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The long-term effects of crop diseases on education and earnings

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Abstract: The economic literature has shown that exogenous transitory shocks affect education by changing the opportunity cost of children. We argue that this is only part of the explanation. When permanent, shocks may change contracts and the organization of labour by eroding the productive structure and decreasing land values. This paper studies the long-term effects of a long-lasting environmental shock on individuals' educational achievement and earnings. We investigate the 1988 witches' broom outbreak in Brazil, the world's second-leading cocoa producer at the time. Our results show that crop disease negatively impacted the long-term education and earnings of exposed cohorts living in affected areas. Our findings suggest that an increase in child labour and family farm work, driven by changes in labour contracts and land use, could explain the results. Also, the prevalence of a type of contract frequently tied to modern slavery and child labour, known as *meeiros* (sharecroppers, in English), increased.

Key words: witches' broom, long-term, education, earnings, child labour

JEL classification: N36, O12, O15

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1 Introduction

Developing countries' rural populations face many risks because of expected and unexpected events, such as conflicts, climate shocks, and crop diseases. Households' ability to smooth transitory shocks—credit access, savings, or good coverage by social protection policies—may determine the severity of the shock and whether it will translate into short or long-run impacts on people's lives. The effects of transitory shocks on education, earnings, and child labour are well documented in the economic literature. Short-run adverse shocks may decrease (Maccini and Yang 2009; Carrillo 2020; Cogneau and Jedwab 2012), or increase (Baker et al. 2019) educational achievement and earnings. Nevertheless, the response of human capital to permanent exogenous shocks remains largely unexplored. In scenarios of enduring adverse events, households can adapt, potentially mitigating the shock over time. However, a permanent shock may result in changes in labour contracts and a sustained decrease in land value, thereby altering long-term household income and, consequently, investments in children's human capital.

This paper studies the long-run effects of a significant exogenous and long-lasting 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 1988, the southeast of Bahia's state in northeast Brazil. The peak of infected fruits happened almost 12 years after the outbreak, and by 2023 the region had yet to recover its full potential. In 1985, this region produced 80% of Brazilian and 62% of Latin American cocoa (IOCC 1993). Data and historical documents report that cocoa production decreased by 80% in the first 10 years after the disease, pushing almost 250 thousand workers to unemployment.

For several reasons, the context of the witches' broom in Bahia is particularly appealing to study the long-run impacts of exogenous permanent agricultural shocks.[1] First, the municipalities affected by the witches' broom disease highly depended on cocoa production. At the outbreak, cocoa was the second most exported product from the Bahia state. One year before the outbreak, the share of cocoa in the total agriculture production was, on average, 84% in the affected municipalities. The median share was 93%. This high dependency made the region very vulnerable since a negative shock to cocoa production automatically converted into a strong shock on the total income of the municipality.

Notably, the region experienced no changes in crop patterns, despite evidence suggesting that similar shocks typically lead to crop substitution (Lange 2009). For instance, in the case of the boll weevil infestation in the U.S., farmers substituted cotton for corn, peanuts, and sweet

[1] Bahia state has about 15 million inhabitants, comprising an area almost the size of France. A high share of its working population has no jobs or works without any formal contract, and it has the highest percentage of the population receiving the cash transfer program *Bolsa Família*, targeted at the poorest families in Brazil.

potato crops (Baker et al. 2019). No other crop substituted the cocoa, and the local agricultural industry never recovered. In 2010, cocoa represented 72% of the total agricultural output in the affected municipalities. However, the total agricultural output was only 7.3% of the 1988 output. A potential explanation for this cocoa dependency is the fact that the cocoa production in this region happened within a large protected forest area. Therefore, crop substitution would be possible only through massive deforestation.[2]

Our empirical strategy exploits variations in the location and time of the outbreak at the municipal level in Brazil. 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 eighteen years old at the time of the witches' broom outbreak, which varies between 1990 and 1992 depending on the city. We then estimate difference-in-differences and event studies regressions.

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 high school is seventeen. In addition, 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 older than 18 in affected and not affected regions. We use the 2000 and 2010's Brazilian demographic Censuses and historical information about the timing and severity of the crisis in each city. Our sample contains 5 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 less than 65 years old at each demographic census.[3]

The main results show that the witches' broom outbreak negatively affected the education and income of individuals living in affected municipalities. People below eighteen years old living in municipalities affected by the witches' broom disease are 2.8 percentage points (p.p.) less likely to have a high school degree and 3.2 p.p. less likely to have an elementary school. Compared to the control group average, these numbers represent a 10.5% lower probability of having a high school degree and an 8% lower probability of having an elementary school degree. The individuals affected by the witches' broom outbreak also have wages 4.8% lower. Those effects are stronger for individuals between zero and 12 years old during the witches'

[2] Many years after the shock, this combination also led to an important new technology for cocoa production, known as the agro-forest production system Cabruca, which currently helps the protection against climate change (Heming et al. 2022). This technology consists of planting cocoa trees under higher native forest trees, which reduces the water soil evaporation. See Appendix Figure A1 for a visual representation of this production system.

[3] For the individual-level regressions, we use the Brazilian Demographic Census 2000 and 2010, and for the municipality-level regressions, we add the 1970, 1980, and 1991 censuses and the Brazilian Agricultural Census 1970, 1975, 1980, 1985, 1995, 2006, and 2017.

broom outbreak. To complement the results, we explore the extensive margin effects of the shock. Our findings suggest that younger cohorts are less likely to work in the agricultural sector, and more likely to work in the services and manufacture. Additionally, we show that they moved to the last two sectors in low-skilled jobs, as informal or self-employed workers. Finally, we show that witches' broom did not impact women's fertility decisions.

The heterogeneity analysis suggests that the impacts were 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 in 1988. The effects on high school achievement and wages increase to 3.2 p.p. and 8.5 p.p., respectively. Following the empirical strategy proposed by Clay et al. (2020), we also provide evidence that the effects are stronger for girls than boys and do not differ by race.

To investigate the mechanisms that may explain our main results, we estimate an event-study regression at the municipality level 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.[4] The result suggests an increase in child labour by 2.5 percentage points in 2000 and 2010 in affected regions compared to non-affected regions. However, one may question how child labour increased if cocoa production was decimated. To investigate what happened in the region, we used the Brazilian agricultural census. More specifically, we show that because of the outbreak, the land value was reduced by 48% 16 years after the outbreak, and the share of the family employment on the total agricultural employment increased by 10 p.p. five years after the outbreak and 20 p.p. in 2017.

In addition, using Brazilian Agricultural Census data, we show that the share of properties run by sharecroppers (*meeiros*, in Portuguese)—informal contracts where workers use their whole family in a rented small piece of land in exchange of a share of the production—consistently increased by 4 p.p. years after the outbreak in affected municipalities, relative to non-affected ones. This pattern is consistent with qualitative interviews with politicians, farmers, and social movement leaders that we conducted in the most important city in the region (Ilhéus).[5] This piece of evidence is also consistent with our previous estimates on child labour and family labour, since the *meeiro* contracts are appointed as one of the main forms of modern slavery

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

[5] See Appendix B.

and child labour relations in Brazil by the International Labour Organization (ILO) and the Ministry of Labour.[6]

We further 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. We also performed two placebo tests to reinforce the reliability of our baseline results. First, we estimate the same regressions in older census waves of 1970 and 1980, assuming a placebo shock in 1960 (30 years before the actual shock), and found no differences in human capital accumulation between treatment and control groups. In the second placebo test, we dropped the treated municipalities affected by the crop disease from the sample and assigned treatment status to unaffected cocoa-producer municipalities. Using this approach we found no differences between treatment and control individuals. Combined, the placebo tests show that other idiosyncratic characteristics at the municipality level or concurrent shocks at the same time as the outbreak are unlikely to explain our results.

This paper provides two main contributions to the literature. As far as our knowledge goes, this is the first paper that explores a major permanent shock in a developing country. For instance, Banerjee et al. (2010) shows that the phylloxera insects destroyed a large share of French wine production in the nineteenth century leading to negative impacts on health. Moreover, our setting is particular because the peak of the disease only happened a few years after the outbreak, the disease was never eliminated, and farmers could not substitute the production for other crops. The witches' broom destroyed the foundations of the cocoa region, one of the wealthiest micro-regions of the Brazilian Northeast.[7]

Our results speak with the studies that explore transitory exogenous shocks.[8] However, none of the studies nor other research focuses on a highly dependent region in a specific monoculture, such as the cocoa region in Bahia. Therefore, our analysis draws important conclusions about large monocultures that are still prominent in many poor areas of developing countries, such as cocoa in the Ivory Coast, palm oil in specific parts of West African countries such as Ghana, or maize in Zambia. In particular, our study is similar to Baker et al. (2019), which found an increase in school enrollment and years of schooling due to the boll weevil in the US cotton belt.

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[6] See page 36 of https://www.ilo.org/wcmsp5/groups/public/---americas/---ro-lima/---ilo-brasilia/documents/publication/wcms_817094.pdf. The word *meeiro* in Portuguese would be translated to 'those who own half of it'.

[7] The northeast of Brazil has 23 micro-regions.

[8] Boll weevil disease in the US Cotton belt (Baker et al. 2019; Ager et al. 2020), recessions (Stuart 2022), coffee shock prices in Latin America (Padrón and Burger 2015; Carrillo 2020; Kruger 2007), desert locust in African countries (Le and Nguyen 2022) or the impact of climate events, such as droughts (R. Rocha and Soares 2015) and floods (Maccini and Yang 2009).

The conflicting results may be explained by the differences in the educational infrastructures between the US cotton belt regions and a Brazilian rural area, the shock effects on child labour, and a particular change in the relationship between land owners and employers. We could not test the first hypothesis because of the limitations of Brazilian data.

The second main contribution is showing that child labour increased due to the disruption of family incomes (direct effect), which may have led young individuals to search for services and manufacture low-skilled jobs, and structural change in the labour contract between landowners and farmers (indirect effects). The results on child labour 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. 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). More specifically, we provide a better test of what happens when there is a change in the full household income. Short-term fluctuations in wages and income should be mostly associated with increases in the opportunity cost of children's time (substitution effect). A permanent shock is related to changes in households' total income, representing pure income effects (luxury axiom) (Soares et al. 2012).

In addition to the conventional child-labour papers approach, we add by showing the change in the land property administration through the introduction of the *meeiros*. Therefore, temporary shocks that affect household income may change the opportunity cost of schooling. Children are forced to work to help the family's income while the shock lasts. However, the combination of a change to the worst labour contract and permanent shocks change not only the cost of opportunity of children's time but also the total household's total income and production form, and children may be sent for long periods to work to support their families. The empirical evidence using Brazilian data and exploring temporary shocks corroborate our findings.[9]

Finally, this study has two minor contributions. First, we add to the literature that explores the effects of economic shocks on populations without access to savings, credit markets, and social protection systems (Beegle et al. 2006; Bandara et al. 2015; Jensen 2000). During the witches' broom outbreak, Brazil was facing the worst inflationary period in its history.[10] Therefore, most of the credit markets in the country were nonexistent, and most households had no savings.

[9] Soares et al. (2012) provide an empirical test of the Basu model to the Brazilian context, showing that higher household wealth 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, Lam, and Levison (2007) found that when a head of the Brazilian household lost their job, the probability of having children working increases.

[10] 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.

Furthermore, cocoa production intensively uses low-skilled workers, reducing their mobility to other activities in a crisis.

Second, we also dialogue with the recent literature that investigates the potential impacts of climate change on fungi, insects, and disease outbreaks and spread into agriculture production (Kawasaki 2023). Witches' broom fungus are common in the Amazon forest as well, however, the southeast of Bahia has a very particular climate that makes the disease spread extremely fast, while it doesn't happen in the Amazon Forest cocoa farms.[11] Therefore, analyzing this event also provides a suggestive impact of the potential impact that climate change may have on agricultural production, especially in mono-culture productions that are common in many developing countries.

2 Background

Between 1961 and 1988, Brazil was the second biggest global cocoa producer. In 1985 for example, Brazilian production was about 448,577 tons of cocoa, representing 70.5% of Ivory Cost production, the biggest producer in the world. Bahia was the state with the higher share of the national production, approximately 86%.[12] The southeast of Bahia's state concentrated the cocoa production. Figure 1 shows the map of Bahia state and highlights the municipalities with cocoa production, most known as the Ilhéus-Itabuna microregion. Many studies, technical reports, and books described the importance of cocoa production for the region, associating cocoa with the development of agribusiness to investments in infrastructure and development of local human capital (Gomes and Pires 2015; Ceplac 2009).

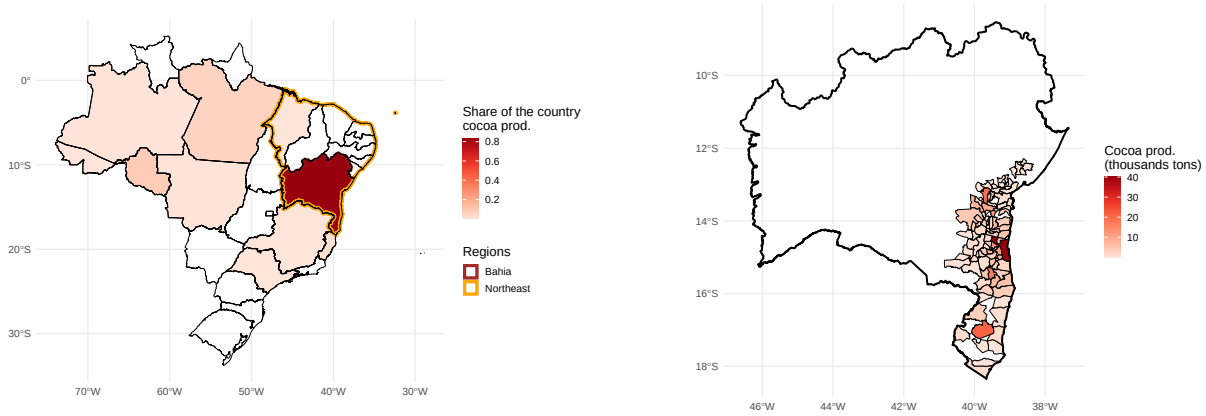
The cocoa production in the region was characterized by large farms owned by a few elite families, which led to very high inequality in the region. Besides, it became a mono-culture because of the high prices of cocoa, the inequality in land ownership, and the environmental characteristics of the region, which is covered by tropical forests. Therefore, the region was highly dependent on it, with very low diversification in income sources. Indeed, during that period, cocoa ranked as the second most exported commodity from the Bahia state. The average municipality affected by the witches' broom in the state attributed 44% of their total

[11] The meeting happened on August 28, 2022. The technicians work at Ceplac, an agency from the Ministry of Agriculture that works only with cocoa. Two of the three personnel who participated in the meeting worked at Ceplac during the witches' broom outbreak.

[12] Bahia is a large-sized state with about 15 million inhabitants and whose territory is about the size of France. It is one of the poorest states in Brazil. 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 of educational attainment. In 2010, the share of informal workers—those not contributing to social security—was 35.4% in Brazil and 49.4% in Bahia. In 2019, Bahia had the second-highest unemployment rate in Brazil—17% against the national rate of 11%.

agricultural output to cocoa production, while some municipalities exceeded 80%. 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

Note: Panel (a) displays the distribution of cocoa production by state in Brazil during 1988. The yellow border line delineates the Northeast region. Panel (b) illustrates the spatial distribution of cocoa production in municipalities of the state of Bahia with production levels greater than zero in 1988. Data is from Ipeadata.

Witches' broom. The witches' broom disease is a fungal disease that affects cocoa trees, caused by the pathogen Moniliophthora perniciosa. The disease is characterized by the appearance of abnormal growth on the branches of the cocoa tree that resembles a broom, hence the name 'witches' broom'. The fungus infects the young shoots and causes them to grow into dense clusters, which are unsuitable for cocoa production. The affected branches can produce small and malformed pods, leading to a significant reduction in yield. The disease is prevalent in many cocoa-growing regions, particularly in South America, and can have a devastating impact on cocoa production.[13]

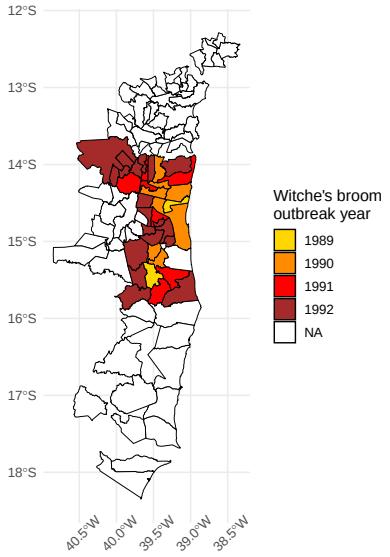
In May 1989, the Ilhéus-Itabuna microregion's fate started to change with the first discovery of the witches' broom in Uruçuca municipality. In October 1989, Camacan municipality also reported the presence of the disease. Figure 2 shows each municipality with official reports of witches' broom disease in Bahia's State. The disease was known to be endemic in the Amazon region for many years but had never arrived in the south of Bahia until the sudden outbreak in 1989.

At that time, the principal explanations for the disease were bioterrorism conducted by cocoa producers' competitors in the Amazon Forest and Ivory Coast. 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

[13] Appendix Figures A2, A3, and A4 show, respectively, a healthy cocoa, an infected cocoa, and an image of the witches' broom mushroom.

and the coincidental timing of the first two infections (two different and 100km apart focus sites located in the cocoa region's center), Pereira et al. (1996) concluded that the disease was criminally introduced. The spread, however, was random and explained mainly by the wind and animals carrying the witches' broom mushroom.

Figure 2: Witches' broom outbreak by municipalities and year

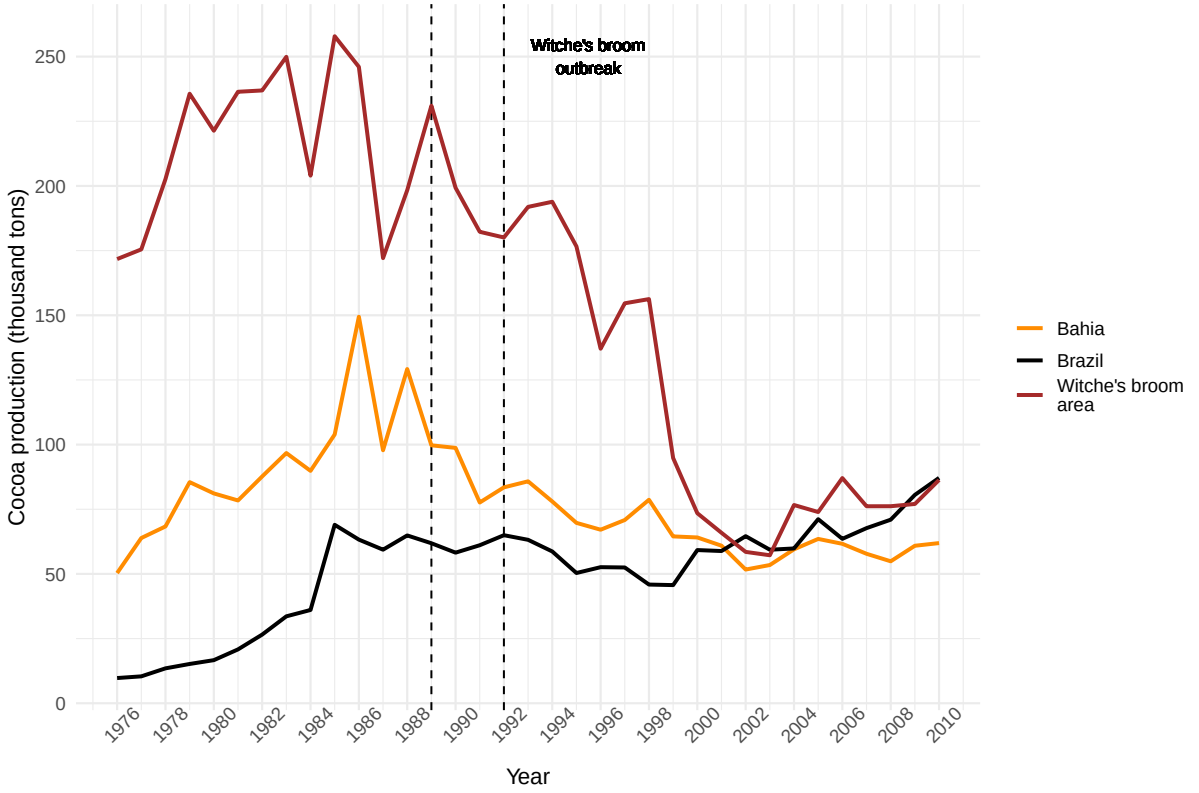


Note: this figure depicts the spatial distribution of outbreak dates of witches' broom disease in affected municipalities, based on data from Lisboa et al. (2020). The municipalities depicted with border lines but lacking any color indicate cocoa production in 1989 but were not impacted by the disease.

Because witches' broom is one of the most dangerous diseases for cocoa production, many studies tried 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). There are three remarkable differences between the witches' broom fungus and other crop diseases. First, the outbreak was sudden and unexpected, making it impossible for the producers to take preventive measures, whereas price and weather shocks were somewhat anticipated. Second, even though the Brazilian government was aware of the potential destructive impact of the disease, farmers in the region did not know how to conduct inspections to identify the disease, adopt preventive practices, and eradicate it. Third, while price and weather shocks are temporary, witches' broom is permanent and becomes endemic to the region once it arrives.

Appendix Figure A5 shows the number of infected cocoa fruits per year. At the outbreak moment in Bahia, there was very little knowledge about how to fight the disease, with the main recommendation being to cut and burn sick trees. It leads to the destruction of farms and families' sources of income. This recommendation was proven wrong, but no specific cure or management exists for the witches' broom. The treatment is evaluated case by case based on the local climate and cocoa genetics. In addition, it is essential to point out that no program was created by the Municipalities, the State, or the Federal level governments to support the affected families.

Figure 3: Trends in cocoa production 1976 to 2010

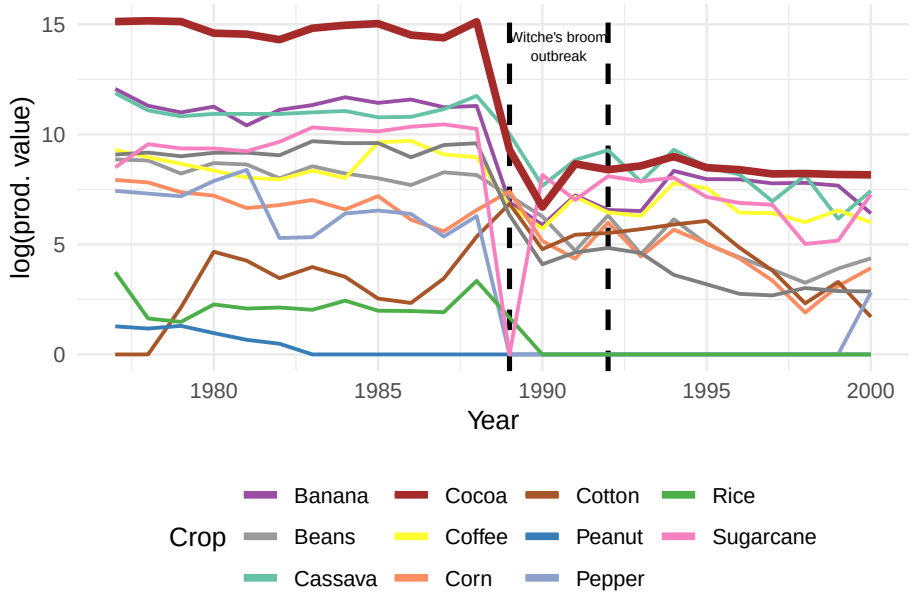


Note: this figure displays the trends of cocoa production over time, measured in thousand tons, for different regions. The red line indicates the production in municipalities affected by the witches' broom disease. The orange line represents the net production of the Bahia state, excluding the production in municipalities impacted by the disease. Finally, the yellow line represents the net production of Brazil, excluding the production in Bahia. Data is from Ipeadata.

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 thousand 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, achieving lower production levels in 2000, the peak year of cocoa-infected products (Ceplac 2009).

Figure 4 shows that the average yearly agriculture income decreased over time, suggesting that there was no transformation in the sector and no other crop development was sufficient to recover the agricultural industry. It is important to highlight some characteristics of the cocoa tree and the region to understand why crop substitution was difficult. First, most of the region is covered by tropical forests and is protected by environmental laws. So, farmers can not destroy the area to open plantation fields, even though they own a large share of the territory. Second, cocoa trees are huge compared to other traditional crops studied in the literature, like coffee, cotton, and beans. Cocoa trees grow in the tropical forest environment. Removing it is costly and difficult because of the trees' size and roots.

Figure 4: Trends in agricultural production values by crop



Note: the figure illustrates trends in the logarithmic value of agricultural production for various crops in municipalities impacted by the witches' broom disease. The data is derived from multiple sources compiled by IPEADATA, including Brazilian official statistics agencies.

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 2000s and 2010s censuses do not ask individuals the municipality of birth, we keep on the sample only 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 excluded from the sample individuals older than 65. To improve the comparability of age cohorts, we restricted 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 individuals with 0 to 35 years by 1989, the first year of the disease. Finally, each municipality's witches' broom outbreak dates 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 wages in the long run. Our empirical strategy

exploits variations in the location and time of the outbreak at the municipal level in Brazil.[14] First, we estimate 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 eighteen years old living in affected and not affected municipalities at the time of the outbreak. The estimated parameters must be interpreted as an intention to treat the effect because not everyone in the treated municipalities was directly affected by the shock.

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

X_i is a vector of socioeconomic characteristics, such as gender and 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_{im}, which summarizes the magnitude of the witches' broom (WB) impact. A negative and significant estimate would suggest that exposure to witches' broom disease reduces education or earnings in the long run. 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.

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

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 18 and 35 years when the witches' broom happened in their municipality of residence do not alter their educational decisions.[15]

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

[15] In a setting like Brazil, where school completion rates were not 100% in the 1990s, one may think that the ideal cutoff would be at 15 years old, the age of completing secondary education and before moving to high school. Therefore, Table A3 shows a robustness check using 15 years old as a cutoff to split the treated and control groups. The main conclusions hold.

Under this identifying assumption, our empirical framework yields estimates of the causal effects of the 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, young adults had minimal options to choose between work and study after eighteen. 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.

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 5 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 verify if there are heterogenous impacts by gender or race.

We further provide many robustness checks. First, because of the differential timing of the outbreak across municipalities, section 6 presents the Sun and Abraham (2021) estimator for a DiD with staggered adoption. The main results do not change, eliminating potential bias arising from the OLS estimation. Second, 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 6 shows that migration does not seem to drive our results. Besides, Section 6 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. Third, in Section 6 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 eighteen years old at the time of the witches' broom disease exposure are 2.8 percentage points (p.p.) less likely to have a high school degree, representing a 10.5% lower probability when compared to the control group average. Columns (3) and (4) show a slightly stronger estimate, but compared to the control group average, it represents an 8% lower probability of completing elementary school. Columns (5) and (6) show that cohorts exposed to the witches' broom have wages -5.1% lower than cohorts not exposed to the witches' broom.

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***	-0.058***	-0.051**
	(0.008)	(0.008)	(0.010)	(0.010)	(0.022)	(0.022)
R^2	0.081	0.084	0.111	0.117	0.208	0.227
Observations	5,056,631	5,031,826	5,056,631	5,031,826	1,934,196	1,927,801
Municipality FE	✓	✓	✓	✓	✓	✓
Birth-year FE	✓	✓	✓	✓	✓	✓
Census wave FE	✓	✓	✓	✓	✓	✓
Ind. Controls		✓		✓		✓

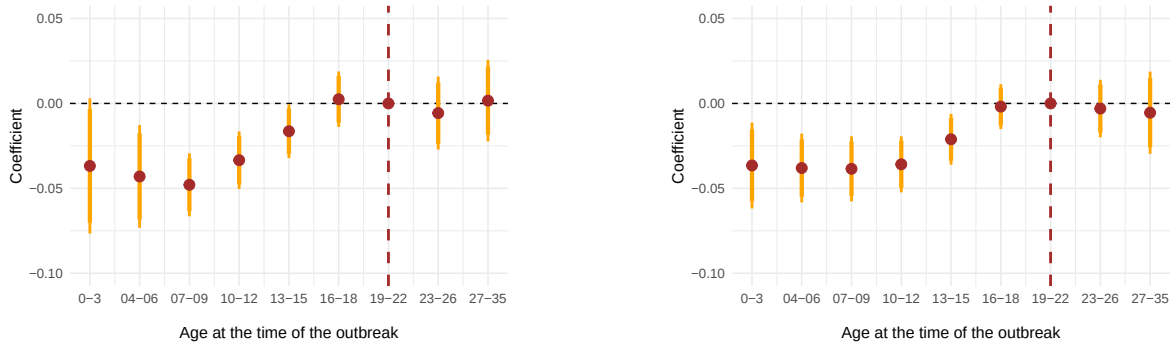
Note: the table displays the regression results of the estimation of Equation 1 and also alternative specifications. The dependent variable in columns (1) and (2) is a dummy that equals one if the individual completed high school. In columns (3) and (4) the dependent variable is an indicator variable 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.

Figures 5 and 6 add by showing the long-term witches' broom effects for different cohorts estimated using 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.

Figure 7 shows the impact of the witches' broom on the probability of having a job. The result also suggests a negative impact on the cohorts younger than 12 years old. Interpreting the extensive margin is not straightforward in our setting because it is also expected that individuals older than 18 years old were affected by the witches' broom. A potential explanation is that older cohorts stayed in the rural areas, which corroborates with our mechanism session, while

the younger cohorts may have moved to urban low-paid jobs. To investigate whether the shock also led to changes in sectoral employment.

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

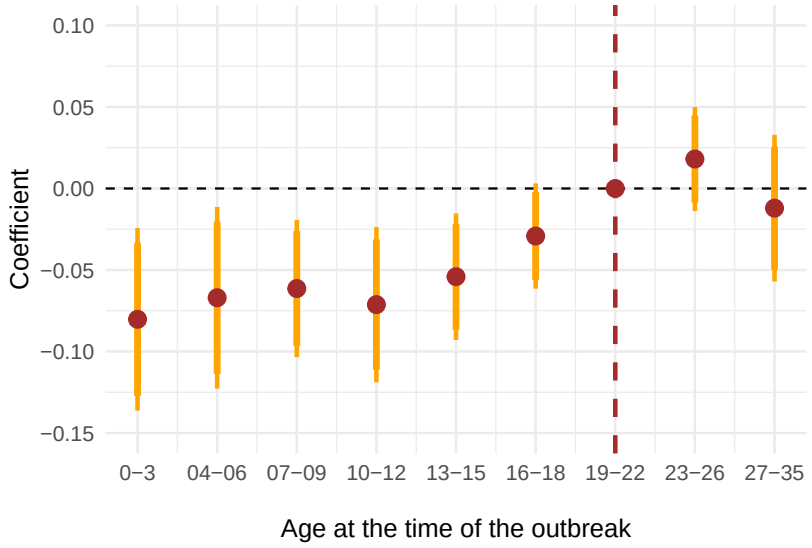


(a) Elementary school

(b) High school

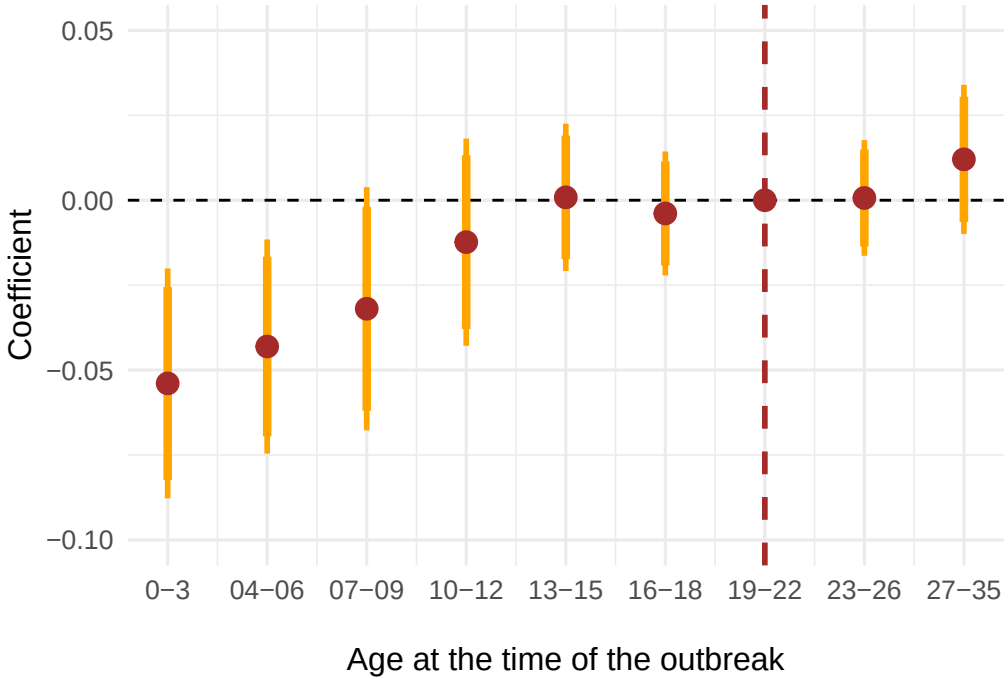
Note: the figure displays the baseline results for the probability of having completed elementary and high school up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to an ITT effect—to the estimated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

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



Note: the figure displays the baseline results for 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 an ITT effect—to the estimated coefficient of Equation (2). Standard errors are clustered at the municipality level. Confidence intervals: 95%.

Figure 7: Long-run consequences of witches' broom outbreak on the probability of having a formal or informal job

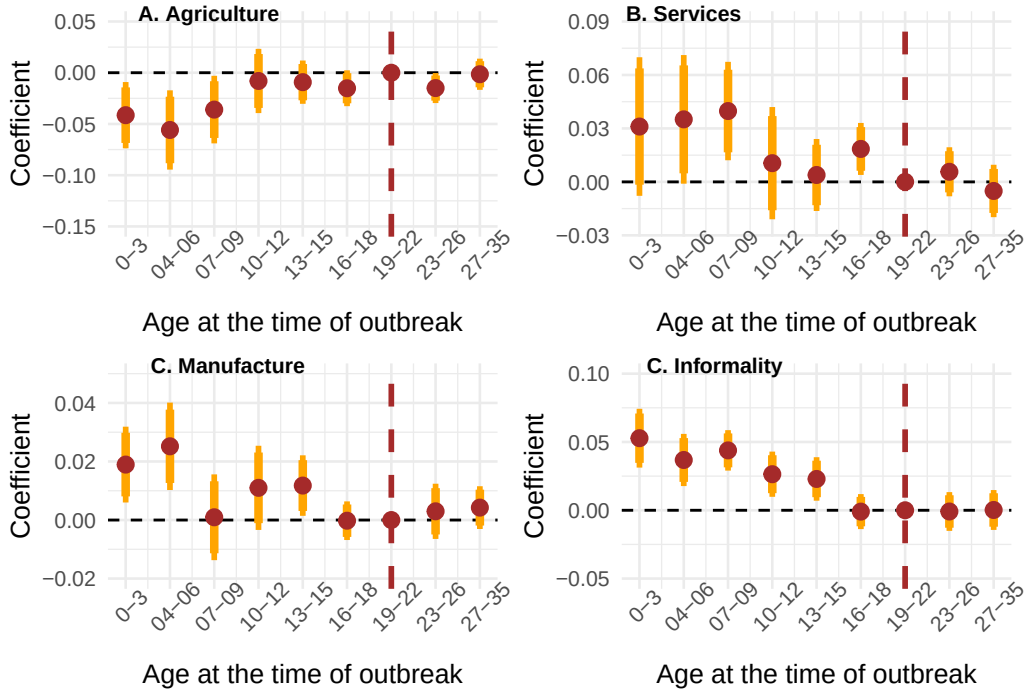


Note: the figure displays the baseline results for the probability of having formal or informal job up to 20 years after the witches' broom outbreak. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to an ITT effect—to the estimated coefficient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

Panel (a) of Figure 8 shows a decrease in the probability of having a job in the agricultural sector for the younger cohorts. This last result is also consistent with the responses of the qualitative interview, which mentioned 'a current lack of workers for cocoa production' in the region. In addition, panels (b), (c), and (d) show suggestive evidence that younger cohorts moved to informal self-employment in the manufacturing and services sectors.

Finally, there is a theoretical reason to expect that the overall reduction in earnings may also lead to lowering fertility. For example, Ager et al. (2020) found in the case of the Boll Weevil, lower agricultural earnings lowered fertility and child labour. For Brazil, in particular, Moorthy (2024) finds that technological change in Brazilian soy led to increased fertility by lowering the demand for female work (and also found no changes in child labour usage). Appendix Figure A11 shows that witches' broom did not impact the probability of having children or the number of children.

Figure 8: Long-run consequences of witches' broom outbreak on employment by sector



Note: the figure displays the baseline results for 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 an ITT effect—to the estimated coefficient of Equation (2). Standard errors are clustered at the municipality level. Confidence intervals: 95%.

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 A12 shows the share of cocoa production in relation to the total agriculture production in each city affected by the witches' broom in 1988, before the outbreak. The average share of cocoa in total agricultural production was 84%, and the median was 93%. We use this information to create two groups, municipalities above and below the median of cocoa production in 1988. The visual representation is presented in Appendix Figure A13. The control group is the same, individuals living in municipalities not affected by the disease.

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 very similar impact for municipalities below the median. Municipalities above the median experienced a small increase in the impact of the witches' broom on earnings and elementary schools. In addition, there was an 18% increase in the estimated impact on the likelihood of completing elementary school.

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	-0.033***	-0.035***	-0.052**	-0.025**	-0.030**	-0.062**
	(0.009)	(0.010)	(0.026)	(0.010)	(0.013)	(0.026)
R^2	0.081	0.111	0.208	0.081	0.111	0.208
Observations	4,993,100	4,993,100	1,907,572	5,011,237	5,011,237	1,915,683
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 considers only treated municipalities above the average of cocoa dependence, dropping from the sample treated municipalities below the median. Panel B considers only treated municipalities below the average of cocoa dependence, dropping the treated municipalities above the median from the sample. 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.

Table 3 shows the estimation of a triple-difference model as in Clay et al. (2020). The results provide suggestive evidence of the higher impacts on girls than boys, which can be translated into a more intense use of girls in cocoa production when a price shock happens (Cogneau and Jedwab 2012). Girls have a lower likelihood of completing elementary and high school than boys. Appendix Tables A1 show that there is no evidence of differential effects of the witches' broom outbreak by race.

We further explore the heterogeneous effects of the witches' broom outbreak by sex and race using the event study design. Appendix Figure A14 shows that the witches' broom outbreak affected both groups equally when considering the impacts in each cohort. Figure A14 also shows no difference in which broom impacts by race. The result by race differs from other studies that use a similar identification strategy, like in the case of long-term impacts of the boll weevil, which found larger impacts on black children (Baker et al. 2019).

Table 3: Witches' broom effect by gender

	High school (1)	Elementary school (2)	log(wage) (3)
Childhood exposure	-0.021***	-0.026***	-0.045
	(0.007)	(0.009)	(0.029)
Childhood exposure * Women	-0.016**	-0.012*	-0.025
	(0.006)	(0.007)	(0.030)
R^2	0.085	0.116	0.220
Observations	5,056,631	5,056,631	1,934,196
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓
Women × Municipality FE	✓	✓	✓
Women × Birth-year FE	✓	✓	✓
Women × 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 an ITT effect—to the estimated coefficient of Equation (1). Standard errors are clustered at the municipality level.

5 Mechanisms

The previous sessions showed that the 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 send 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). In a historical study, Walker (2007) showed that cocoa production in the 19th century in Brazil made highly intense use of women and children enslaved people in cocoa production. He also explains that there was a formal state recommendation for using both groups because of the low-skilled and lower-strong labour demand for cocoa harvest. Child labour is a remarkable characteristic in Brazilian agriculture (Manacorda and Rosati 2011; Duryea et al. 2007). And Cogneau and Jedwab (2012) provide descriptive evidence that boys in the agricultural sector in the Ivory Coast 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.

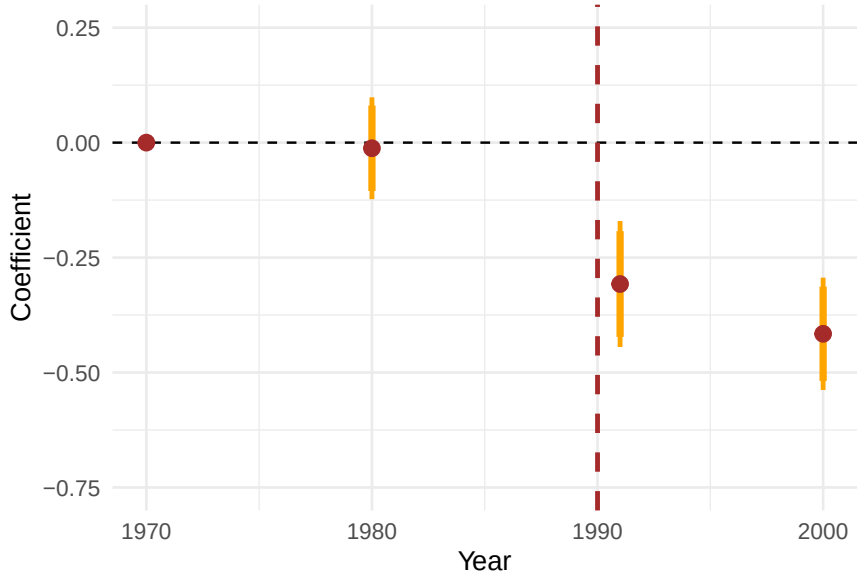
To further explore this hypothesis, we extend our analysis to the municipal level, utilizing data from the Brazilian Census and the Brazilian Agricultural Census. We estimate the following event-study regressions:

$$Y_{ct} = \sum_{\tau=1970}^{k} \beta_\tau WB_c \times I(\tau = t) + \theta_c + \gamma_{st} + \varepsilon_{cst} \tag{3}$$

Where Y_{cst} represents one of the census outcomes in municipality c, state s, and census year t. WB_c is a dummy variable that equals one if municipality c is within the witches' broom affected area. Our parameters of interest, $\beta_{t,t>1990}$, under the parallel trends assumption, measure the impact of witches' broom on the outcomes of interest. θ_c denotes a set of municipality fixed effects, while γ_{st} represents state-by-census-year dummies. ε_{cst} is the error term, clustered at the municipality level, following the methodology proposed by Bertrand et al. (2004).

As a first step, we investigate the impact of witches' broom on municipality income using data from different waves of the Brazilian Census. Figure 9 shows the disease's effects on average earnings within municipalities. Results show that municipal income decreased by 25 to 38 percent between 1991 and 2000 due to witches' broom.

Figure 9: The short-term effect of witches' broom outbreak on average earnings



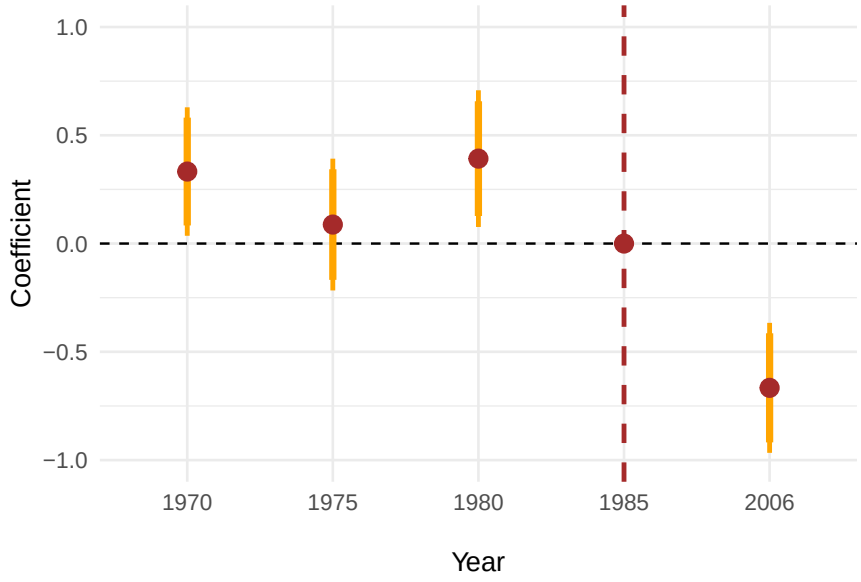
Note: the figure displays estimated coefficients of an event-study regression of the interaction of year dummies with a treatment indicator, where the treatment is being affected by the witches' broom outbreak, on the income of municipalities in the Northeast of Brazil.

As discussed in previous sections, the disease significantly impacted agricultural production in the affected areas. Figure 9 further demonstrates that the average income in these municipalities experienced a substantial decline. To understand how the outbreak influenced wealth and, consequently, the capacity to generate long-term income for households, we utilized land price data from the Brazilian Agricultural Census. We estimated Equation 3, using the log of total land value in the municipalities as the dependent variable. Compared to our control group, land

values in municipalities affected by witches' broom disease dropped by 48%[16], relative to the mean, ten years after the shock.

Utilizing data from the Brazilian Agricultural Census, we can calculate the total value of assets owned by agricultural establishments within Brazilian municipalities[17]. Figure A18 in the Appendix displays the results of estimating Equation 3 using the logarithm of the total value of assets in municipalities as the dependent variable. The results indicate that, in municipalities affected by witch's broom disease, assets decreased by 71%[18], relative to the mean, compared to those that were unaffected. Putting Figures 9 and 10 together, our results indicate that municipalities affected by the disease experienced substantial losses in income and wealth compared to the control group.

Figure 10: The effect of witches' broom outbreak on total land values



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 total land values in the Northeast of Brazil. The dependent variable is the log of the total value of lands of agricultural establishments. Data is from the Brazilian Agricultural Census of 1970, 1975, 1980, 1985, and 2006.

The fall in family wealth and income can lead to the growth in child labour (Basu and Van 1998). According to the Brazilian statute of children and teenagers,[19] any work is strictly prohibited for people younger than fourteen years old in Brazil. Therefore, we aggregate the share of children between ten and thirteen years old working in each city of the Northeast region

[16] $(\exp^{-0.66} - 1) \times 100 \approx -48\%$.

[17] Assets include real estate (buildings, facilities, and other improvements, land (including natural forests), permanent crops, and planted forests), as well as vehicles, tractors, machinery and implements, and animals (for breeding, rearing, and other purposes).

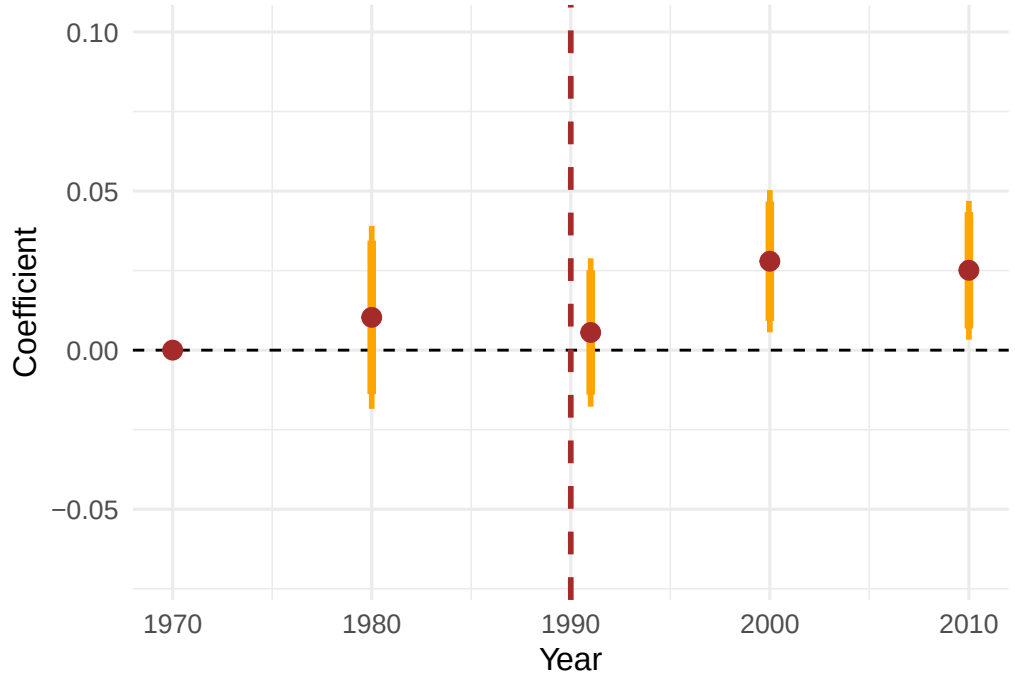
[18] $(\exp^{-1.25} - 1) \times 100 \approx -71\%$

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

and estimate the event-study regression presented in Equation 3 using the share of children working as the dependent variable.

Figure 11 suggests a strong positive effect of the witches' broom outbreak on the prevalence of child work at the municipality level. The 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, even though the introduction of the National Program Against Child Labor (PETI) in 1996 and its expansion in 2002 when the program was coupled with the Brazilian cash transfer program Bolsa Família. Brazilian law also specifies stringent rules under which people between fourteen and seventeen can work. The main rule is that they can work short-term as an apprentice and restrict the activities they can do. However, because we cannot disentangle what child labour and apprentice work would be, we restrict our sample to people below fourteen years old.

Figure 11: The 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 in the Northeast of Brazil. Data is from the 1970, 1980, 1991, 2000, and 2010 censuses.

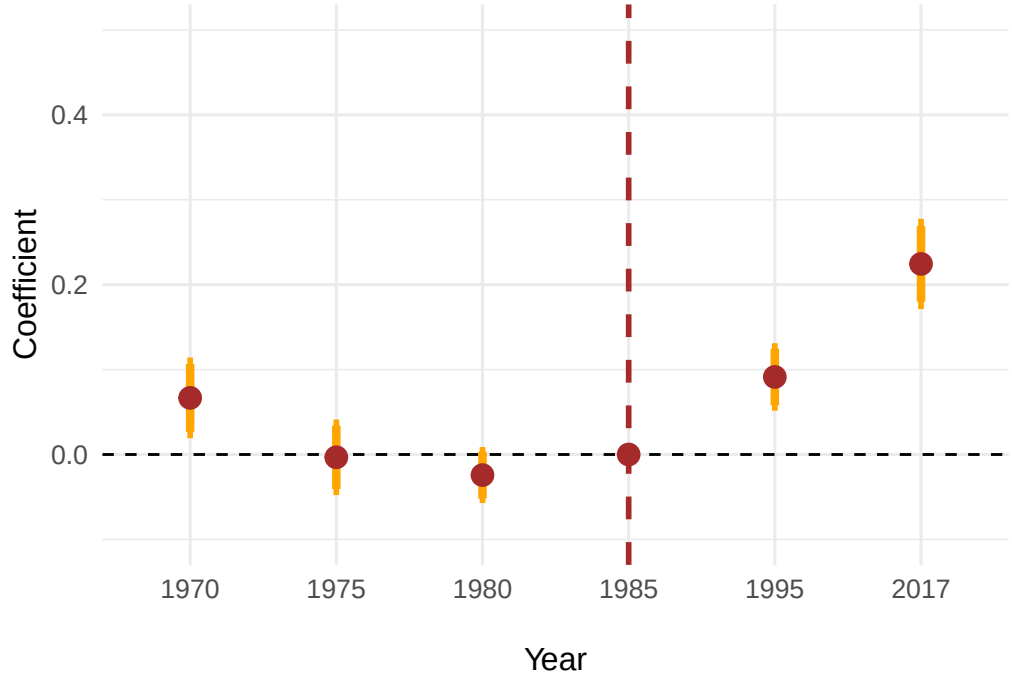
Although the results presented in Figure 11 are compelling, the 10-year gap between each demographic census wave may reduce confidence in the findings. Therefore, we also utilized data from the Brazilian Agricultural Census, conducted every five years. This census inquired about the familial relationships among workers on each farm.[20] With this information, we were able to count the number of workers who were family members of the administrator of the farm.

[20] We have this information for the waves of 1970, 1975, 1980, 1985, 1995 and 2017.

Thus, we calculated the share of the agricultural workforce of the municipality composed of family members and used this variable as the dependent variable in the model described in Equation 3. Results are displayed in Figure 12.

If the decline in income due to the spread of witches' broom disease encouraged families to employ children as labourers, as suggested by the results in Figure 11, an increase in the percentage of family workers in the municipalities affected by the disease, compared to those not affected, should also be observed. Indeed, this pattern is illustrated in Figure 12. Relative to the control group, municipalities affected by the disease exhibit an increase in the proportion of family workers in agriculture by 10 percentage point in 1995 and almost 20 p.p. in 2017.

Figure 12: The effect of witches' broom on the share of family employment over agricultural employment

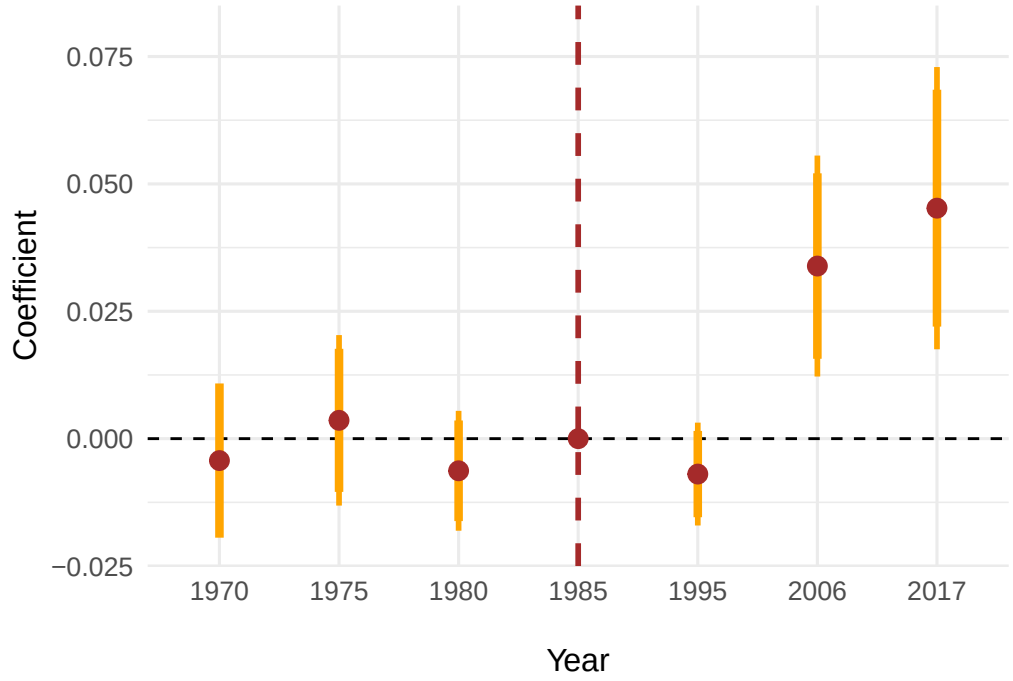


Note: the figure displays estimated coefficients of an event-study regression of the interaction of year dummies with a treatment indicator, where the treatment is being affected by the witches' broom outbreak, on the share of family employment over total agricultural employment in municipalities in the Northeast of Brazil. Data is from different waves of Brazilian Agricultural Census.

To complement the series of analyses presented, we examine the impact of witch's broom disease on the number of properties managed by *meeiros*. The *meeiro* arrangement is widespread throughout Brazil and involves an often informal agreement between the landowner and the farmer. Under this system, the landowner provides land at no cost to the farmer, who in return, resides on and cultivates the land, sharing half of the produce with the landowner. This arrangement, however, is fraught with challenges due to the informal nature of the agreements, difficulties in accurately measuring production, and the disproportionate power dynamic favoring the landowner over the farmer. As a result, *meeiros* are frequently exploited and, in many cases, find themselves in situations akin to modern forced labour. Additionally, the *meeiro*

system often involves family labour, including child labour, and is identified by the International Labour Organization (ILO) and the Ministry of Labour as one of the primary conduits for modern slavery and child labour in Brazil.[21]

Figure 13: The effect of witches' broom on the share of properties run by *meeiros*



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 meeiros over agricultural employment in municipalities in the Northeast of Brazil. Data is from different waves of Brazilian Agricultural Census.

Figure 13 shows that the number of *meeiros* properties increased by 3.75 p.p. 16 years after the outbreak and by 5 p.p. 27 years after the outbreak. Again, this piece of evidence is consistent with the increase in child labour documented in the previous estimates presented in Figues 11 and 12.

6 Robustness

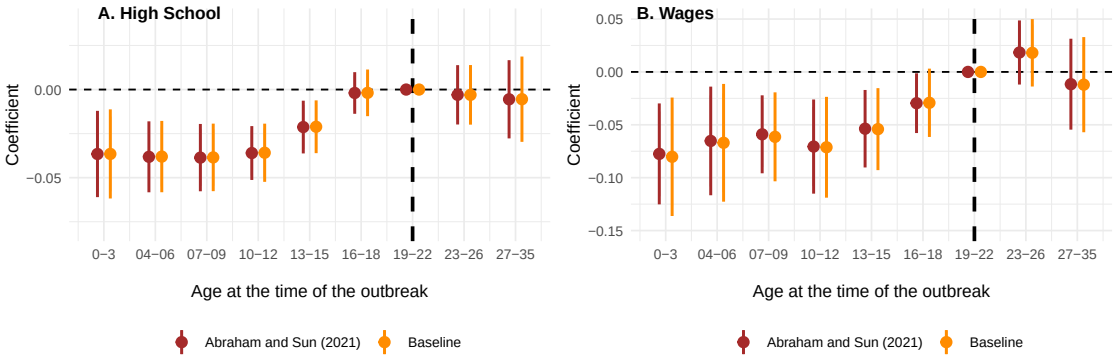
6.1 Staggered difference-in-differences

Section 2 and Figure 2 explain that the witches' broom outbreak had differential timing across municipalities. Therefore, the two-way fixed effect estimation can be biased (Roth et al. 2023). To overcome that, we estimate Equation 2 using Sun and Abraham (2021) estimator. Figure 14

[21] For further details, refer to the ILO report on the cocoa production chain, *meeiro* relationships, and modern slavery [https://www.ilo.org/wcmsp5/groups/public/---americas/---ro-lima/---ilo-brasilia/documents/publication/wcms_817094.pdf].

suggests that the estimate presented in previous sections is not biased by the staggering outbreak of the disease since results from the 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, the fact that treatments occurred in a short interval of time (1989 to 1992), and because the incubation period of the witches broom, indicating no clear reasons for the treatment effect to vary by treatment groups.

Figure 14: Long-run consequences of witches' broom outbreak: baseline vs Abraham and Sun (2021) estimator

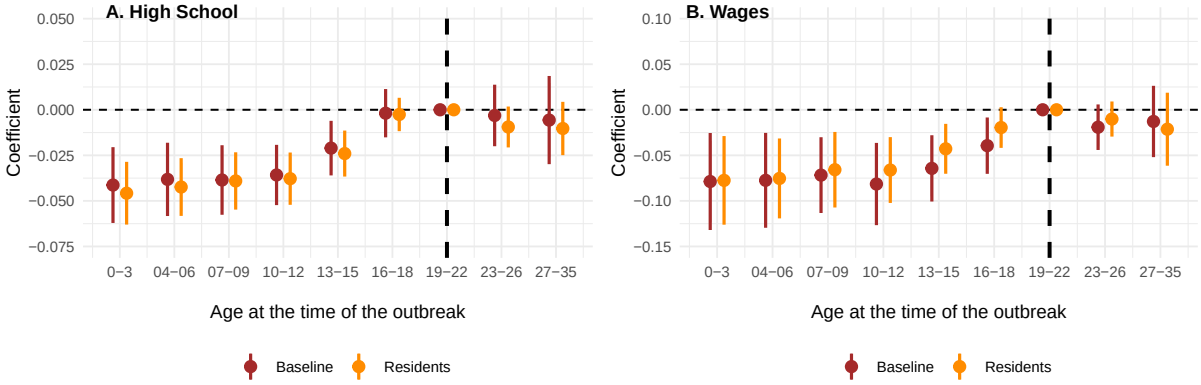


Note: the figure displays the baseline results for the probability of having completed high school and the log of earnings up to 20 years after the witches' broom outbreak and results for the estimator proposed by Sun and Abraham (2021). The horizontal axis shows the age at the moment of the witches' 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%.

6.2 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 15 compares our baseline results with the ones when considering the municipality of residence, whenever the birth municipality is. As can be seen in Figure 15, 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).

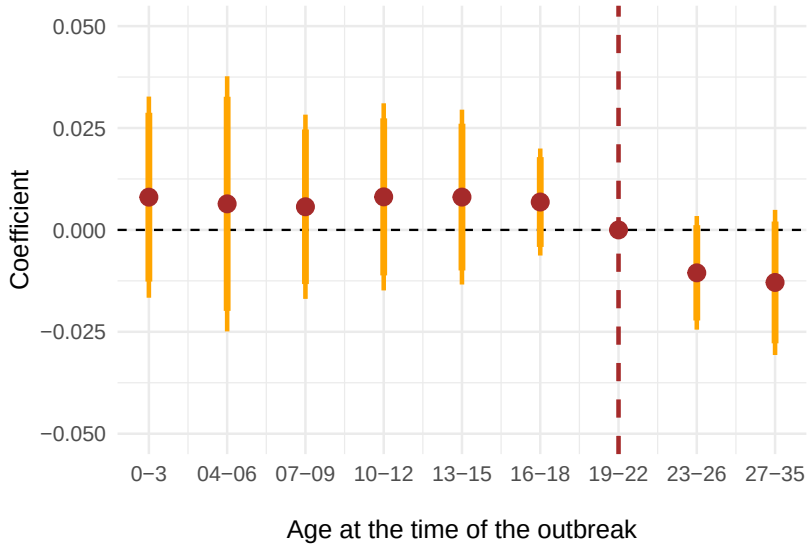
Figure 15: Long-run consequences of witches' broom outbreak: baseline vs non-movers



Note: this figure displays the baseline results and results considering the municipality of residence as a proxy for the municipality of birth. The probability of having high school and wages up to 20 years after the witches' broom outbreak are the dependent variables. 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%.

Parallel to the earlier findings, we perform another robustness check to test the migration hypothesis. For this, we consider the sample including all individuals, regardless of their local birth status. We then estimate our baseline specification described in Equation 2 using a dummy variable that equals one if individuals declared to have been born in the same municipality where they were interviewed as the dependent variable. If the migration hypothesis can explain our baseline results, one would expect that younger individuals have a lower probability of being born in the same municipality as the interview. However, as seen in Figure 16, we found no statistically significant differences in the probability of being a local between the exposed cohorts, reinforcing the robustness of our baseline results.

Figure 16: Witche's broom exposure and local birth status



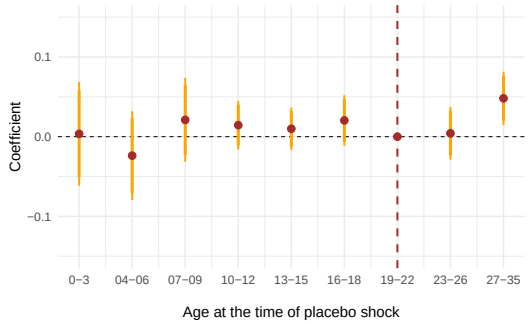
Note: the figure displays the results for our baseline specification of Equation 2 where the dependent variable is a dummy equal to one if the individual was born in the municipality he was interviewed. The horizontal axis shows the age at the moment of the witches' broom outbreak. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

6.3 Idiosyncratic characteristics of affected municipalities

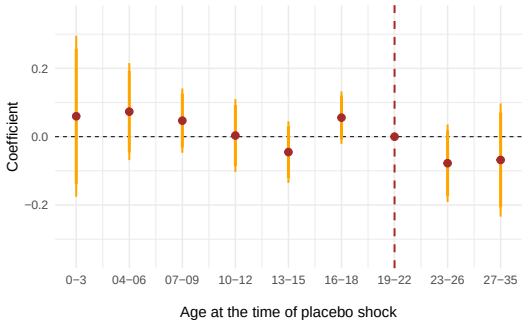
So far, we have shown how individuals' exposure in childhood to the witches' broom outbreak today have worse labour market and education outcomes than cohorts in municipalities not exposed to the shock. However, it might be the case that younger cohorts in treated municipalities were always worse off 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 microdata, we do not have information on individual wages. 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 have 0 to 35 years old in 1960. Figure 17 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 60s. Indeed, as shown in Figure 17, there is no difference in wages or years of schooling between younger and older cohorts' exposure and no exposure to the placebo shock, reinforcing the robustness of our baseline estimates.

Figure 17: The long-run consequences of a placebo treatment



(a) Earnings



(b) Years of schooling

Note: the figure displays the results of 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%.

6.4 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 4. The results suggest that no other shock happened in the cocoa market simultaneously to the witches' broom disease.

Table 4: 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.

7 Conclusion

This paper studies the long-run effects of a significant long-lasting shock 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 1988, the southeast of Bahia's state in the northeast of Brazil.

Our results show that the witches' broom outbreak negatively affected the education and earnings of individuals living in affected municipalities. Those effects are greater for individuals between zero and twelve 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 household earnings and land values since the witches' broom disease pushed the southeast region of Bahia into a recession period and pushed children in affected municipalities to start to work early. We also innovate by showing that there was a structural change in the labour contracts with the introduction of *meeiro*, which may explain more children working after the outbreak.

Our results have a very important implication for other developing countries in which large monocultures are still the main form of production. Climate change impacts on crops can disseminate new pests, fungus and diseases that can affect short and long term outcomes. Therefore, our results draws important lessons for the potential impact of climate change on developing countries' agricultural production.

References

Ager, P., Herz, B., and Brueckner, M. (2020). 'Structural Change and the Fertility Transition'. *Review of Economics and Statistics*, 102(4): 806–822. https://doi.org/10.1162/rest_a_00851

Araújo, D., Carrillo, B., and Sampaio, B. (2021). 'The Long-Run Economic Consequences of Iodine Supplementation'. *Journal of Health Economics*, 79(June): 102490. https://doi.org/10.1016/j.jhealeco.2021.102490

Baker, R. B., Blanchette, J., and Eriksson, K. (2019). 'Long-Run Impacts of Agricultural Shocks on Educational Attainment: Evidence from the Boll Weevil'. *Journal of Economic History*, 80(1): 136–74. https://doi.org/10.1017/S0022050719000779

Bandara, A., Dehejia, R., and Lavie-Rouse, S. (2015). 'The Impact of Income and Non-Income Shocks on Child Labor: Evidence from a Panel Survey of Tanzania'. *World Development*, 67(March): 218–37. https://doi.org/10.1016/j.worlddev.2014.10.019

Banerjee, A., Duflo, E., Postel-Vinay, G., and Watts, T. (2010). 'Long-Run Health Impacts of Income Shocks: Wine and Phylloxera in Nineteenth-century France'. *The Review of Economics and Statistics*, 92(4): 714–728. https://doi.org/10.1162/REST_a_00024

Basu, K., and Van, P. H. (1998). 'The Economics of Child Labor '. *The American Economic Review*, 88(3): 412–427. Available at: https://www.jstor.org/stable/116842

Beegle, K., Dehejia, R. H., and Gatti, R. (2006). 'Child Labor and Agricultural Shocks'. *Journal of Development Economics*, 81(1): 80–96. https://doi.org/10.1016/j.jdeveco.2005.05.003

Carrillo, B. (2020). 'Present Bias and Underinvestment in Education? Long-run Effects of Childhood Exposure to Booms in Colombia'. *Journal of Labor Economics*, 38(4): 1227–65. https://doi.org/10.1086/706535

Ceplac (2009). 'Serviço público federal ministério da agricultura, pecuária e abastecimento comissão executiva do plano da lavoura cacaueira'. Nota técnica (Abril/2009). Brasília: Serviço Público Federal, Ministério Da Agricultura, Pecuária E Abastecimento, Comissão Executiva Do Plano Da Lavoura Cacaueira.

Clay, K. B., Schmick, E., and Juster, T. (2020). 'The Boll Weevil's Impact on Racial Income Gaps in the Early Twentieth Century'. NBER Working Paper 27101. Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w27101

Cogneau, D., and Jedwab, R. (2012). 'Commodity price shocks and child outcomes: The 1990 cocoa crisis in Côte d'Ivoire'. *Economic Development and Cultural Change*, 60(3): 507–34. https://doi.org/10.1086/664017

Conley, T. G. (1999). 'GMM Estimation with Cross Sectional Dependence'. *Journal of Econometrics*, 92(1): 1–45. https://doi.org/10.1016/S0304-4076(98)00084-0

De Carvalho Filho, I. E. (2012). 'Household Income as a Determinant of Child Labor and School Enrollment in Brazil: Evidence from a Social Security Reform'. *Economic Development and Cultural Change*, 60(2): 399–435. https://doi.org/10.1086/662576

Duryea, S., Lam, D., and Levison, D. (2007). 'Effects of Economic Shocks on Children's Employment and Schooling in Brazil'. *Journal of Development Economics*, 84(): 188–214. https://doi.org/10.1016/j.jdeveco.2006.11.004

Edmonds, E. V. (2007). 'Chapter 57 Child Labor'. In T. P. Schultz and J. A. Strauss (eds), *Handbook of Development Economics, Volume 4* (pp. 3607–709). Amsterdam: Elsevier. https://doi.org/10.1016/S1573-4471(07)04057-0

Fioravanti, C. H., and Velho, L. (2011). 'Fungos, fazendeiros e cientistas em luta contra a vassoura-de-bruxa'. *Sociologias*,(27): 256–283. https://doi.org/10.1590/S1517-45222011000200010

Gomes, A. d. S., and Pires, M. d. M. (eds). (2015). *Cacauicultura: Estrutura Produtiva, Mercados e Perspectivas*. Salobrinho, Ilhéus: Editus - Editora da UESC.

Heming, N. M., Schroth, G., Talora, D. C., and Faria, D. (2022). '*Cabruca* Agroforestry Systems Reduce Vulnerability of Cacao Plantations to Climate Change in Southern Bahia'. *Agronomy for Sustainable Development*, 42(48): 1–16. https://doi.org/10.1007/s13593-022-00780-w

IOCC (1993). 'International Witches' Cocoa Growers'. Cocoa Growers' Bulletin No. 41. Abidjan: International Cocoa Organization (ICCO).

Jensen, R. (2000). 'Agricultural Volatility and Investments in Children'. *American Economic Review*, 90(2): 399–404. https://doi.org/10.1257/aer.90.2.399

Kawasaki, K. (2023). 'Impact of Climate Change on Crop Pests and Diseases: Ensemble Modeling of Time-Varying Weather Effects'. *Journal of the Association of Environmental and Resource*

Economists, 10(6): 1515–1543. https://doi.org/10.1086/725323

Kruger, D. I. (2007). 'Coffee Production Effects on Child Labor and Schooling in Rural Brazil'. *Journal of Development Economics*, 82(2): 448–63. https://doi.org/10.1016/j.jdeveco.2006.04.003

Lange, F. (2009). 'The Impact of the Boll Weevil, 1892–1932'. *The Journal of Economic History*, 69(3): 685–718. https://doi.org/10.1017/S0022050709001090

Le, K., and Nguyen, M. (2022). 'Desert Locust Swarms and Child Health'. *Economics and Human Biology*, 44(January): 101094. https://doi.org/10.1016/j.ehb.2021.101094

Lisboa, D. O., Evans, H. C., Araújo, J. P., Elias, S. G., and Barreto, R. W. (2020). '*Moniliophthora Perniciosa*, the Mushroom Causing Witches' Broom Disease of Cacao: Insights into its Taxonomy, Ecology and Host Range in Brazil'. *Fungal Biology*, 124(12): 983–1003. https://doi.org/10.1016/j.funbio.2020.09.001

Maccini, S., and Yang, D. (2009). 'Under the Weather: Health, Schooling, and Economic Consequences of Early-life Rainfall'. *American Economic Review*, 99(3): 1006–1026. https://doi.org/10.1257/aer.99.3.1006

Manacorda, M., and Rosati, F. C. (2011). 'Industrial Structure and Child Labor Evidence from the Brazilian Population Census'. *Economic Development and Cultural Change*, 59(4): 753–776. https://doi.org/10.1086/660002

Medeiros, F. H., Pomella, A. W., de Souza, J. T., Niella, G. R., Valle, R., Bateman, R. P., Fravel, D., Vinyard, B., and Hebbar, P. K. (2010). 'A Novel, Integrated Method for Management of Witches' Broom Disease in Cacao in Bahia, Brazil'. *Crop Protection*, 29(7): 704–711. https://doi.org/10.1016/j.cropro.2010.02.006

Moorthy, V. S. (2024). 'Agricultural Technological Change, Female Earnings and Fertility: Evidence from Brazil'. *The Economic Journal*, -(-): ueae069. https://doi.org/10.1093/ej/ueae069

OECD (2021). *Education in Brazil: An International Perspective.* Paris: OECD Publishing. https://doi.org/10.1787/60a667f7-en

Padrón, B. R., and Burger, K. (2015). 'Diversification and Labor Market Effects of the Mexican Coffee Crisis'. *World Development*, 68(April): 19–29. https://doi.org/10.1016/j.worlddev.2014.11.005

Pereira, J. L., De Almeida, L. C., and Santos, S. M. (1996). 'Witches' Broom Disease of Cocoa in Bahia: Attempts at Eradication and Containment'. *Crop Protection*, 15(8): 743–752. https://doi.org/10.1016/s0261-2194(96)00049-x

Rocha, L. B. (2006). *A Região Cacaueira da Bahia - Uma Abordagem Fenomenológica* [Doctoral dissertation]. Universidade Federal de Sergipe.

Rocha, R., and Soares, R. R. (2015). 'Water Scarcity and Birth Outcomes in the Brazilian Semiarid'. *Journal of Development Economics*, 112(January): 72–91. https://doi.org/10.1016/j.jdeveco.2014.10.003

Roth, J., Sant'Anna, P. H. C., Bilinski, A., and Poe, J. (2023). 'What's Trending in Difference-in-Differences? A Synthesis of the Recent Econometrics Literature'. *Journal of Econometrics*, 235(2): 2218–2244. https://doi.org/10.1016/j.jeconom.2023.03.008

Scarpari, L. M., Meinhardt, L. W., Maizzafera, P., Pomella, A. W., Schiavinato, M. A., Cascardo, J. C., and Pereira, G. A. (2005). 'Biochemical changes during the development of witches' broom: The most important disease of cocoa in Brazil caused by Crinipellis perniciosa'. *Journal of*

Experimental Botany, 56(413): 865–77. https://doi.org/10.1093/jxb/eri079

Soares, R. R., Kruger, D., and Berthelon, M. (2012). 'Household choices of child labor and schooling: A simple model with application to Brazil'. *Journal of Human Resources*, 47(1): 1–31. https://doi.org/10.3368/jhr.47.1.1

Stuart, B. A. (2022, January). 'The Long-Run Effects of Recessions on Education and Income'. *American Economic Journal: Applied Economics*, 14(1): 42–74. https://doi.org/10.1257/app.20180055

Sun, L., and Abraham, S. (2021). 'Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects'. *Journal of Econometrics*, 225(2): 175–99. https://doi.org/10.1016/j.jeconom.2020.09.006

Walker, T. (2007). 'Slave Labor and Chocolate in Brazil: The Culture of Cacao Plantations in Amazonia and Bahia (17th-19th Centuries)'. *Food and Foodways*, 15(1-2): 75–106. https://doi.org/10.1080/07409710701260214

A Appendix

A1 Cocoa farms

Figure A1: Cabruca agro-forest system

Source: this photo was taken by one of the authors during the visit conducted in the region in January 2024.

Figure A2: Healthy cocoa

Source: photo courtesy of USDA Agricultural Research Service; see https://agresearchmag.ars.usda.gov/2005/oct/cocoa/.

Figure A3: Cocoa with witches' broom

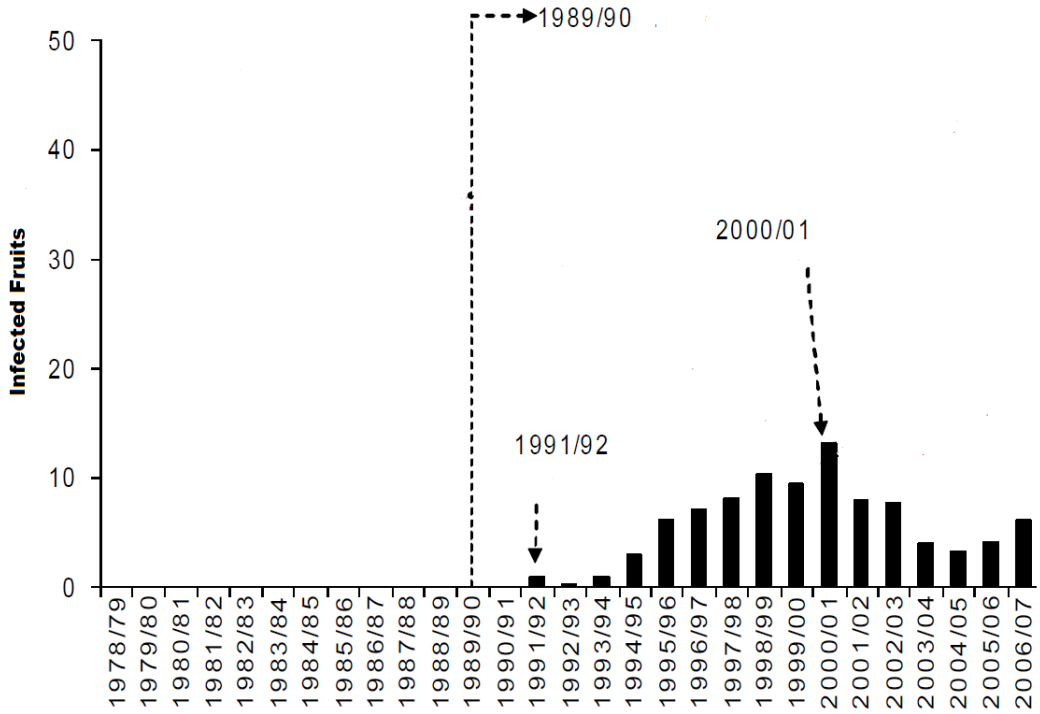
Source: photo courtesy of USDA Agricultural Research Service; see https://agresearchmag.ars.usda.gov/2005/oct/cocoa/.

Figure A4: *Moniliophthora perniciosa* mushroom

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

A2 Number of infected fruits

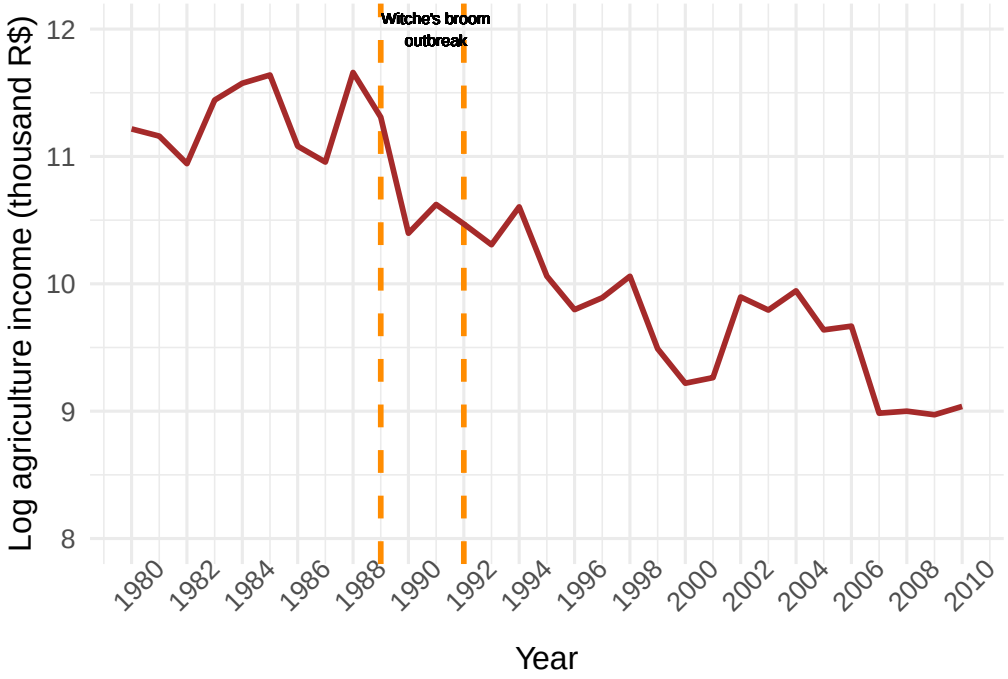
Figure A5: Tons of cocoa fruits infected with the witches' broom by year



Note: this graph is based on a representative sample of 139 farms in the cocoa produced region. Ceplac and the Ministry of Agriculture do not have information about the number contaminated fruits per municipality and year throughout the time. This figure is adapted from Ceplac (2009).

A3 Trends in agriculture income for affected municipalities

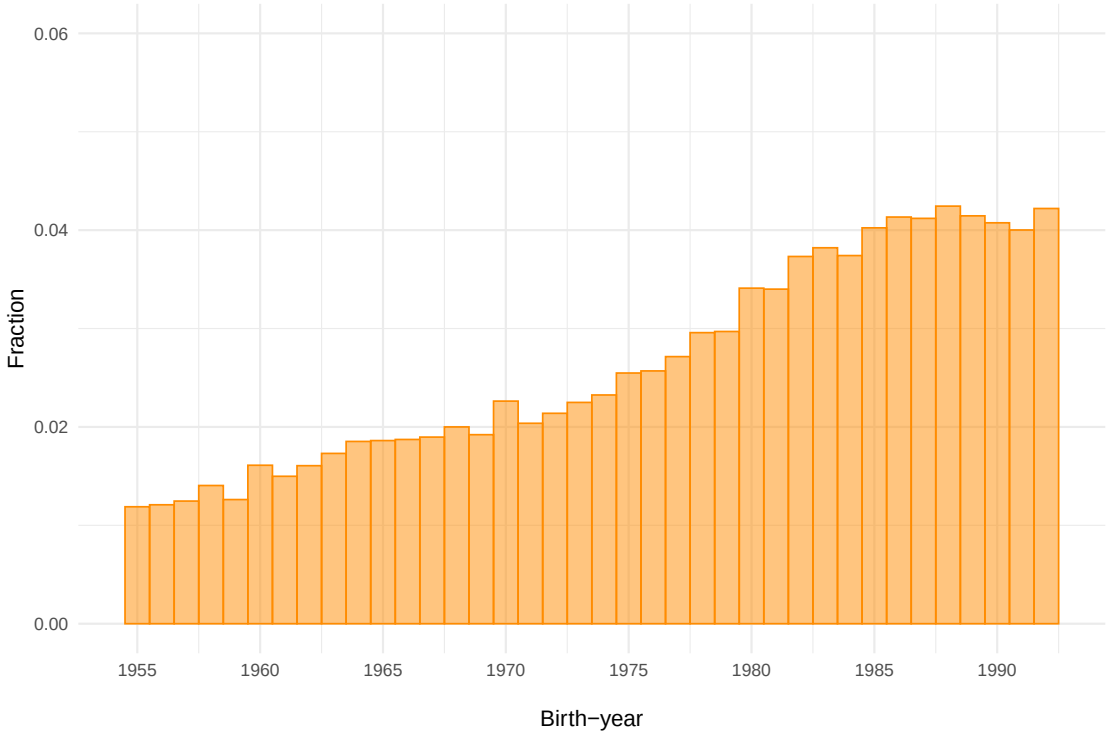
Figure A6: Average yearly agriculture income in the witches' broom area from 1980 to 2010



Note: this figure presents a plot of the logarithm of the average yearly agricultural income (value of production) in municipalities impacted by the witches' broom disease, utilizing data obtained from the Brazilian Municipal Agriculture Survey.

A4 Birth cohorts in estimation sample

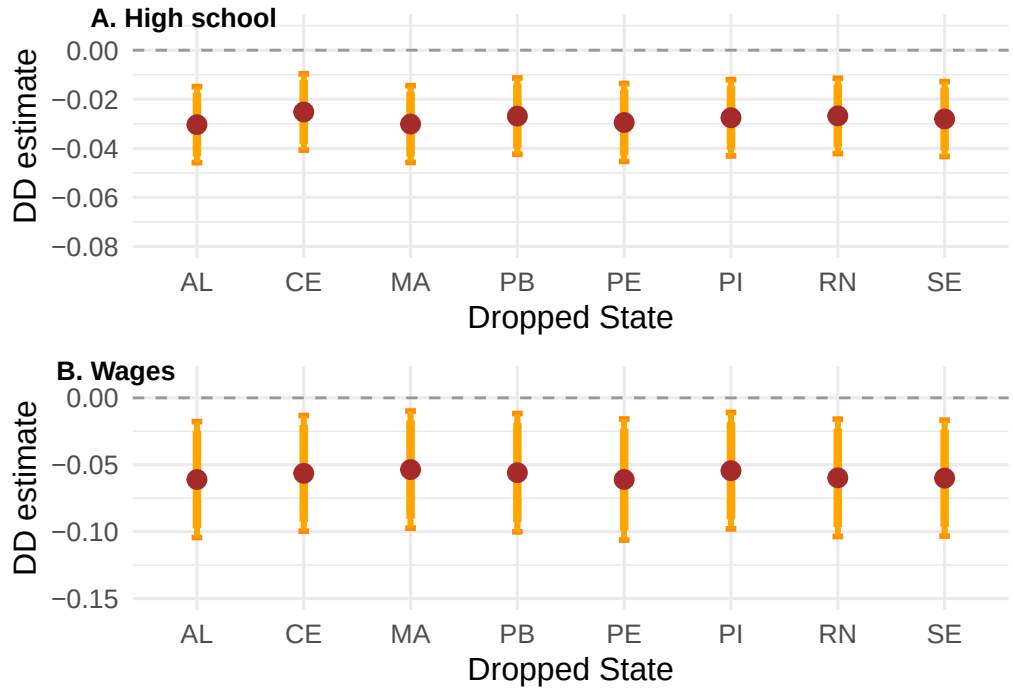
Figure A7: Birth cohorts in estimation sample



Note: this figure presents the birth cohorts in our estimation sample; based on the Brazilian Census (2000–2010).

A5 Robustness check: leave-one-state-out

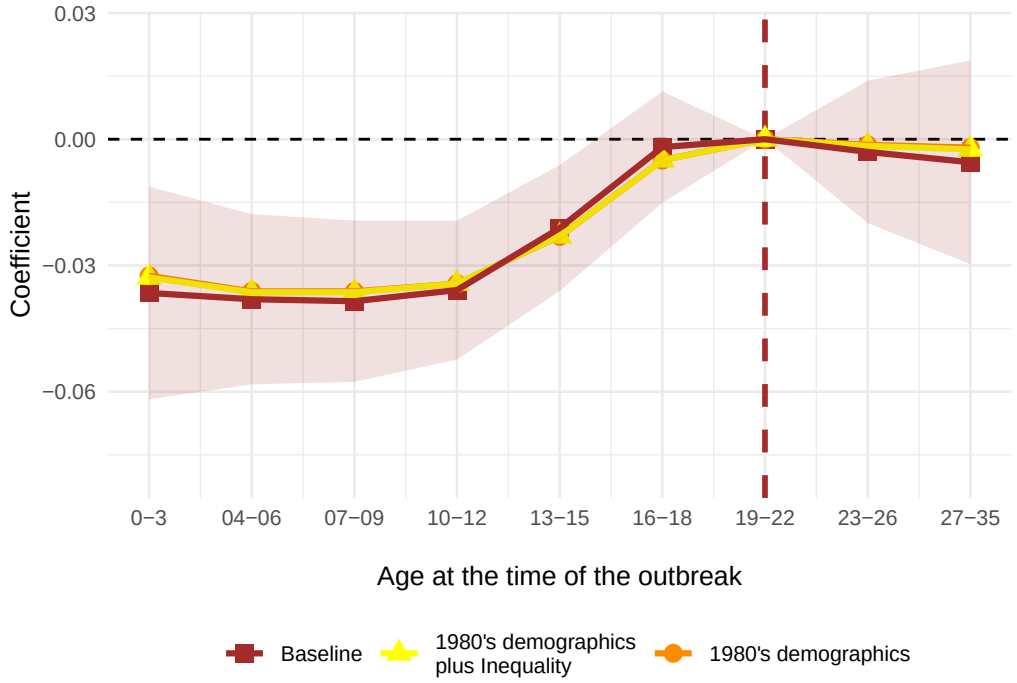
Figure A8: Robustness check: leave-one-state-out



Note: this figure presents results from estimates of the baseline specification of Table 1, but dropping, one-by-one, states from the control group. The dependent variable in panel A is the probability of high school completion. The dependent variable in panel B is the log of wages.

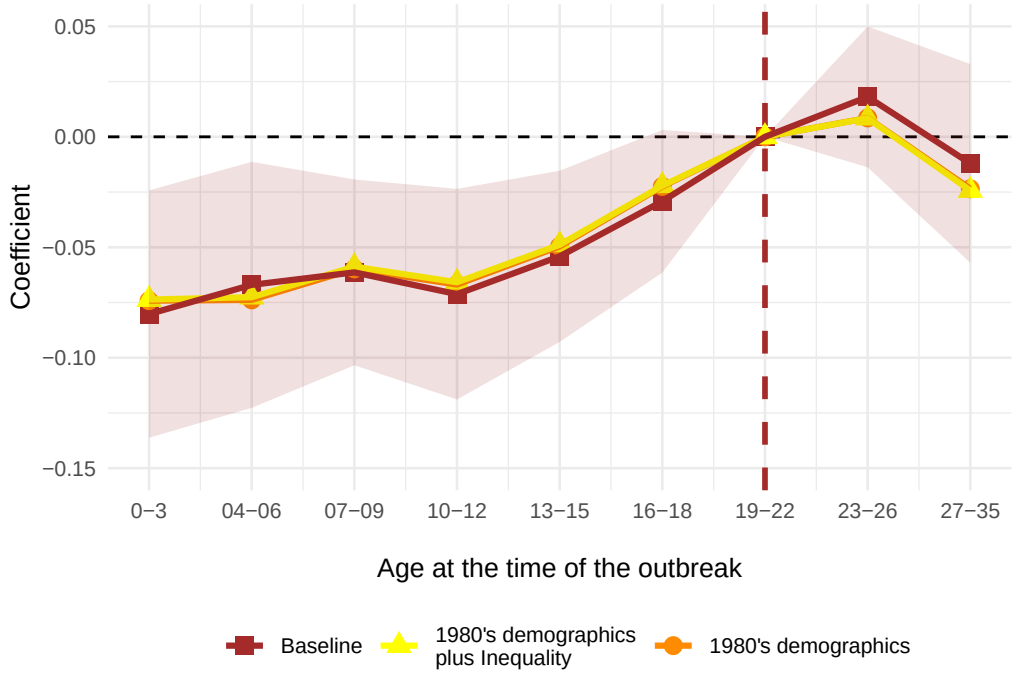
A6 Robustness check: controlling for 1980's covariates trends

Figure A9: Robustness check: controlling for 1980's covariates trends - high school



Note: this figure presents results from estimates of alternative specifications of equation 2. 1980's controls include the share of the literate population, the share of the rural population, the share of the employed population, and the share of the black population. We interacted all these variables with Birth-year fixed effects. We plot 95% confidence intervals for our baseline specification. The dependent variable is a dummy variable that equals to one if individual finished high school.

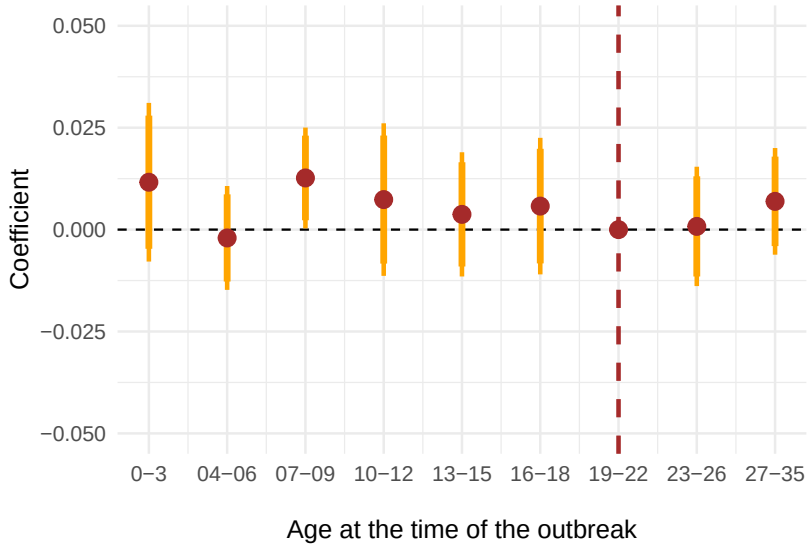
Figure A10: Controlling for 1980's covariates trends - log(wage)



Note: this figure presents results from estimates of alternative specifications of equation 2. 1980's controls include the share of the literate population, the share of the rural population, the share of the employed population, and the share of the black population. We interacted all these variables with Birth-year fixed effects. We plot 95% confidence intervals for our baseline specification. The dependent variable is the log of wages.

A7 The long-run effects on fertility

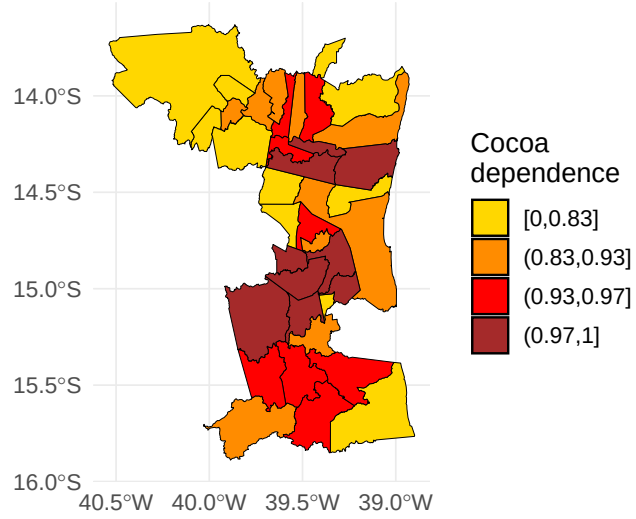
Figure A11: Long-run effects on the probability of having children



Note: the figure displays the baseline results for the probability of having children 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%.

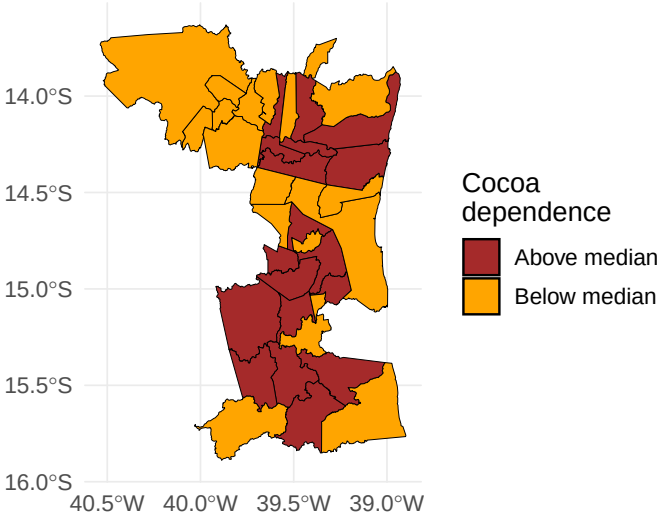
A8 Maps on cocoa dependence

Figure A12: 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 the witches' broom, based data from Ipeadata. The index is the share of cocoa production over total agriculture production on the municipality in 1988, a year before the first witches' broom outbreak.

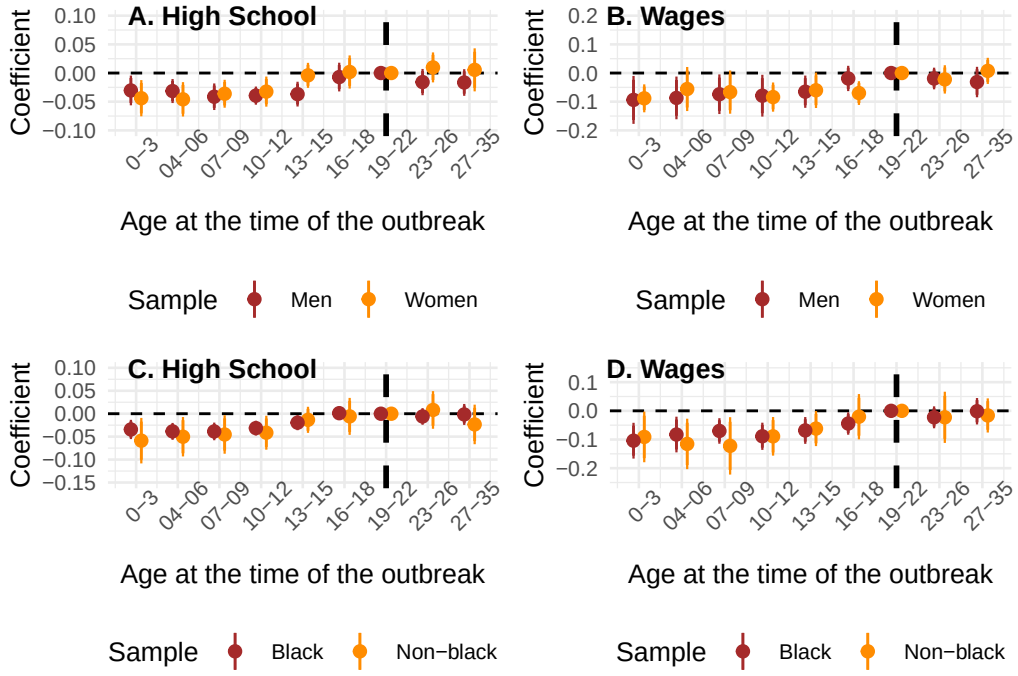
Figure A13: Cocoa dependence in municipalities affected by the witches' broom disease



Note: the figure plots the spatial distribution of an index of cocoa dependence in municipalities affected by the witches' broom, based data from Ipeadata. The index is the share of cocoa production over total agriculture production on the municipality in 1988, a year before the first witches' broom outbreak.

A9 Heterogeneity: effects by gender and race

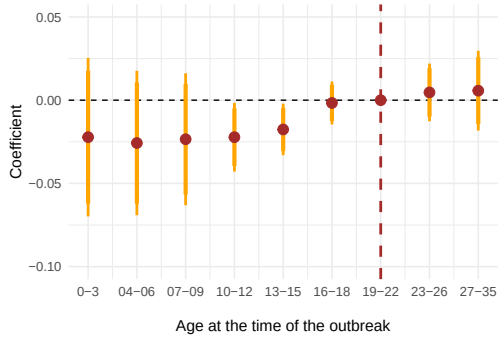
Figure A14: Long-run consequences of witches' broom outbreak by gender and race



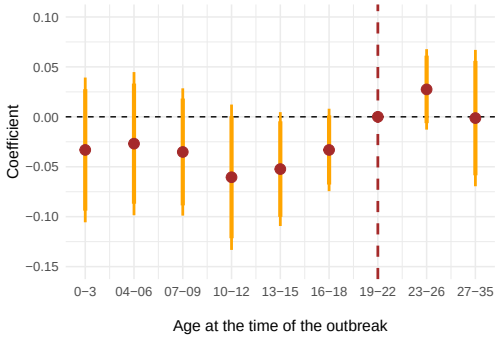
Note: the figure displays results for heterogeneous effects by race and gender. The probability of having high school and wages up to 20 years after the witches' broom outbreak are the dependent variables. The horizontal axis shows the age at the moment of the witches' broom outbreak. The estimate corresponds to an ITT effect—to the estimated coefficient of Equation (1). Standard errors are clustered at the municipality level. Confidence intervals: 95%.

A10 Robustness check: alternative control group

Figure A15: The long-run consequences of witch-broom - alternative control group including only Bahia state



(a) High School

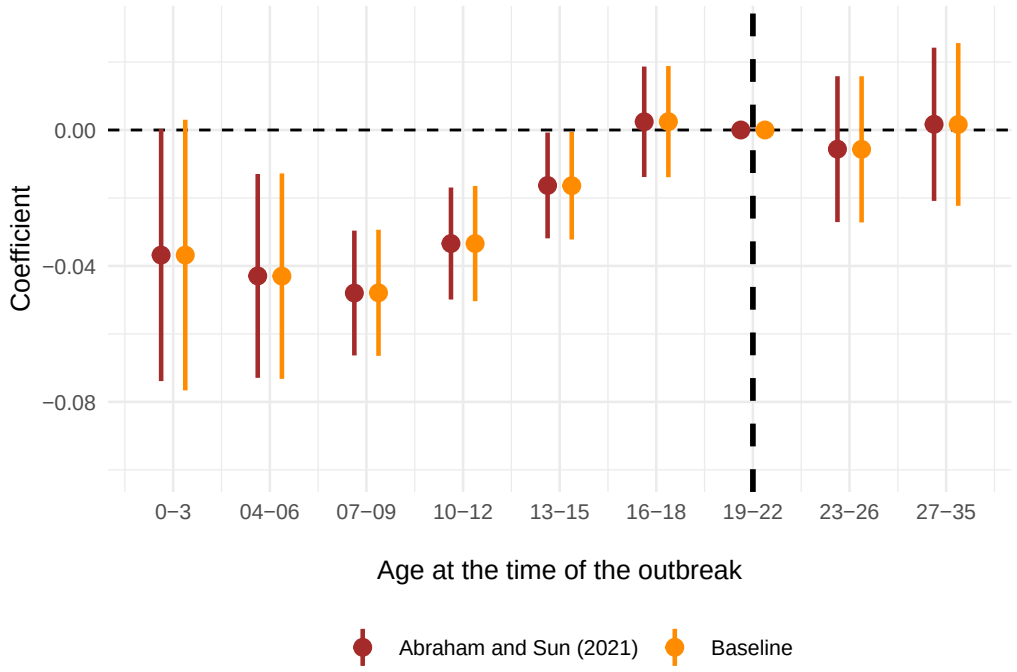


(b) Wages

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 an ITT effect—to the estimated coefficient of Equation (2). Standard errors are clustered at the municipality level. Confidence intervals: 95%.

A11 Robustness check: Abraham and Sun (2021) estimator - elementary school

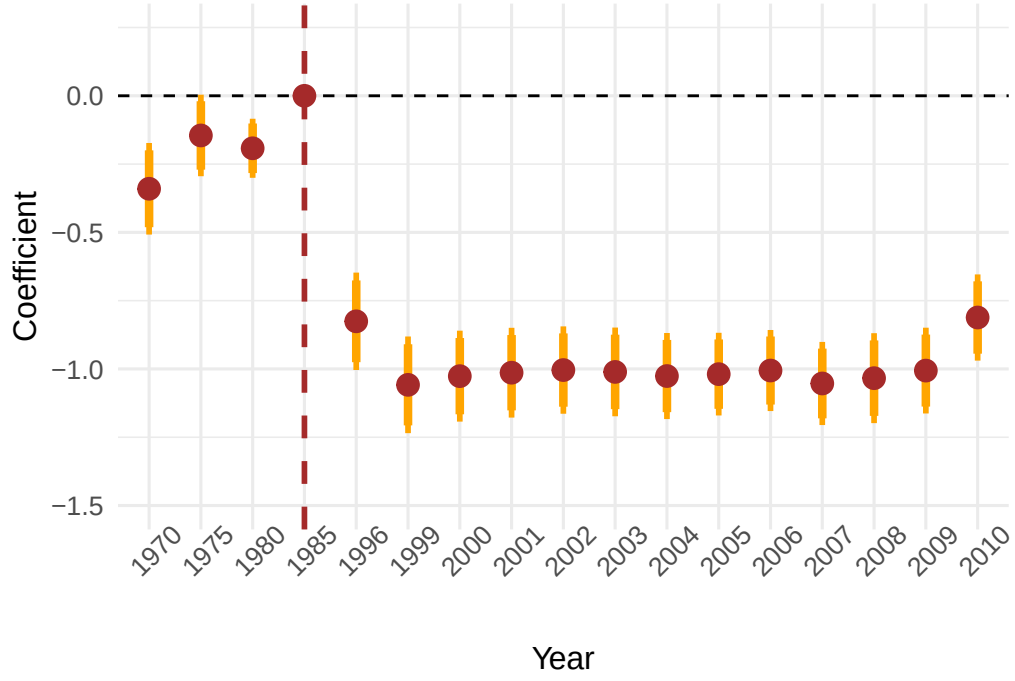
Figure A16: Baseline estimates vs Abraham and Sun (2021) estimator - Elementary school



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 (1)—. Standard errors are clustered at the municipality level. Confidence intervals: 95%.

A12 The effect of witche's broom on per capita GDP

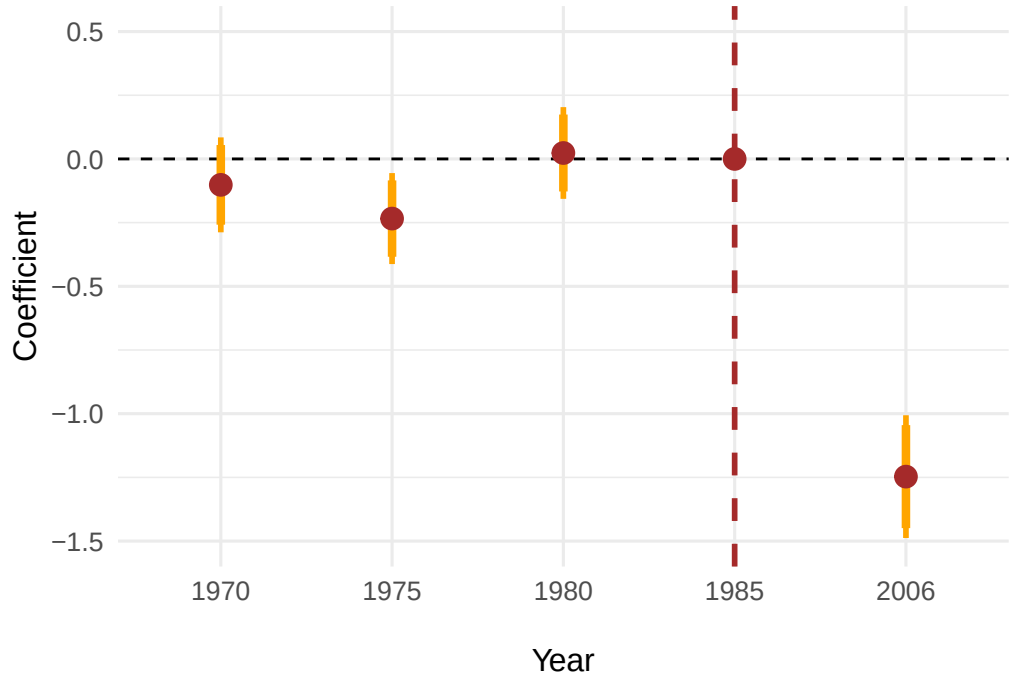
Figure A17: The effect of witche's broom on per capita GDP



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. The dependent variable is the log of GDP per capita. Data is from the Brazilian Institute of Geography and Statistics (IBGE).

A13 The effect of witche's broom on the value of assets owned by agricultural establishments

Figure A18: The effect of witche's broom on the value of assets owned by agricultural establishments



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 total land values in the Northeast of Brazil. The dependent variable is the log of total value of assets owned by agricultural establishments. Real estate (buildings, facilities, and other improvements, lands (including natural forests), permanent crops, and planted forests), as well as vehicles, tractors, machinery and implements, and animals (breeding, rearing, and other purposes) are considered as assets. Data is from the Brazilian Agricultural Census of 1970, 1975, 1980, 1985, and 2006.

Table A1: Witches' broom effect by race

	High school (1)	Elementary school (2)	log(wage) (3)
Childhood exposure	-0.031***	-0.031***	-0.066**
	(0.011)	(0.012)	(0.031)
Childhood exposure * Black	0.004	-0.002	-0.003
	(0.011)	(0.012)	(0.021)
R^2	0.086	0.117	0.224
Observations	5,031,826	5,031,826	1,927,801
Municipality FE	✓	✓	✓
Birth-year FE	✓	✓	✓
Census wave FE	✓	✓	✓
Black × Municipality FE	✓	✓	✓
Black × Birth-year FE	✓	✓	✓
Black × 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.

A14 Robustness check: Conley (1999) std. errors

Table A2: Long-run effect of witches' broom on exposed cohorts: Conley (1999) std. errors

	High school		Elementary school		log(wage)	
	(1)	(2)	(3)	(4)	(5)	(6)
Childhood exposure	-0.028***	-0.028***	-0.032***	-0.032***	-0.051***	-0.051***
	(0.005)	(0.005)	(0.006)	(0.007)	(0.016)	(0.008)
Conley standard-errors	150km	250km	150km	250km	150km	250km
R^2	0.084	0.084	0.117	0.117	0.227	0.227
Observations	5,031,826	5,031,826	5,031,826	5,031,826	1,927,801	1,927,801
Municipality FE	✓	✓	✓	✓	✓	✓
Birth-year FE	✓	✓	✓	✓	✓	✓
Census wave FE	✓	✓	✓	✓	✓	✓
Ind. Controls	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 1 using Conley (1999) standard errors for different distance cutoffs. The dependent variable in columns (1), (2), and (3) 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 (4), (5), and (6). Finally, in columns (7), (8), and (9), 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.

A15 Robustness check: 18y vs 15y exposure

Table A3: 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.

A16 Descriptive statistics: child labour in cocoa region

To provide more evidence on the child labour mechanism, we used a yearly national microdata survey called PNAD.[22] We used PNAD 1995 to create the appendix Table A4 because, in 1996, PETI was launched. This table shows in column 2 the share of children that work 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 Appendix Table A4 shows the share of young individuals below 18 years that work in cocoa and reported that they started working at the age *i*, in column 1. The denominator is the share of children that work in any other agricultural production and reported that they started working at the 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 10 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.

Finally, Table A5 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 areas not affected. Besides, the difference is higher for individuals between 11 and 12 years old. Unfortunately, we cannot recover this information from the 1991 census.

[22] *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 A4: 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 displays 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 with eleven years, in 1995, working in Bahia is working at cocoa production. Column 3 should be interpreted as 6.4% of all people below eighteen years old that is working in Bahia in 1995, works in cocoa production, and started working at eleven years old. Finally, the last column shows the average starting working age of children that was working in cocoa production in 1995.

Table A5: 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.

B Interview summary report

Period: January 15th to 22nd, 2024. Location: Ilhéus, Brazil

B1 Interviewees

- Head of Department, Universidade Estadual de Santa Cruz (UESC)
- Workers and researchers at Cocoa Innovation Center (CIC)
- Farmers associated with ChocoSol Industry
- Owner of a medium-sized farm engaged in tourism activities
- Key figures in regional social movements
- Former politician turned entrepreneur

B2 Methodology

Due to resource constraints, the interviews were primarily conducted in Ilhéus, focusing on stakeholders involved in cocoa plantation, chocolate production, and regional socio-political dynamics. The interviews were facilitated through introductions from the Head of Department at UESC and subsequent networking within the cocoa industry and local community.

Our approach adheres to a semi-structured interview protocol. The questions provided herein do not serve as a rigid questionnaire to be mechanically followed during the interview process. Instead, they represent a flexible framework encompassing pertinent topics. This framework serves as a guide, allowing for organic exploration of the subject matter. Flexibility is paramount, affording us the freedom to adapt and deviate from the initial outline as dictated by the interviewee's insights and the natural flow of conversation. Thus, the formulation and sequencing of questions varied across interviews, dynamically evolving in response to the trajectory of dialogue and issues raised by the interviewee. The overarching thematic areas addressed include: (a) recollection of significant events and associated perceptions; (b) personal and communal experiences relating to the event under study; (c) the interplay of local politics within the context of the subject matter; and (d) the personal life history of the interviewee, intertwined with their involvement in political affairs. All the interviews were recorded with the a verbal agreement of the interviewed. Not, however, that he did not collected any sensible information such as income, health indicators, etc.

After this introduction, we read to each person the following paragraph:

'This interview will be recorded solely for academic research purposes. The identity of the interviewees will be kept strictly confidential, and no data or excerpts from the interview will be made available publicly or privately. The project is conducted by researchers from UNU-WIDER, UESC, and independent consultants.'

Do you agree to participate in this research and authorize its recording?

B3 Life history of the interviewee and personal involvement in politics

- Are you from Ilhéus?
- If Yes, have you always lived here?
- What do you do for a living?
- Are you involved in any way in the civic affairs of Ilhéus? If Yes, when did you start getting involved and why?
- Are you affiliated with any party/movement/association heavily involved in politics?
- Have you ever been involved in institutional politics (municipal administration, political parties)?

B4 Recollection of relevant events and related perceptions

- When and how did you first hear about Witch's Broom?
- People have given different interpretations of this event, what was Witch's Broom to you?
- In your opinion, what were the main consequences for the region?
- Do you think there are those to blame for the emergence of witch's broom or was it a natural event? If there are those to blame, who are they?

B5 Personal and community experience with the disaster

- How did Witch's Broom affect your work and livelihood?
- Did you suffer any direct losses from the disaster? If Yes, did you receive any compensation for your losses? Was this compensation adequate?
- Did any of your personal acquaintances suffer any loss from the disaster? If Yes, who? If Yes, did they receive adequate compensation for it?

- How do you think the city of Ilhéus was affected as a whole? Do you think the disaster had any consequences beyond the economic ones?
- Can you tell us more about life in Ilhéus before the arrival of Witch's Broom? How has life in Ilhéus changed since then?
- Do you think the consequences of Witch's Broom were similar in Ilhéus and in the surrounding cities?
- What happened to the families directly affected by the broom? How did they compensate for the loss of income? Did they stay in the same locations or migrate?
- How about their children?

B6 The role of local politics

- How do you think different political parties, at national and regional levels, behaved during these years regarding issues related to Witch's Broom in the affected areas? Is there any party that you think behaved particularly well or poorly? If Yes, why? Was Witch's Broom a theme for local politics?
- Did local politicians use Witch's Broom in their campaigns? How do you think local politicians behaved regarding the Witch's Broom issue?
- How do you think the disaster was managed? Who were the actors that helped the most? And who were the ones that helped the least? In other words, who is responsible for what (good and bad) happened in this disaster?
- Is there any other association or organization besides political parties that you think played an important role in trying to address issues related to Witch's Broom?
- In 2006, an article in Veja magazine mentioned a potential case of bioterrorism. Are you familiar with this story? Do you believe in this story?

B7 Interview process

The initial interview was held with the Head of Department at Universidade Estadual de Santa Cruz (UESC), who provided valuable insights into the academic perspective on cocoa production and related research initiatives. Subsequently, introductions facilitated by the Head of Department led to interactions with workers at the Cocoa Innovation Center (CIC), where technical procedures from cocoa plantation to seed quality assessment and chocolate production were elucidated.

Further connections within the industry led to engagements with farmers associated with the ChocoSol Industry, providing firsthand accounts of cocoa cultivation practices and their involvement in the supply chain. Additionally, a visit to a medium-sized farm engaged in tourism activities offered insights into artisanal chocolate production and the intersection of agriculture with tourism.

The interview with the farm owner, who is also a former politician deeply involved in farmers' associations, provided a unique perspective on the socio-economic dynamics of the region. This interaction paved the way for interviews with key figures in local social movements, offering valuable insights into the challenges and opportunities faced by communities in the cocoa-producing regions.

Finally, an interview with a former politician turned entrepreneur provided insights into the historical context and evolution of cocoa cultivation, particularly within families owning large properties.

B8 Key findings

- The interviews corroborated our quantitative findings, reinforcing the validity of our research outcomes.
- They highlighted the significant impact of the fungal disease on cocoa plants, leading to widespread destruction and contributing to the impoverishment of the population.
- All interviewees mentioned the transition of labor contracts to "meeiros," which failed to improve workers' conditions. They also reported instances of young individuals seeking employment in low-skilled occupations, such as cleaning, housekeeping, and security.
- Furthermore, interviewees reported that migration primarily occurred towards urban areas within the region, with minor cases of migration to cities like São Paulo and Brusque.