of residence do not alter their educational decisions. Under this identifying assumption, our empirical framework yields estimates of the causal effects of witches' broom on long-run outcomes. There are two reasons to expect that. The first is that the offer of technical and college education was very scarce in this region before 2000 (OECD 2021). Therefore,

[9] See Araújo et al. (2021) and Baker et al. (2019) for a similar empirical strategy.

young adults had minimal options to choose between work and study after 18. The second is that the typical age for finishing elementary education in Brazil is 14, while the typical age to finish high school is 17. Therefore, only a very strong belief would refuse these two assumptions together.

$$Y_{icm} = \sum_{k=0}^{8} \beta_k * 1\{19 \leq WB_c - K \leq 18\} + \gamma X_i + \theta_c + \rho_m + a_{2010} + _{icm} \quad (2)$$

We believe that three potential mechanisms explain the results. The first one is the increase in child labour, which is consistent with the luxury axiom (Basu and Van 1998; Soares et al. 2012). In Section 4.3 we estimate an event study regression that confirms that child labour may explain the findings. The second is the potential impacts of the income drop on health outcomes, which is also well established in the literature (R. Rocha and Soares 2015), and the third is that which broom shock may have led to a reduction in education inputs in the affected municipalities, such as school closure due to the drop in municipality revenues. Unfortunately, there are no available data in Brazil at the municipality level before the shock to test the educational and health hypothesis. Even though we cannot rule out those potential mechanisms, we provide some descriptive evidence that individuals in the affected regions have lower education indicators ten years after the outbreak. We also estimate a triple-difference model proposed by Clay et al. (2020) to show that there are no differential impacts by gender or race.

Finally, because of the differential timing of the outbreak across municipalities, Section 4.4 presents the Sun and Abraham (2021) estimator for a difference-in-differences (DiD) with staggered adoption. The main results do not change, eliminating potential bias arising from the OLS estimation. Another potential concern is that migration could bias our results. Affected families may have chosen to migrate to other municipalities to find better employment opportunities. To overcome that, we also estimate a model in a restricted sample composed of individuals that reported that they were born and always lived in the city c. Section 4.4 shows that migration does not seem to drive our results. Besides, Section 4.4 also explains that there is some sparse evidence of internal migration within municipalities in the Ilhéus-Itabuna region, but not about people leaving the micro-region. Finally, in Section 4.4 we provide evidence that the effects are not driven by some municipality idiosyncratic characteristic by assuming that there was some shock in the same municipalities in 1970 or 1980, or by any concurrent event in 1990.

4 Results

This section presents the results of the empirical strategy described in Section 3.2. We split the section into three parts. First, we present the main results for all cohorts. Second, we present the heterogeneity analysis by cocoa dependency before the shock, sex, and race. Finally, we present a bunch of robustness checks and placebo analyses.

4.1 Baseline results

Columns (1) and (2) of Table 1 show the impact of the witches' broom disease on the probability of having completed at least a high school degree using equation 1. Cohorts younger than 18 years old at the time of the witches' broom disease exposure have a 2.8% lower probability of having at least a completed high school degree. Columns (3) and (4) show a slightly stronger result for the probability of completing elementary school. Columns (5) and (6) show that cohorts exposed to witches' broom have wages -4.8% lower than cohorts not exposed to witches' broom.

Figures 5 and 6 add by showing the long-term witches' broom effects for different cohorts estimated using the equation 2. These figures present two main messages. First, the results are stronger for cohorts younger than 12 years old, both for education and wages. Second, the results are not statistically significant for cohorts between 16 and 18 years old at the time of the shock.

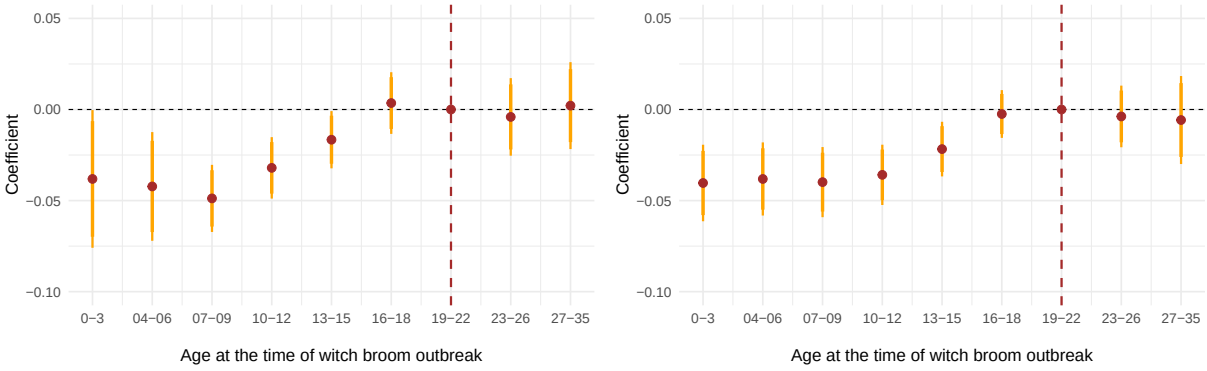
Table 1: Long-run effect of witches' broom on childhood exposure cohorts

	High school		Elementary school		log(wages)	
	(1)	(2)	(3)	(4)	(5)	(6)
Childhood exposure	-0.028***	-0.028***	-0.032***	-0.032***	-0.056***	-0.048**
	(0.008)	(0.008)	(0.010)	(0.010)	(0.022)	(0.022)
R^2	0.075	0.079	0.101	0.107	0.207	0.227
Observations	4,647,460	4,625,295	4,647,460	4,625,295	1,884,097	1,877,702
Municipality FE	✓	✓	✓	✓	✓	✓
Birth-year FE	✓	✓	✓	✓	✓	✓
Census wave FE	✓	✓	✓	✓	✓	✓
Ind. Controls		✓		✓		✓

Note: the table displays the regression results of the estimation of equation 1 and also alternative specifications. The dependent variable in columns (1) and (2) is a dummy that equals one if the individual completed high school. In columns (3) and (4) the dependent variable is an indicator variable that equals one if the individual completed elementary school. Finally, in columns (5) and (6), the dependent variable is the log of wages. The estimate corresponds to an ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level.

Source: authors' calculations based on method described in Section 3.

Figure 5: Long-run consequences of witches' broom outbreak on education

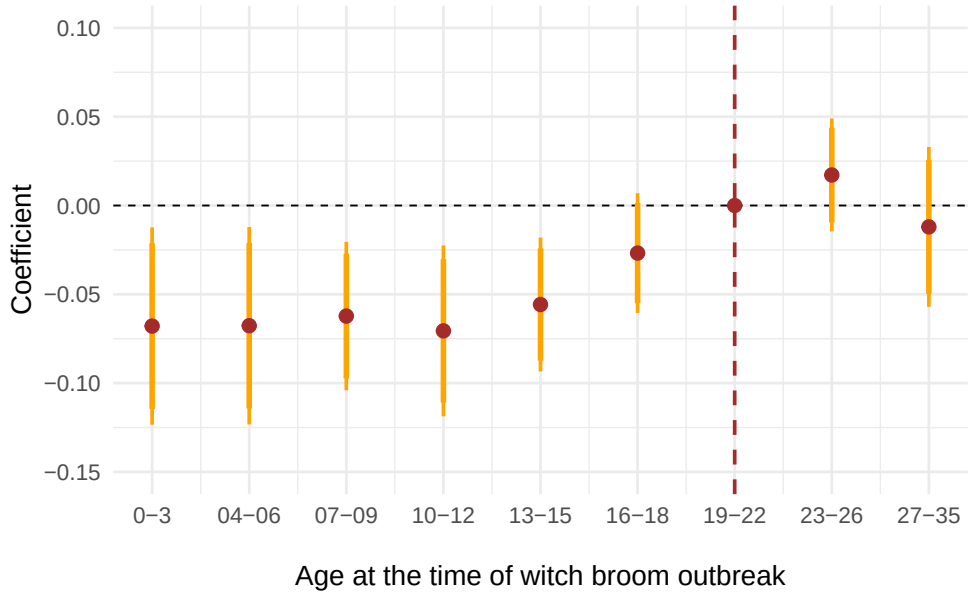


(a) Elementary school (b) High school

Note: the figure displays the baseline results for the probability of having completed elementary and high school up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to an ITT effect—to the estimated coefficient of equation 2. Standard errors are clustered at the municipality level. Confidence intervals: 95% and 90%.

Source: authors' calculations based on method described in Section 3.

Figure 6: Long run consequences of witches' broom outbreak on wages



Note: the figure displays the baseline results for the wages up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 2. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

Source: authors' calculations based on method described in Section 3.

4.2 Heterogeneous effects

As explained before, cocoa production in Bahia was a monoculture with low diversification. Many municipalities' economic systems were dependent on it. Appendix Figure A7 shows the share of cocoa production in relation to the total agriculture production in each city affected by the witches' broom in 1989, before the outbreak. The average share of cocoa in the total agricultural production was 40%, achieving about 80% in some municipalities. We use this information to create two groups, municipalities above and below the median of cocoa production in 1989. The visual representation is presented in Appendix Figure A8. Columns 1 to 3 of Table 2 show the results for the municipalities above the median, and columns 4 to 6 the results for the municipalities below the median. The results suggest a higher impact of witches' broom on municipalities more dependent on cocoa production as a share of the total agricultural production.

Table 2: Long-run effect of witches' broom on exposed cohorts by cocoa dependence

	Panel A: Above median			**Panel B: Below median**		
	High school	Elementary school	log(wages)	High school	Elementary school	log(wages)
	(1)	(2)	(3)	(4)	(5)	(6)
Childhood exposure	-0.032***	-0.041***	-0.085***	-0.024	-0.020	-0.015
	(0.006)	(0.008)	(0.021)	(0.015)	(0.015)	(0.030)
R^2	0.075	0.101	0.208	0.075	0.100	0.207
Observations	4,602,391	4,602,391	1,865,592	4,583,480	4,583,480	1,857,458
Municipality FE	✓	✓	✓	✓	✓	✓
Birth-year FE	✓	✓	✓	✓	✓	✓
Census wave FE	✓	✓	✓	✓	✓	✓

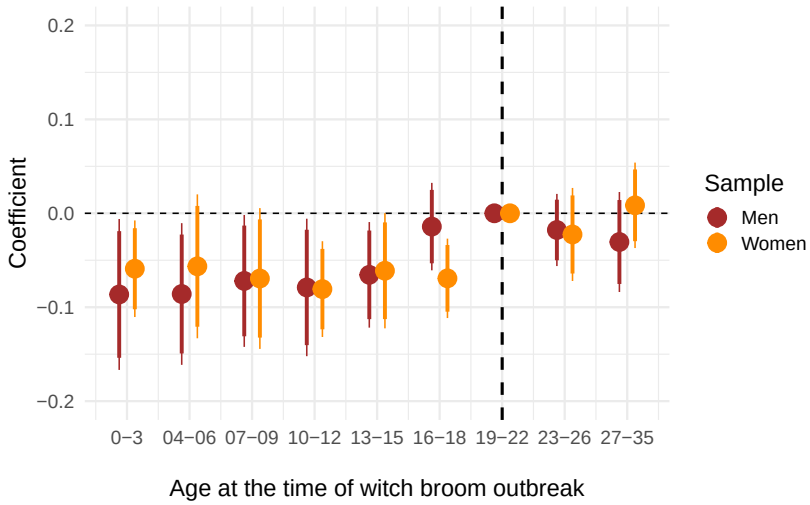
Note: each panel of the table displays the regression results of the estimation of equation 1 dropping treated municipalities from the sample according to a measure of cocoa dependence. The measure consists of the share of cocoa production in each municipality over the total agriculture production, before the witches' broom outbreak. Panel (a) only considers treated municipalities above the average of cocoa dependence, dropping from the sample treated municipalities below the median. Panel (b) only considers treated municipalities below the average of cocoa dependence, dropping from the sample treated municipalities above the median. Both panels use the same municipalities in the control group as our baseline specifications. The estimate corresponds to an ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level.

Source: authors' calculations based on method described in Section 3.

Although child labour is a remarkable characteristic in Brazilian agriculture, Manacorda and Rosati (2011) suggested, using the Brazilian census, that it is more intense on girls' labour than boys'. Cogneau and Jedwab (2012) provide descriptive evidence that boys in the agricultural sector in Côte d'Ivoire present higher enrollment and lower probability of working than girls. Besides, they also show that this difference is higher in cocoa production areas than in non-cocoa production areas.

We explore the heterogeneous effects of the witches' broom outbreak by sex and race. Figures 7 and 8 show that the witches' broom outbreak affected both groups equally. Therefore, despite historical documents (Walker 2007) and the above descriptive evidence of the cocoa production in using girls more than in other crop production, the effect of witches' broom was homogeneous across sex. Figure 9 shows that there is no difference in witches' broom impacts by race. We also estimate a triple-difference model as in Clay et al. (2020). Appendix Tables A3 and A2 show that there is no evidence of differential effects of the witches' broom outbreak by gender or race.

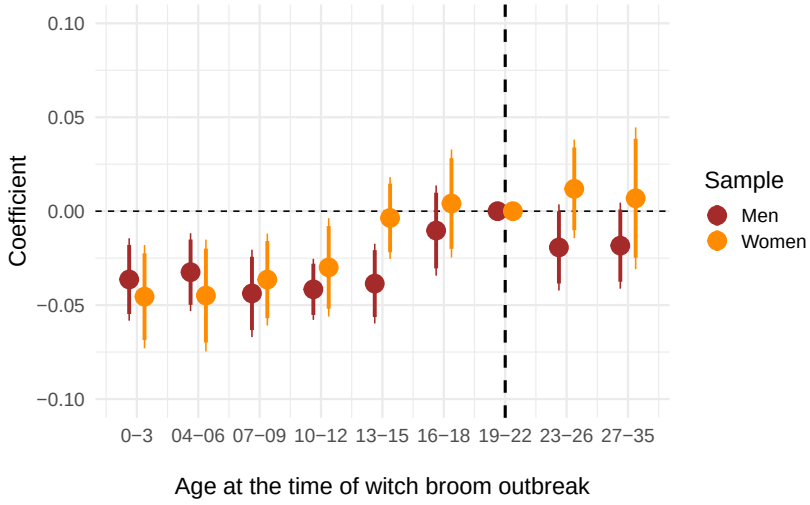
Figure 7: Long-run consequences of witches' broom outbreak by gender - Wages



Note: the figure displays the baseline results for the probability of having high school up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

Source: authors' calculations based on method described in Section 3.

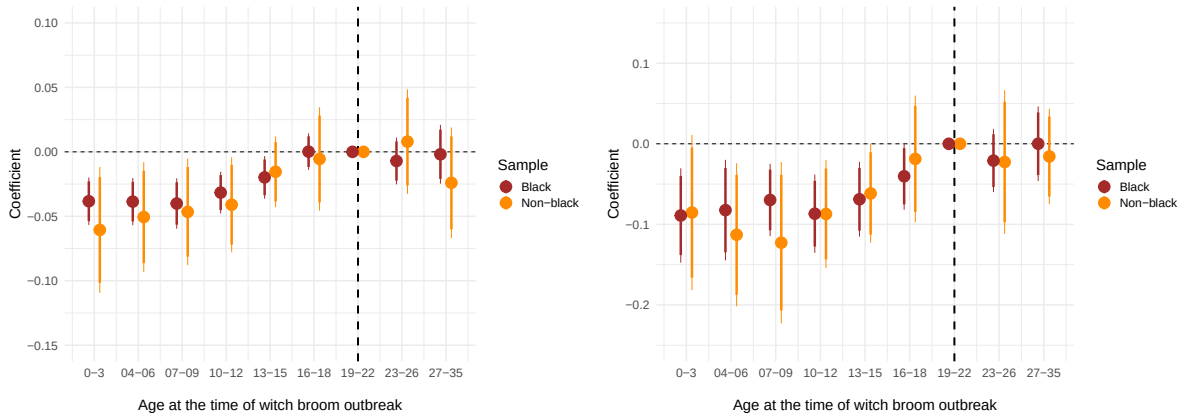
Figure 8: Long-run consequences of witches' broom outbreak by gender - High school



Note: the figure displays the baseline results for the probability of having high school up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

Source: authors' calculations based on method described in Section 3.

Figure 9: Long-run consequences of witches' broom outbreak by race



(a) High school (b) Wages

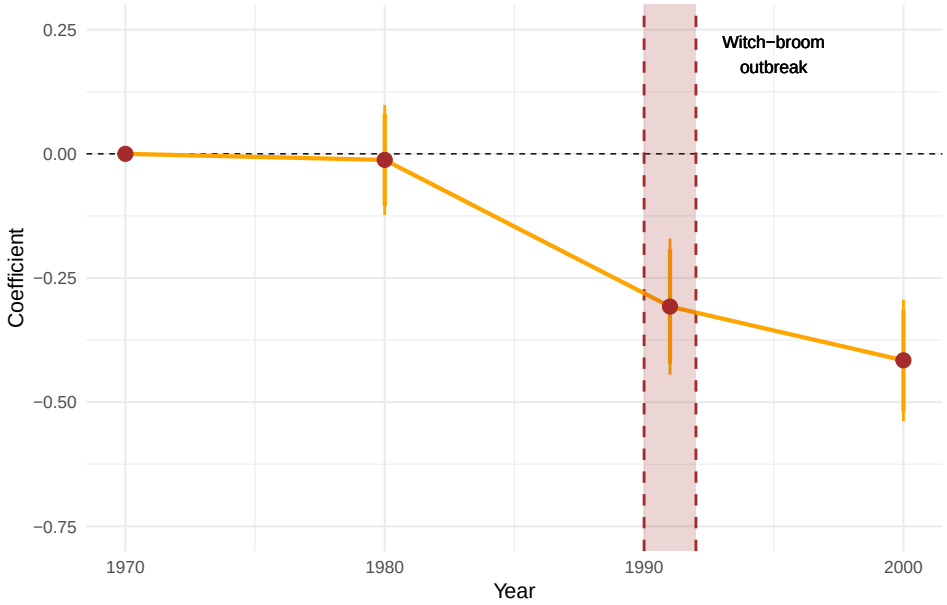
Note: the figure displays the baseline results for the probability of having completed elementary and high school up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to an ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level. Confidence intervals: 95% and 90%.

Source: authors' calculations based on method described in Section 3.

4.3 Mechanism

The previous sections showed that witches' broom had long-term effects on human capital accumulation (education) and wages. Our central assumption is that due to the drop in earnings and the lack of savings, families decided to put their children to work to compensate for the income loss, which is in line with the main models of child labour (Basu and Van 1998; Edmonds 2007). Figure 4 suggested an impact of the disease on the GDP and GDP per capita of the affected municipalities. As explained, we can not use the GDP data for estimation, so we use the Brazilian census data to recover the income at the municipality level and estimate an event-study regression to complement the previous evidence about the impact of witches' broom at the aggregate level. The census has a centralized organization and data collection by the IBGE. Figure 10 shows the short-term impacts of the disease. The results suggest that the municipalities' income fell between 25% to 38% between 1991 and 2000 because of witches' broom.

Figure 10: The short-term effect of witches' broom outbreak on average earnings



Note: the figure displays estimated coefficients of an event-study regression of the interaction of year dummies with a treatment indicator, where the treatment is being affected by the witches' broom outbreak, on the income of municipalities on the northeast of Brazil. Data from 1970, 1980, 1991, and 2000 censuses.

Source: authors' calculations based on method described in Section 3.

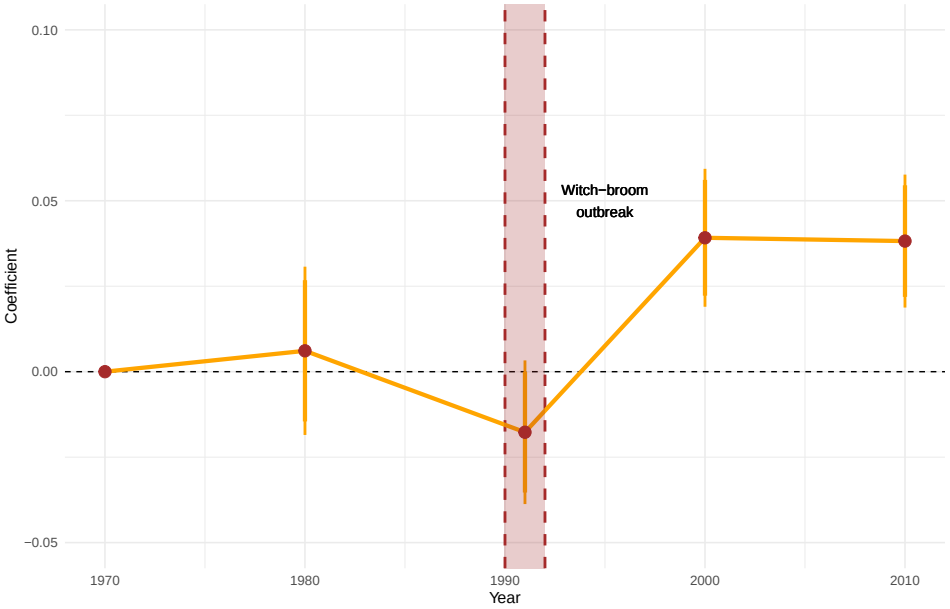
The fall in family income can lead to the growth in child labour according to Basu and Van (1998). According to the Brazilian statute of children and teenager,[10] any work is strictly prohibited for people younger than 14 years old in Brazil. Therefore, we aggregate the share of children between ten and 13 years old working in each city of the northeast region and estimate an event-study regression of the interaction of year dummies with a treatment indicator, where the treatment is being affected by the witches' broom outbreak, such as the one presented in Figure 10, but as the share of children working as the dependent variable.

Figure 11 suggests a strong positive effect of the witches' broom outbreak on the probability of child work at the municipality level.[11] Witches' broom increased the child labour in affected municipalities by 2.5 percentage points, an increase of 30% compared to the control group average. The effects appeared in 2000 and stood until 2010, despite the introduction of the national programme against child labour (PETI) in 1996 and its expansion in 2002 when the programme was coupled with the Brazilian cash transfer programme Bolsa Família. The Brazilian law also specifies stringent rules under which people between 14 and 17 can work. The main rule is that they can work short term as apprentices and restrict the activities they can do. However, because we cannot disentangle what would be child labour and what is apprentice work, we restrict our sample to people below 14 years old, only. The null result in 1990 reinforces the fact that the disease took time to spread and destroy the region's economy.

[10] Estatuto Brasileiro da Crianca e do Adolescente - ECA. Law 8.069/1990. http://www.planalto.gov.br/ccivil_03/leis/L8069.htm.

[11] In the appendix, we show the same estimation but assume 1970 as the baseline. The main results do not change.

Figure 11: The short-term effect of witches' broom outbreak on the share of working children



Note: the figure displays estimated coefficients of an event-study regression of the interaction of year dummies with a treatment indicator, where the treatment is being affected by the witches' broom outbreak, on the share of children working in municipalities on the northeast of Brazil. Data from 1970, 1980, 1991, 2000, and 2010 censuses.

Source: authors' calculations based on method described in Section 3.

To provide more evidence that the probable mechanism that led to the long-term impacts on education and health is child labour, we used a yearly national microdata survey called PNAD.[12] We used PNAD 1995 to create Table 3, because in 1996, PETI was launched. This table shows in column 2 the share of children that works in cocoa in Bahia state, compared to the total number of children working in agriculture. Although the interviewed population of Bahia could indicate that they worked in 19 different broad agricultural productions at PNAD 1995, which can be disaggregated in almost 375 specific activities, cocoa production responded to 4.3% of all child labour in the agricultural sector of Bahia state in 1995.

Column 3 of Table 3 shows the share of young individuals below 18 years that works in cocoa and reported that they started working at age i, in column 1. The denominator is the share of children that works in any other agricultural production and reported that they started working at age i. Thus, in 1995, 18.2% of the individuals below 18 that reported starting working at seven years old worked in cocoa production. Finally, column 4 shows the average age at which individuals started working per age group in 1995. It shows that individuals between ten and 17 started working right after the first years of the witches' broom outbreak (1990). Unfortunately, the PNAD only provides information at the state level, and we cannot reproduce this table after 2000 due to changes in the methodology to define the sectors.

[12] Pesquisa Nacional por Amostra de Domicílios. It is usually indicated as a 'micro census', nationwide representative, and also conducted by the Brazilian Bureau of Statistics - IBGE.

Table 3: Percentage of individuals younger than 18 years old working in the cocoa, compared to other agricultural productions in Bahia state in 1995

Age i	# child working - cocoa / # child working in any agr. /	# age child working in cocoa started # age child working in any agr. started	Average starting / working age
5		9.5%	
6		17.6%	
7		18.2%	
9		3.3%	
10	9.4%	3.1%	8.33
11	5.1%	5.9%	8.50
12	2.2%	6.1%	8
13	2.3%	6.4%	10
05-13		5.9%	
10-13	4.3%	4.2%	
14	4%	11.5%	7.99
15	6%	27.3%	10.85
16	6%	50.0%	9.8
17	11%	10.76	

Note: the table display in column 1 the age indicator. Column 2 displays the share of children working in cocoa in Bahia state (on the total of children working in any agriculture production in the state). This should be interpreted as: 5.1% of all children aged 11 years in 1995 that are working in Bahia, is working at cocoa production. Column 3 should be interpreted as 6.4% of all people below 18 years old that are working in Bahia in 1995, works in cocoa production, and started working at 11 years old. Finally, the last column shows the average starting working age of children that was working in cocoa production in 1995.

Source: authors' calculations based on PNAD 1995.

Finally, Table 4 adds by showing, using the census data, that in 2000 the percentage of individuals that used to go to school or that never went is much higher in witches' broom-affected areas than in not affected areas. Besides, the difference is higher for individuals between 11 and 12 years old. Unfortunately, we cannot recover this information from the 1991 census.

Table 4: Percentage of individuals younger than 18 years old that are enrolled in school or kindergarten in 2000

	Witches' broom municipalities				Others			
	Yes, priv.	Yes, pub.	No, but used to	Never	Yes, priv.	Yes, pub.	No, but used to	Never
10	0.0	92.9	7.1	0.0	0.6	92.4	4.7	2.2
11	0.0	81.6	13.2	5.3	0.6	92.8	4.0	2.5
12	0.0	75.9	17.2	6.9	0.5	91.0	5.9	2.6
13	1.5	75.0	14.7	8.8	0.7	87.6	8.8	2.9
14	1.6	68.8	26.4	3.2	0.7	82.8	13.5	3.0
15	0.5	67.4	29.5	2.6	0.7	73.8	21.7	3.9
16	0.0	52.6	39.9	7.5	0.6	63.6	31.3	4.5
17	0.4	44.5	46.3	8.9	0.6	52.2	41.7	5.6

Note: the table display, using the 2000 census, the percentage of individuals younger than 18 years old that are enrolled in school or kindergarten in 2000. They are split into two groups, regions affected and not affected by the witches' broom. Yes, priv = yes, she is studying in a private school. Yes, pub = yes, she is studying in a public school. No, but used to = no, she is not studying, but she used to study. Never = she never ever studied.

Source: authors' calculations based on the 2000 census.

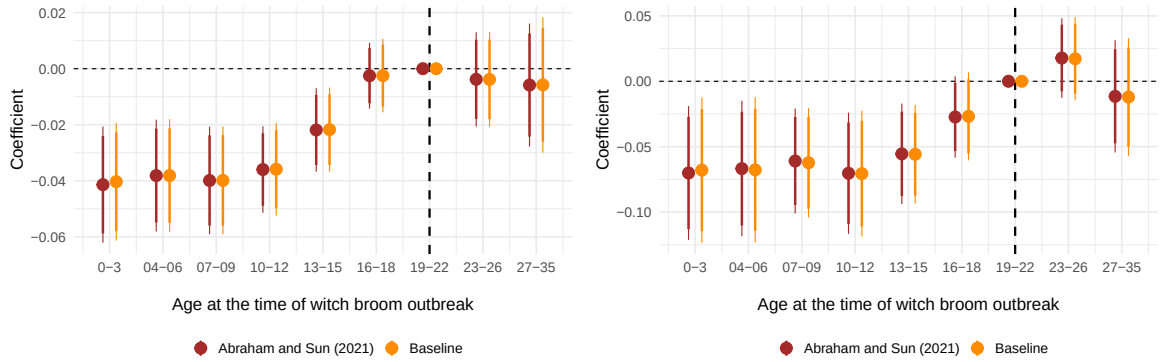
4.4 Robustness

Staggered difference-in-differences

Section 2 and Figure 2 explain that the witches' broom outbreak had differential timing across municipalities. Therefore, the OLS estimation can be biased (Roth et al. 2022). To overcome that, we estimate equation 2 using the Sun and Abraham (2021) estimator. Figure 12 suggests that the estimation presented in previous sections is not biased by the staggering outbreak of the disease since results from baseline are

qualitatively identical and quantitatively similar to the estimator proposed by Sun and Abraham (2021). It is somewhat expected, given that we used a large number of never treated municipalities in the control group and the fact that treatments occurred in a short interval of time (1990 to 1992), indicating no clear reasons for the treatment effect to vary by treatment groups.

Figure 12: Long-run consequences of witches' broom outbreak:
baseline vs Abraham and Sun (2021) estimator



(a) High school (b) Wages

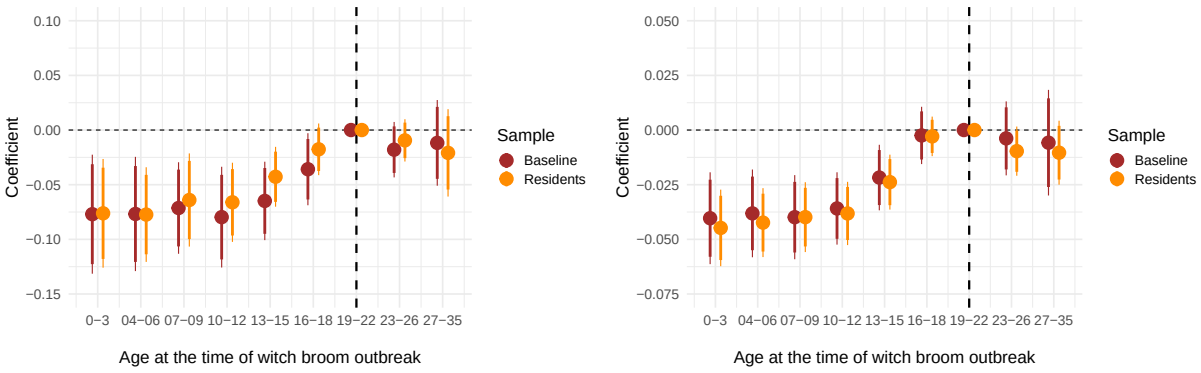
Note: the figure displays the baseline results for the probability of having completed high school and the log of earnings up to 20 years after the witches' broom outbreak and results for the estimator proposed by Abraham and Sun (2021)). The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level. Confidence intervals: 95% and 90%.

Source: authors' calculations based on method described in Section 3.

Migration

A potential concern is that migration could bias our results. Affected families may have migrated to other municipalities to find better employment opportunities. Since in our primary sample, we are only considering individuals born in the same municipality where they were interviewed in the censuses, migration could lead to biased estimates. To check how much of an impact migration could have on our baseline estimates, Figure 13 compares our baseline results with the ones when considering the municipality of residence, whenever the birth municipality is. As can be seen in Figure 13, results don't change much across both specifications, indicating that if there is some bias due to migration, it is limited. Some historical documents report some migration within Ilhéus-Itabuna micro-region, in which migrants moved to the region's biggest municipalities, such as Porto Seguro, Ilhéus, and Itabuna, but not to other parts of the state or other states (Gomes and Pires 2015; Pereira et al. 1996; CEPLAC 2009; L. B. Rocha 2006).

Figure 13: Long-run consequences of witches' broom outbreak: baseline vs non-movers



(a) Income (b) High school

Note: the figure displays the baseline results for the probability of having high school up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

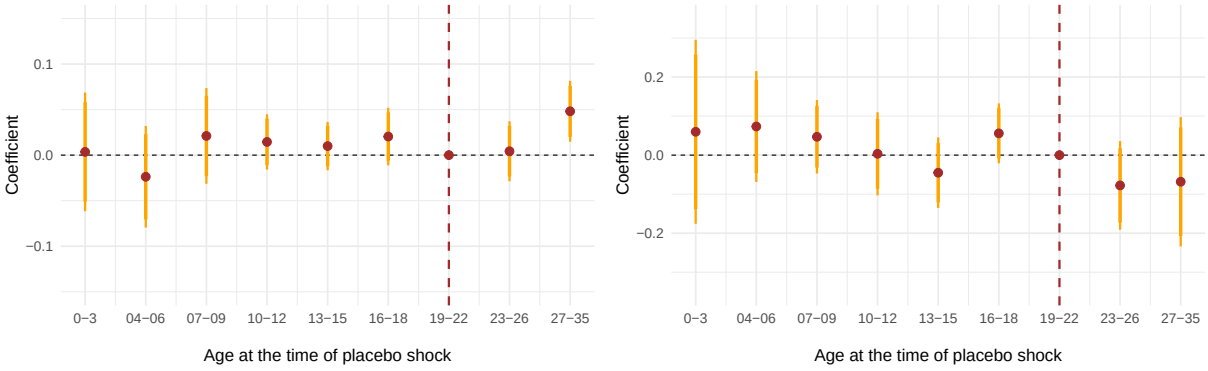
Source: authors' calculations based on method described in Section 3.

Placebo 1: idiosyncratic characteristics of affected municipalities

So far, we have shown how individuals' exposure in childhood to the witches' broom outbreak have today worse labour market and education outcomes than cohorts in municipalities not exposed to the shock. However, it might be the case that younger cohorts in treated municipalities were always worse off than the ones in non-treated municipalities because of the idiosyncratic characteristics of affected municipalities. To test if that is the case, we estimated equation 2 arbitrarily assigning a placebo shock in 1960 to the same municipalities that, in the future, will be affected by the witches' broom outbreak and look for differences in the same outcomes of individuals on the census of 1970 and 1980.

Due to limitations of the 1970s census, we do not have information on individual wages and use. Instead, family income is the dependent variable. We measure education using the number of years of schooling, a variable compatible between the 1970s and 1980s censuses. The sample is composed only of individuals in the Brazilian Northeast that were 0 to 35 years old in 1960. Figure 14 presents the results of the falsification exercise. Since the 1970s and 1980s censuses and interviews occurred before the witches' broom outbreak, we should not expect any difference in the labour market and education outcomes of cohorts' exposure in childhood to the placebo shock in the 1960s. Indeed, as shown in Figure 14, there is no difference in wages or years of schooling between younger and older cohorts' exposure and not exposure to the placebo shock, reinforcing the robustness of our baseline estimates.

Figure 14: The long-run consequences of a placebo treatment



(a) Income (b) Years of schooling

Note: the figure displays the results for a placebo exercise using 1970s and 1980s census data and a fictional shock in 1960 on the municipalities that will be affected by the witches' broom in the future. The horizontal axis shows the age at the moment of the placebo shock. The estimate corresponds to an ITT effect—to the estimated coefficient of equation 2. Standard errors are clustered at the municipality level. Confidence intervals: 95% and 90%.

Source: authors' calculations based on 1970s and 1980s census data and method described in Section 3.

Placebo 2: concurrent effects

In the previous sections, we assume that no other effects are affecting the cocoa producer region at the time of the outbreak. Those effects may arise due to price changes, global demand changes, or any other idiosyncratic shock affecting the region that we cannot observe. To rule out those potential effects, we run the following exercise. First, we drop all witches' broom-affected municipalities from the sample. Second, we assume that the municipalities with cocoa production that were not affected by the witches' broom are treated, and some idiosyncratic shock happened to them in 1990. Recall from Figure 1 that there are some municipalities that were not affected. Third, we run equation 1 comparing the cocoa producer region net of witches' broom affected municipality against non-cocoa producer municipalities. The results are displayed in Table 5. The results suggest that no other shock happened in the cocoa market simultaneously to the witches' broom disease.

Table 5: Placebo analysis: concurrent effects

	High school (1)	Elementary school (2)	log(wages) (3)
Childhood exposure	-0.003	0.006	0.005
	(0.009)	(0.010)	(0.020)
R^2	0.075	0.100	0.208
Observations	4,538,411	4,538,411	1,838,953
Municipality FE	✓	✓	✓
Birt-year FE	✓	✓	✓
Census wave FE	✓	✓	✓

Note: the table displays the regression results of the estimation of equation 1 dropping municipalities affected by the witches' broom from the sample and considering cocoa producer municipalities not affected by the witches' broom as treated units, assigning 1990 as the treatment date. The estimate corresponds to an ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level.

Source: authors' calculations based on method described in Section 3.

5 Conclusion

This paper studies the long-run effects of a significant agro-terrorism event in cocoa production in Brazil on education and the labour market. We explore the witches' broom outbreak in cocoa farms in the world's second most important cocoa production region until 1989, the southeast of Bahia state in the northeast of Brazil.

Our results show that the witches' broom outbreak negatively affected the education and income of individuals living in affected municipalities. People below 18 years old living in municipalities affected by the witches' broom disease have 2.8% less probability of having a high school degree, 3.2% less probability of having elementary school, and wages 4.8% lower. Those effects are greater for individuals between zero and 12 years old during the witches' broom outbreak. We provide suggestive evidence that these long-run adverse effects on human capital and wages are explained by the aggregated impacts on cocoa production that led to a fall in the GDP per capita and household incomes since the witches' broom disease pushed the southeast region of Bahia to a recession period and pushed children in affected municipalities to start to work early. We also show that the impacts are homogeneous between gender.

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A Appendix: figures and tables

Figure A1: Healthy cocoa

Source: photo by Keith Weller, USDA Agricultural Research Service. Available at: https://www.ars.usda.gov/oc/images/photos/oct05/k4636-12/.

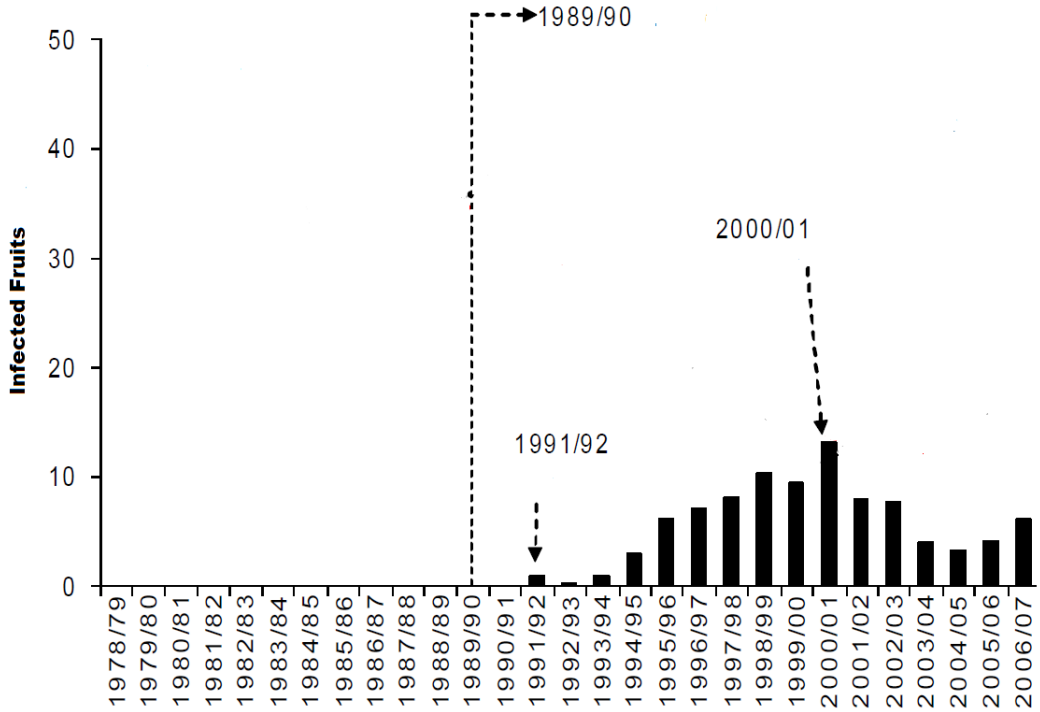
Figure A2: Cocoa with witches' broom

Source: photo by Scott Bauer, USDA Agricultural Research Service. Available at: https://www.ars.usda.gov/oc/images/photos/oct05/k8618-1/.

Figure A3: An example of mushroom causing the witches' broom disease

Source: photo by Scott Bauer, USDA Agricultural Research Service. Available at: https://www.ars.usda.gov/oc/images/photos/nov99/k8626-1/.

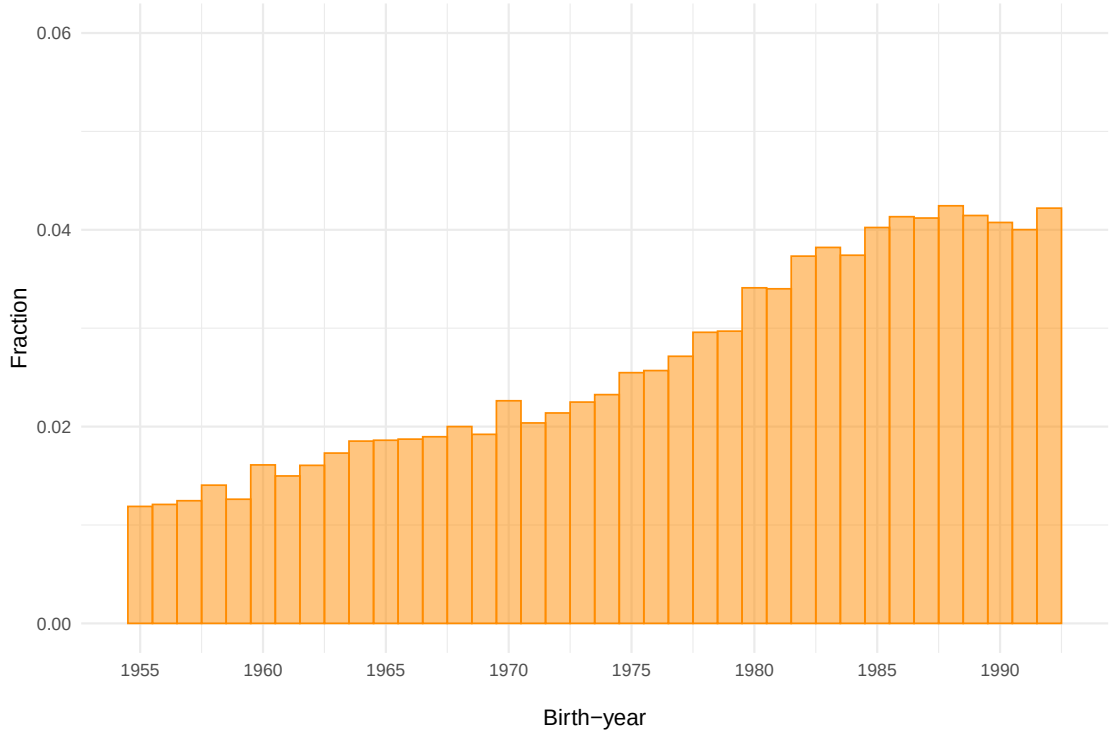
Figure A4: Tons of cocoa fruits infected with the witches' broom by year



Note: this graph is based on a representative sample of 139 farms in the cocoa produced region. The CEPLAC and the Ministry of Agriculture do not have information about the number contaminated fruits per municipality and year throughout the time.

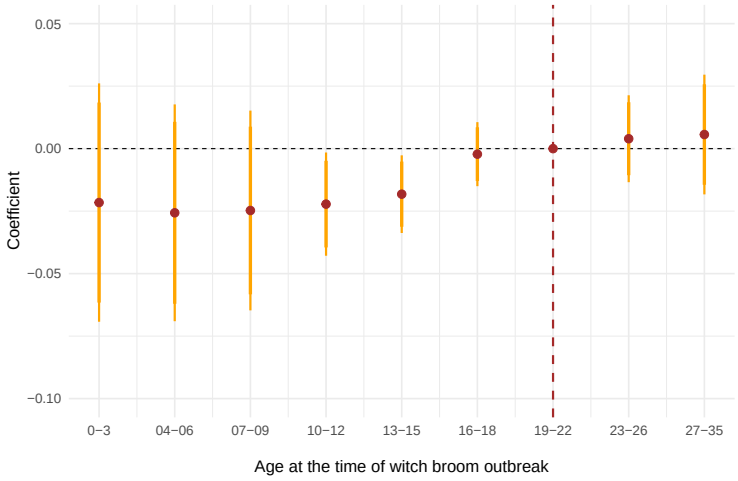
Source: adapted from CEPLAC (2009).

Figure A5: Birth cohorts in estimation sample

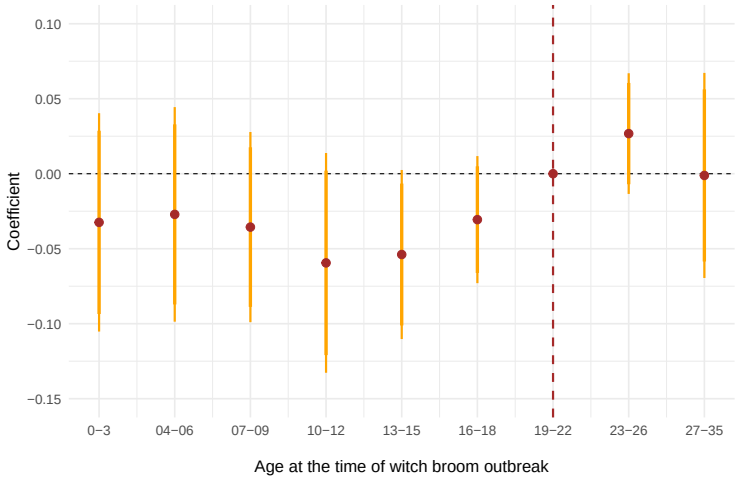


Note: this figure presents the birth cohorts in our estimation sample.
Source: Brazilian census (2000–10).

Figure A6: The long-run consequences of witches' broom - alternative control group including only Bahia state



(a) High school



(b) Wages

Note: the figure displays the results for the probability of having high school and wages up to 20 years after the witches' broom outbreak. The control group includes only municipalities in the state of Bahia. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 2. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

Source: authors' calculations based on method described in Section 3.

Table A1: Long-run effect of witches' broom on exposed cohorts

	High school		Elementary school		log(wages)	
	(1)	(2)	(3)	(4)	(5)	(6)
Bellow 18y exposure	-0.028***		-0.032***		-0.056***	
	(0.008)		(0.010)		(0.022)	
Bellow 15y exposure		-0.032***		-0.037***		-0.058***
		(0.008)		(0.010)		(0.020)
R^2	0.075	0.075	0.101	0.101	0.207	0.207
Observations	4,647,460	4,647,460	4,647,460	4,647,460	1,884,097	1,884,097
Municipality FE	✓	✓	✓	✓	✓	✓
Birth-year FE	✓	✓	✓	✓	✓	✓
Census wave FE	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of equation 1 and also results for an alternative definition of childhood exposure, considering individuals with 15 years old or less as treated. The dependent variable in columns (1) and (2) is a dummy that equals one if the individual completed high school, and a dummy equals one if the individual completed elementary school in columns (3) and (4). Finally, in columns (5) and (6), the dependent variable is the log of wages. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level.

Source: authors' calculations based on method described in Section 3.

Table A2: Witches' broom effect by race

	Panel A: All sample		
	High school	Elementary school	log(wage)
	(1)	(2)	(3)
Childhood exposure	-0.030***	-0.028***	-0.065**
	(0.010)	(0.010)	(0.030)
Childhood exposure * Black	0.002	-0.005	-0.002
	(0.011)	(0.011)	(0.020)
R^2	0.081	0.107	0.224
Observations	4,625,295	4,625,295	1,877,702
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓
Black × Municipality FE	✓	✓	✓
Black × Birth-year FE	✓	✓	✓
Black × Census wave FE	✓	✓	✓
	Panel B: Only blacks		
	High school	Elementary school	log(wage)
	(1)	(2)	(3)
Childhood exposure	-0.028***	-0.033***	-0.067***
	(0.009)	(0.011)	(0.020)
R^2	0.066	0.092	0.203
Observations	3,226,017	3,226,017	1,292,217
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓
	Panel C: Only whites		
	High school	Elementary school	log(wage)
	(1)	(2)	(3)
Childhood exposure	-0.030***	-0.028***	-0.065**
	(0.010)	(0.010)	(0.030)
R^2	0.106	0.130	0.234
Observations	1,399,278	1,399,278	585,485
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of equation 1 and also results for the interaction of the childhood exposure dummy with a dummy equal to one if the individual is black as in Clay et al. (2020). The dependent variable in columns (1) and (2) is a dummy that equals one if the individual completed high school. Finally, in columns (3) and (4), the dependent variable is the log of wages. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level.

Source: authors' calculations based on method described in Section 3.

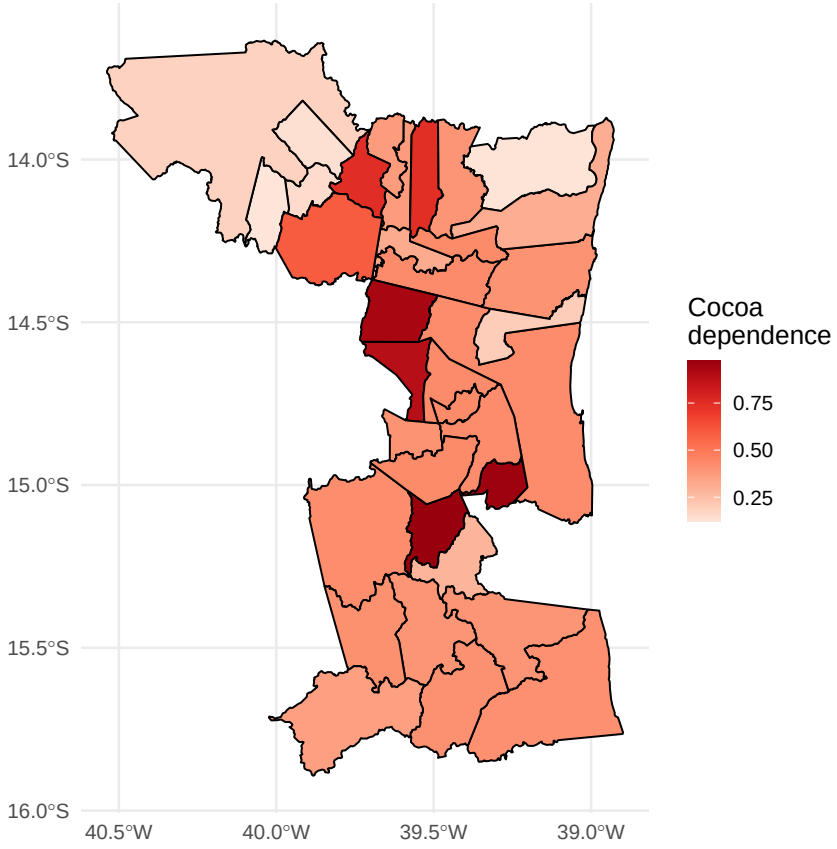
Table A3: Witches' broom effect by gender

	Panel A: All sample		
	High school	Elementary school	log(wage)
	(1)	(2)	(3)
Childhood exposure	-0.022***	-0.028***	-0.043
	(0.007)	(0.009)	(0.028)
Childhood exposure * Women	-0.014**	-0.010	-0.025
	(0.006)	(0.007)	(0.030)
R^2	0.079	0.106	0.220
Observations	4,647,460	4,647,460	1,884,097
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓
Women × Municipality FE	✓	✓	✓
Women × Birth-year FE	✓	✓	✓
Women × Census wave FE	✓	✓	✓
	Panel B: Only women		
	High school	Elementary school	log(wage)
	(1)	(2)	(3)
Childhood exposure	-0.036***	-0.037***	-0.068***
	(0.010)	(0.012)	(0.022)
R^2	0.089	0.115	0.204
Observations	2,296,981	2,296,981	701,563
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓
	Panel C: Only men		
	High school	Elementary school	log(wage)
	(1)	(2)	(3)
Childhood exposure	-0.022***	-0.028***	-0.043
	(0.007)	(0.009)	(0.028)
R^2	0.065	0.090	0.225
Observations	2,350,479	2,350,479	1,182,534
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of equation 1 and also results for the interaction of the childhood exposure dummy with a dummy equal to one if the individual is female as in Clay et al. (2020). The dependent variable in columns (1) and (2) is a dummy that equals one if the individual completed high school. Finally, in columns (3) and (4), the dependent variable is the log of wages. The estimate corresponds to a ITT effect—to the estimated coefficient of equation 1. Standard errors are clustered at the municipality level.

Source: authors' calculations based on method described in Section 3.

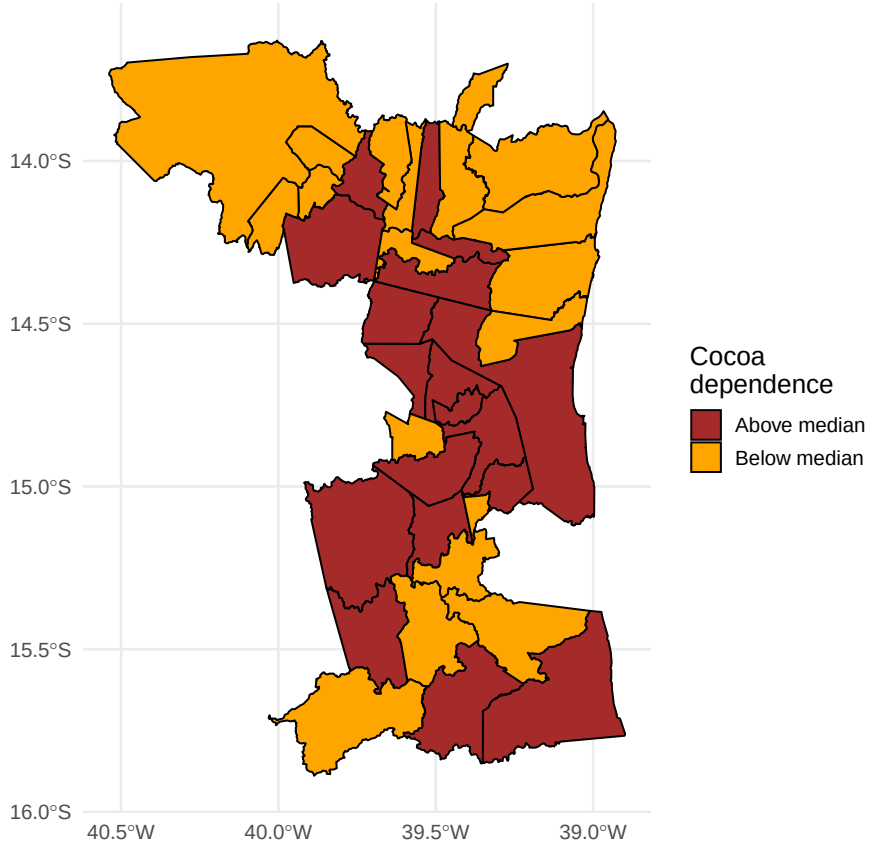
Figure A7: Cocoa dependence in municipalities affected by the witches' broom disease



Note: the figure plots the spatial distribution of an index of cocoa dependence in municipalities affected by witches' broom. The index is the share of cocoa production over total agriculture production on the municipality in 1989, a year before the first witches' broom outbreak.

Source: authors' calculations based on Ipeadata.

Figure A8: Cocoa dependence in municipalities affected by the witches' broom disease



Note: the figure plots the spatial distribution of an index of cocoa dependence in municipalities affected by witches' broom. The index is the share of cocoa production over total agriculture production on the municipality in 1989, a year before the first witches' broom outbreak.

Source: authors' calculations based on Ipeadata.

Figure A9: Baseline estimates vs Abraham and Sun (2021) estimator - elementary school

Note: the figure displays the baseline results for the probability of having completed elementary school and the log of earnings up to 20 years after the witches' broom outbreak and results for the estimator proposed by Sun and Abraham (2021). The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to a ITT effect—to the estimated coefficient of equation (refeq:did. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

Source: authors' calculations based on method described in Section 3.