DANYELLE KARINE SANTOS BRANCO

DROUGHT SHOCKS AND ITS ECONOMICS IMPACTS ON NORTHEASTERN BRAZIL

Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Economia Aplicada, para obtenção do título de *Doctor Scientiae*.

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A Deus e a minha família.

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CONTENTS

ABSTRACT

BRANCO, Danyelle Karine Santos, D.Sc., Universidade Federal de Viçosa, July, 2018. **Drought shocks and its economic impacts on Northeastern Brazil**. Advisor: José Gustavo Féres.

This thesis studies two topics on drought shocks and related economic development using Brazilian data. In the first essay, we study the effects of drought shocks on rural households labor allocation in Northeastern Brazil. We analyze whether rural households use labor allocation to mitigate the effect of drought shocks. While previous studies provide strong evidence that droughts and floods can have an immediate effect on rural income, the extent to which families adjust labor supply to mitigate these effects has been very little investigated. Documenting the quantitative importance of labor supply and other behavioral household responses is crucial for shaping the targeting of policies intended to mitigate the adverse consequences of climate change. Our identification strategy exploits variation in rainfall records over time within municipalities, and relies on the assumption that weather shocks, conditional on municipality and year fixed-effects, are not correlated with other latent determinants of labor supply. We begin our analysis by providing evidence that negative rainfall shocks affect household income in our setting. The results present evidence of a relationship between negative rainfall events and labor time reallocation. We find that drought shocks are significantly associated with lower income derived from one's main job. This is especially true when we consider income derived from farm activities. Moreover, a higher incidence of drought shocks is significantly associated with increased income from secondary jobs. Our results show that droughts negatively affect hours spent on farm work, whereas it leads to increased supply of non-agricultural jobs. The results show the importance of non-agricultural activities as an autonomous mitigation mechanism. The second essay investigates the impact of drought shocks on educational outcomes of children attending schools in rural Northeastern Brazil. In particular, we assess how droughts may affect students achievement measured by Prova Brasil scores in math and language, a national standardized exam. We believe that there are three main different mechanisms through which weather shocks may affect child schooling: school supply, infant health, and child labor. The findings provide evidence that students from schools that are exposed to drought shocks perform worse on standardized math and Portuguese exams. Our results also suggest that the shock effect seem to be more detrimental for girls and those students with lower educated mothers. We also find suggestive evidence that drought tends to be more harmful to children that study in schools with no cistern or other water storage device. Therefore, investing in basic infrastructure is a low-cost policy strategy in rural areas that may considerably improve school performance. By investigating the potential transmission mechanisms linking weather shocks to school performance, we find that the impact of negative rainfall shocks on child health is an important mechanism driving our results. Exposure to a drought shock increase the hospitalization rate among children. In addition to that, one more drought shock per year is associated to a 4.24% increase in the likelihood of a child being employed. Both health and job-market related effects may be associated to lower school attendance and therefore contribute to poor student achievements. Together, the two essays contribute to a better understanding about the relationship between extreme weather-related events and important economic development issues.

RESUMO

BRANCO, Danyelle Karine Santos, D.Sc., Universidade Federal de Viçosa, Julho, 2018. **Choques de seca e seus impactos econômicos no Nordeste do Brasil.** Orientador: José Gustavo Féres.

Esta tese estuda dois tópicos relacionados à choques de seca e desenvolvimento econômico usando dados brasileiros. No primeiro ensaio, estudamos os efeitos dos choques de seca sobre a alocação de mão de obra de famílias rurais no Nordeste do Brasil. Analisou-se se as famílias rurais usam a alocação de mão de obra para mitigar o efeito dos choques da seca. Embora estudos anteriores forneçam fortes evidências de que secas e inundações podem ter um efeito imediato sobre a renda rural, a medida em que as famílias ajustam a oferta de trabalho para mitigar esses efeitos tem sido pouco investigada. Documentar a importância quantitativa da oferta de trabalho e de outras respostas comportamentais dos agregados familiares é crucial para definir o direcionamento de políticas destinadas a mitigar as consequências adversas das alterações climáticas. A estratégia de identificação explora a variação nos registros de precipitação ao longo do tempo dentro dos municípios e baseia-se na suposição de que os choques climáticos, condicionais aos efeitos fixos do município e do ano, não estão correlacionados com outros determinantes latentes da oferta de trabalho. A análise inicial fornece evidências de que choques negativos de chuva afetam a renda familiar no ambiente estudado. Os resultados apresentam evidências de uma relação entre eventos negativos de precipitação e realocação do tempo de trabalho. Os choques causados pela seca estão significativamente associados a rendimentos mais baixos derivados do trabalho principal. Isto é especialmente verdade quando considerada a renda derivada das atividades agrícolas. Além disso, uma maior incidência de choques de seca está significativamente associada ao aumento da renda proveniente de empregos secundários fora do setor agrícola. Nossos resultados mostram que as secas afetam negativamente as horas gastas no trabalho agrícola, ao passo que levam a uma maior oferta de trabalho não agrícola. Os resultados mostram a importância das atividades não agrícolas como mecanismo de mitigação autônomo. O segundo ensaio investiga o impacto dos choques da seca sobre os resultados educacionais de crianças que frequentam escolas no Nordeste do Brasil. Em particular, avaliou-se como as secas podem afetar o desempenho dos alunos medido pela pontuação da Prova Brasil em matemática e português, um exame nacional padronizado. A hipótese é que choques de seca têm impacto negativo no desempenho dos alunos. Acredita-se que existem três mecanismos principais pelos quais os choques climáticos podem afetar a educação infantil: oferta escolar, saúde infantil e trabalho infantil. Os resultados fornecem evidências de que alunos de escolas rurais que são expostos a choques de seca têm pior desempenho em exames padronizados de matemática e português. Os resultados também sugerem que o efeito do choque parece ser mais prejudicial para meninas e para aqueles com mães com menor escolaridade. Também foram encontradas evidências sugestivas de que a seca tende a ser mais prejudicial para as crianças que estudam em escolas sem cisternas ou outros dispositivos de armazenamento de água. Portanto, investir em infraestrutura básica é uma estratégia política de baixo custo em áreas rurais que pode melhorar consideravelmente o desempenho escolar. Ao investigar os possíveis mecanismos de transmissão que ligam os choques climáticos ao desempenho escolar, encontrou-se que o impacto de choques negativos sobre a saúde infantil é um mecanismo importante que impulsiona os resultados. A exposição a um choque adicional de seca aumenta a taxa de hospitalização entre crianças. Além disso, mais um choque de seca por ano está associado a um aumento de 4,24% na probabilidade de uma criança estar empregada. Tanto a saúde quanto os efeitos relacionados ao mercado de trabalho podem estar associados à menor frequência escolar, portanto, contribuem para as fracas conquistas dos estudantes. Juntos, os dois ensaios contribuem para uma melhor compreensão sobre a relação entre eventos extremos climáticos e questões importantes de desenvolvimento econômico.

1 Introduction

Extreme weather events may be defined as rare climate events causing important capital destructions over time period that can range from one day to several weeks or months, such as hurricanes, floods, droughts, heat waves, cold waves, and storms (IPCC, 2014). There is a growing consensus that these events are one of the main channels through which climate and economic systems interact.

A consolidated body of research suggests that the risk of extreme events rises with increases in global average temperature (IPCC, 2014; KREFT *et al*, 2014; COATES *et al*, 2014; MARENGO, 2009; SCHÄR *et al*, 2004). Further, these shocks could be intensified by increases in temperature variability. Meteorological conditions that are considered as extremes today will become more frequent. Between 1994 and 2013, more than 530,000 people died worldwide as a direct result of over 15,000 extreme weather events (GERMANWATCH, 2015). Nordhaus (2006) calls out attention to the increase in the frequency of storms over the 1851-2005 period in the United States, particularly since 1980. He also stressed the North Atlantic hurricanes that in 2005 broke many records. As another example, in Colombia the number of extreme weather registered in the decade of the 2000s has increased more than 60 percent with respect to the decade of the 1970s (ANDALON *et al*., 2016). More related to our study, Brazilian Northeast faced in 2015 the worst drought in the last 83 years, the largest dam of the region reached less than 5% of its full capacity, leaving about 1,000 municipalities in emergency situation and affecting more than 7,000 farmers, this (ANA, 2015; MAPA, 2015).

Just as frequency and intensity, extreme weather-related economic costs are also increasing. According the Stern Review (2006), costs of extreme weather alone could reach 0.5 - 1% of world GDP per annum by the middle of the century, and will keep rising if the world continues to warm. The European heat wave experienced in 2003 caused US$15 billion of agricultural losses, besides 35,000 deaths. In 2004, Brazil faced for the first time a hurricane. The hurricane hit Southern Brazil and left 27,500 homeless, 518 injured and 11 dead. Losses totaled approximately US$1 billion and 14 municipalities have declared state of public calamity (PEZZA *et al.,* 2009). More than one decade later the damages still can be seen. Another recent event occurred in the United States, the 2005 Hurricane Katrina. Katrina cost US$81 billion, it was by a wide margin the mostly costly hurricane in recent history not because of its intensity but because it hit the most economically vulnerable region in the United States (NORDHAUS, 2006). Thus the same shock may have quite different effects depending on the place that it hits. These differences in vulnerability arise from multidimensional inequalities often produced by uneven development processes (IPCC, 2014).

Extreme climate-related events have potential direct and indirect impacts across human health, agricultural production, energy production and education. Of all economic sectors, agricultural sector is one of the most affected by the extreme events, since temperature and precipitation are direct inputs to agricultural production. Regarding health, the impacts are huge and have not age group exception, affecting even babies while *in utero*. A set of previous studies attempt to measure the impacts of climatic shocks in different dimensions (ROCHA and SOARES, 2015; ARAÚJO *et al.*, 2013; BARRECA, 2012; DESCHÊNES, GREENSTONE and GURYAN, 2009; DESCHÊNES and MORETTI, 2009; BARRIOS, OUATTARA and STROBL, 2008; VERDIN *et al.*, 2005).

Developing countries are the ones who should face the greatest risks. These countries are more vulnerable because they are located in warmer and greater exposure to climatic shocks regions, and their livelihoods are often tied to subsistence agriculture. Furthermore, agriculture remains the main engine for economic growth for most developing countries, and serves as the backbone for food security. In Brazil, smallholder farmers represent approximately 48% of the establishments, having a maximum of 10 hectares; if subsistence agriculture is considered, this figure reaches about 84,4%. Moreover, family farming represents 75% of the agricultural labor force and accounts for approximately 10% of national GDP (LINDOSO *et al,* 2011). Araújo *et al.* (2013) document that agricultural productivity of Brazilian farmers was strongly affected by El Niño phenomenon from 1970s to 2000s. They find that for all El Niño year the Northeastern Brazil presented productivity losses, reaching up until 50% reduction in crop yields. Due to the decreasing agricultural productivity, agricultural income may be severely affected, providing incentives to rural population to adopt adaptation measures such as seeking off-farm[1] labor opportunities or leaving rural areas. The reduction of agricultural production and the lack of work opportunities in rural areas may trigger major migratory waves, raising poverty on urban areas, and making of

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[1] Off-farm labor in our context refers to any work that is not directly related with agricultural production.

semiarid Northeast the most affected region in Brazil (CEDEPLAR and FIOCRUZ, 2008).

The consequences of climatic shocks also can be seen in educational field. Jensen (2000) compares the differences in the percentage of children enrolled in school in 1986 and 1987 in regions of Cote d'Ivoire that had the adverse shock, relative to the differences in regions that had normal rainfall. Jensen (2000) finds that school enrollment rates declined by 14 and 11 percentage points among boys and girls, respectively, living in areas that experienced the adverse shock, while increased in all other areas. This relationship also can be seen through an anecdotal evidence. As Droughts hit Central Valley California and crops dry up, families are forced to move in search of jobs and housing. Schools are seeing kids leave as their families struggle to cope with the consequences of the dry spell that has been persisting for the last four years. In just one case, enrollment in a small rural school had down 14%, which translates into hundreds of thousands of dollars in lost state aid (NICOSIA, 2015). Such circumstances make children's learning difficulty and retard their progress in school. The same consequences are expected to Brazilian students.

Taken together, these facts suggest that weather shocks, at least in developing countries, could have long-term impacts on economic development and human capital accumulation. Thus, given the increases in extreme weather events in the last years, adaptation actions are being adopted to assuage climate impacts. Successful adaptations may be viewed as those actions that build resilience and decrease vulnerability to multiple threats. For instance, irrigation and change in the mix of crops. Cunha *et al* (2013) show that Brazilian smallholder farmers who adopt irrigation methods would be more resilient to climate change when compared to smallholders producing rainfed crops, confirming the efficiency of irrigation as an adaptive strategy. Implementing techniques soil conservation and genetic improvement through the development of more resistant cultivars to drought and, or, to water stress, are some adaptation strategies that also have been used. Although the strategies before mentioned are effective adaptation responses, their implementation requires better information, advance planning and high costs. Therefore, short-term adaptation actions are being considered by farmers to keep their income, such as non-farm labor activities and migration to urban areas. Yet, as a way to improve household income, children may drop-out school to join the workforce.

Given the increasing incidence of extreme weather episodes, it is necessary to assess their effects and available mitigation measures to the different economic agents. We concentrate on the region of Northeastern Brazil to explore the following issues. First, we seek to understand the relationship between droughts and non-farm labor activities, as a way to complement household income while facing negative climatic shocks. Second, we assess how drought period may affect school performance, considering that parents could send their children to work to improve household income when weather events are faced.

Mitigation actions should be taken by farm workers to respond to unfavorable agricultural production environments, such as unexpected weather shocks. Since agriculture is one of the most affected sectors, households in rural areas face substantial income variability as much of their earnings are derived from agricultural production. Engaging in non-farm labor market would be a potential strategy and could help to reduce risk exposure. Non-farm income sources may help to hedge against declining agricultural profitability.

A wide range of studies have pointed out, even to developed rural economies, the significant role played by non-farm work in the total income of rural households and its stable long-run combination with farming (HAGGBLADE *et al.*, 2010; AHEARN *et al.*, 2006; DIMITRI *et al.*, 2005; BARRETT *et al.*, 2001; REARDON *et al.* 2001; KAGEYAMA , 2001; KAGEYAMA and HOFFMANN, 2000; KIMHI, 2000). Reardon *et al.* (2001) assert the importance of non-farm employment and income to Latin America (LAC) rural households. They find that non-farm income constitutes roughly 40% of LAC rural households incomes. Furthermore, non-farm wage far exceeds farm wages and migration wages. Non-farm income also takes a important role in developed countries. In the United States, it played a key role in increased rural household income. By 2003, ninety percent of farmers had earned non-farm income, helping household income to exceed the national average (DIMITRI *et al.*, 2005).

In view of these considerations, it is important to look at how households adjust their off-farm labor allocations in response to weather shocks. The literature on this subject is still very scarce for developing countries. Rose (2001) and Ito and Kurosaki (2009) examine ex ante and ex post labor supply responses to weather risk for rural Indian farm households. Rose (2001) find that ex ante, farmers facing riskier distributions of rainfall are more likely to participate in the labor market, and ex post, unexpectedly bad weather and low rainfall increase labor force participation. Ito and Kurosaki (2009) find results slightly different from Rose's results (2001). Indeed, they show that the share of the off-farm labor supply could both increase and decrease with rainfall shocks, showing that their results are not robust.

To our knowledge, our study is the first to look at non-farm income as a mitigation strategy face to weather shocks. We also contribute to literature by using detailed climatological data. We make use of high frequency gridded information on precipitation and temperature. While the studies above mentioned make use of grid-level 0.5º resolution climate data (points in this resolution are spaced at approximately 55 kilometers), our data provides a grid cells in the projected climate raster to be 20 kilometers x 20 kilometers. According Dell (2009) grid-level 0.5º resolution is not appropriate when we wish to look at municipality means, once that a resolution that is too low throws away information. We also use a range of many years household-level data while previous papers only covering one year or three consecutive years at most. The previous researches had the potential to find distorted relationships between climatic shocks and non-farm labor if the few years in question were a meteorological outlier.

There is plenty of evidence showing the importance of human capital accumulation to any country economy. Thereby, investment in childhood education could be a first step to diminishing overall inequality in developing countries. However, when hit by a shock, the household has to make a decision regarding children's allocation of time: labor or schooling. If parents react to shocks by taking out their child from school to join the workforce this could raise inequality or even stunt long term growth. Whereas education has been a key to innovation, economic growth and an effective mechanism for poverty reduction, child labor has been viewed as a consequence of poverty (EDMONDS and PAVCNIK, 2005; BALAND and ROBINSON, 2000; BASU and VAN, 1998).

As far as we know, our study is the first to analyze the relationship between negative weather shocks and studying in rural Northeast areas. We believe study this region presents an interesting and particular case once some mechanisms observed in India that could driving children to attend school less, such as malaria, have no occurrence in Brazilian Northeast. Thereby, it becomes necessary to understand the mechanisms linking weather shocks to schooling in Brazil. Also, we are going to assess if the construction of cisterns in rural schools could offset any impact of extreme events and improve children's progress in school. Our findings could have important policy implications.

We believe that focus on Northeastern Brazil provide a compelling setting to investigate the potential impacts of extreme weather events. First, it is the driest Brazilian region and it has long been subject to harsh climatic conditions, with recurrent events of drought and rising temperatures, leading to further enhance evaporation and reduce water availability. (MARENGO, 2006; AB'SÁBER, 1999). Furthermore, one of the most populated semi-arid area of the world is localized in Brazilian Northeast, where more than 23.5 million inhabitants are located, representing approximately 12% of the Brazilian population (Insa/MCTI, 2014; CORREIA *et al.,* 2012; AB'SÁBER, 1999). For a huge fraction of this population collecting water for consumption, hygiene, and agricultural production is a daily task that demands energy and resources. Lack of adequate access to water also increases the susceptibility to climatic shocks associated with fluctuations in rainfall (ROCHA and SOARES, 2015).

In the remainder of this thesis, the chapter two is dedicated to investigate the effects of drought shocks on rural household labor allocation. The third chapter assess how drought shocks may affect student achievement. A final chapter offers some general concluding remarks

2 Weather Shocks and Labor Allocation: Evidence from Northeastern Brazil[2]

Abstract

This paper analyzes whether rural households use labor allocation to mitigate the effect of drought shocks in the Northeaster Brazilian context. We first document that water scarcity leads to lower income derived from farm work as main, and higher income from secondary jobs. We then examine the extent to which extreme droughts affect time labor allocation. Our results indicate that an additional drought shock per year is associated with greater likelihood of have more than one job, lower share of farm activities on the total hours worked, and higher share of secondary job. The effects are higher for poorer municipalities. These findings are consistent with a response to reduced agricultural profitability due to water scarcity and show the importance of non-agricultural activities as an autonomous mitigation mechanism.

Keywords: Drought shocks; rural households; labor allocation; Northeastern Brazil.

2.1 Introduction

A consolidated body of research suggests that the incidence of extreme weather events, such as droughts and floods, will rise in the coming century as a result of increased global average temperature (Coates et al., 2014; IPCC, 2013). The economic costs of these climate-related extreme events may be substantial and far-reaching. Much of the discussion in literature has focused on the direct impacts of extreme weather events on health, agriculture, and income.[3] However, increasing attention is being paid to the mechanisms underlying these relationships. One intriguing question is whether families adopt loss-income mitigation strategies in response to extreme weather events.

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[2] This work was carried out with the aid of a grant from the International Development Research Centre, Ottawa, Canada through Project entitled "Using an Environmental Economics Perspective to Influence Policies in Latin America and the Caribbean - Latin American and Caribbean Environmental Economics Program (LACEEP). The views expressed herein do not necessarily represent those of the IDRC or its Board of Governors. I am also grateful for excellent research assistance and advices by José Gustavo Féres and Claudio Araujo.

[3] See Barreca (2012), Barrios et al. (2008), Blakeslee and Fishman (2017), Deaton (1992), Deschênes and Greenstone (2007), Jayachandran (2006), Maccini and Yang (2009), Rocha and Soares (2015) and Zander et al. (2015).

While previous studies provide strong evidence that droughts and floods can have an immediate effect on rural income, the extent to which families adjust labor supply to mitigate these effects has been very little investigated.[4] Documenting the quantitative importance of these labor supply and other behavioral household responses is crucial for guiding the targeting of policies intended to mitigate the adverse consequences of climate change.

Extreme weather events can have in particular important effects on time allocation of labor. In context where irrigation and genetically improved seed are unavailable, rainfall shocks are likely to negatively affect agricultural productivity, most notably causing lower yields of subsistence crops and reduce income from cash crops. As a result, engaging in agricultural activities become less attractive and household should rise the supply of non-agricultural work to hedge against declining agricultural profitability and consumption smoothing. Therefore, non-farm income plays a significant role in rural households by reducing income volatility.

Understanding the labor supply responses to weather shocks is particularly relevant in developing countries. Since these countries are located in areas that are warmer, they are expected to experience a disproportionate share of extreme weather events in the future due to climate change. Moreover, these countries have limited social safety nets and weak institutions, so households do not have access to the portfolio of adaptation strategies or avoidance behaviors often available in more developed countries.

This paper intends to show the importance of non-agricultural jobs as an autonomous mitigation mechanism. To do so, we provide empirical evidence on the relationship between rainfall shocks and household labor allocation in the Northeast Brazilian context. We believe that focus on Northeastern Brazil provides a compelling setting to investigate this question. First, it is the driest Brazilian region and it has long been subject to harsh climatic conditions, with recurrent events of drought and rising temperatures, leading to further enhance evaporation and reduce water availability (Ab'Sáber, 1999; Marengo, 2009). Second, one of the most populated semi-arid area of the world is localized in Brazilian Northeast, where more than 10 million inhabitants are located in rural areas. For a huge fraction of this population collecting water for consumption, hygiene, and agricultural production is a daily task that demands energy

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[4] See Jessoe et al. (2017) and Rose (2001).

and resources. Lack of adequate access to water also increases the susceptibility to climatic shocks associated with fluctuations in rainfall (Ab’Sáber, 1999; Cirilo, 2008; Insa/MCTI, 2014; Rocha and Soares, 2015). Furthermore, half of all Brazilian rural dwellers and family farming establishments are in Northeast. Almost all of the total area sown in the region is rainfed. Only 2 percent of net area is irrigated.[5] Therefore, we would expect rainfall to be an important driver of agricultural productivity and household income.

We make use of high frequency gridded information on precipitation and temperature to construct a municipality-by-year weather dataset which then is combined with household microdata by using place and survey month. Our identification strategy exploits variation in rainfall records over time within municipalities, and relies on the assumption that weather shocks, conditional on municipality and year fixed-effects, are not correlated with other latent determinants of labor supply. This identifying assumption is plausible insofar as households are unlikely to anticipate precisely a rainfall shock at a given moment in time and place.

We begin our analysis by providing evidence that negative rainfall shocks affect household income in our setting. Although income registries are likely to be subject to considerable measurement error in household surveys, we still observe that drought shocks are significantly associated with lower income derived from the main job. This is especially true when we consider income derived from agricultural activities. Moreover, higher incidence of drought shocks are significantly associated with increased income from secondary jobs, out of agriculture. These results give us confidence that rainfall shocks are in fact an income shifter in our setting.

We then explore the extent to which drought shocks affect labor time allocation. We find that negative rainfall shocks are associated with greater likelihood of being employed in more than one job, lower share of farm activities, and higher share of non-agriculture secondary job. We also assess whether these effects vary heterogeneously according with municipality's level of development. The results indicate stronger effects among families residing municipalities with lower per capita income. Taken in their entirety, these results are consistent with a mitigation response to reduced agricultural profits due to water scarcity.

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[5] These information are based on the Brazilian Agricultural Census 2006.

A potential identification issue pervading our analysis is migration. What if families migrate away from areas affected by extreme droughts? Empirically this would be problematic only if families that migrate in response to a negative rainfall shock are different from those who do not. To explore this issue, we estimate the main regressions considering only families that live for at least five years in the current municipality. The results are broadly similar compared to our benchmark specification. In addition, when we explore whether rainfall shocks are associated with predetermined individual or household characteristics, we find no evidence that this happen. Thus, selective migration is unlikely to be a major problem. This is consistent with recent work in rural Pakistan that finds no effect of rainfall on the mobility of men or women (Mueller et al., 2014).

A small number of papers, focused mostly on reallocation of main job, have examined the relationship between weather and labor allocation. As part of a larger analysis, Jessoe et al. (2017) evaluate the effects of annual fluctuations in weather on employment in rural Mexico. They find no effect of rainfall or temperature shocks on agricultural sector, but show that non-agricultural labor decreases with increases in extreme temperature. Rose (2001) looks at rural Indian farm households to test labor supply responses to rainfall shock. She finds that the probability of participating in the labor market is significantly greater when unexpectedly low levels of precipitation are faced. To our knowledge, there has been no study of drought shocks on labor allocation as mitigation strategy in Brazil. In this paper, we use more detailed information of the individual's work. We know the number of works the person is employed, whether the individual is employed in agricultural sector or not for each job, and the hours worked in both main and secondary job. The fact we know the hours worked supply and not just whether the person participates or not in the labor market, allow us to look at farm and non-farm work as complementary rather than as substitutes only.

We start in the next section with a little contextual information about Northeastern Brazil. In section 2.3 we present our motivating model of the joint rural household decision regarding farm and non-farm labor supply. Section 2.4 describes our data and empirical strategy. Section 2.5 presents our benchmark results, and explores further empirical results. Section 2.6 concludes.

2.2 The Brazilian Northeast

The Brazilian Northeast comprises nine states and 1,794 municipalities. This region is also the poorest and the driest Brazilian region and it has long been subject to harsh climatic conditions, with irregular annual precipitation, recurrent events of drought and rising temperatures. Furthermore, one of the most populated semi-arid area of the world is localized in Northeastern Brazil, where more than 23.5 million inhabitants are located, representing approximately 12% of the country's population (Ab'Sáber, 1999; Marengo, 2009). For a huge fraction of this population collecting water for consumption, hygiene, and agricultural production is a daily task that demands energy and resources. Lack of adequate access to water also increases the susceptibility to climatic shocks associated with fluctuations in rainfall (Ab'Sáber, 1999; Cirilo, 2008; Insa/MCTI, 2014; Rocha and Soares, 2015).

In Figure 1, we have yearly precipitation between 1979 and 2016 for the Northeast and for the rest of Brazil. Brazilian average historical precipitation is slightly above 1700 mm. In Northeast the average is quite below than what is observed for the rest of the country (749 mm). The figure illustrates that, in the 38-year interval portrayed, yearly precipitation in Northeastern Brazil did only reach the historical average for the rest of the country at a point in time, which was the year of 1981. The figure also shows the recurrence of rainfall deficits throughout the past decades.

The Northeastern Brazil is also the region with vast majority of the rural dwellers, more than 14 million inhabitants, which represents almost 50% of Brazilian rural population. The economy is largely based on extensive agriculture, 73% of rural dwellers have farm work as their principal employment. In this context, 89% of agricultural establishments are classified as family farms, employing more than 6 million people. The majority are small producers (with areas smaller than 10 ha) and occupy less than 5% of agricultural land. Also, almost all of the total area sown in the region is rainfed, with only 2 percent of irrigated net area.

In the context of Brazilian Northeast, where most of the farmers have no access to irrigation and genetically improved seed, rainfall shocks can disrupt agricultural production, most notably causing lower yields of subsistence crops and reduce income from cash crops. The limited access to credit or insurance markets and many internal and external constraints and stresses also could affect the farmers choice of mitigation strategies, and the labor market out off agriculture may be an alternative path to help rural households to hedge against declining agricultural profitability and consumption smoothing.

2.3 A model of rural household labor

We developed a simple model of the joint rural household decision regarding farm and non-farm labor supply. The household decides to allocate the time T among three activities: leisure (l^z), farm labor (l^{farm}) and non-farm labor (l^{off}), such that $T = l^z + l^{farm} + l^{off}$. Let c be consumption. The rural household utility function $U(c, l^z)$ is concave and twice differentiable. The total utility function of the rural household is

$$U(c, l^z) = u(c) + \alpha l^z \qquad (1)$$

Let $\bar{w}$ denote the non-farm wage and, since the agricultural household is a price-taker in all markets (Singh, Squire and Strauss, 1986), we assume that $\bar{w}$ is determined exogenously. So, household will be paid $\bar{w}l^{off}$ for time spent working in non-farm labor. Let π be the revenue from agriculture, which is given by agricultural production. Agricultural production is determined by the amount of farm labor, weather shocks, and fixed capital and land. It may be represented by the production function $q(l^{farm}, R, \bar{K})$, where l^{farm} is the quantity of labor allocated to farm activities, R the weather shock, and $\bar{K}$ is capital and land.[6] R is a random variable that affects farm profits, a higher value of R indicates better weather. It could be defined as the deviation between the total rainfall in given moment of time and the historical average rainfall.[7] Literature shows that rural Northeastern Brazil turns positive rainfall shocks into unequivocally beneficial events, enabling us to assume that $\frac{\partial q}{\partial R} > 0$.[8] Total rural household income is given by the sum of farm revenue and non-farm income, and it may be represented by $I = Pq(l^{farm}, R, \bar{K}) + \bar{w}l^{off}$. Thus, consumption will be

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[6] In general, we assume that $\frac{\partial q}{\partial l^{farm}} > 0$, $\frac{\partial^2 q}{\partial l^{farm^2}} < 0$ and $\frac{\partial^2 q}{\partial l^{farm} \partial R} > 0$.

[7] Rainfall deviations below the historical average characterizes a negative shock, whereas deviations above the historical average settles a positive shock.

[8] See Rocha and Soares (2015).

$$c = I \tag{2}$$

$$c = Pq(l^{farm}, R, \overline{K}) + \overline{w}l^{off} \tag{3}$$

The time allocated to leisure is expressed by $l^{z} = T - l^{farm} - l^{off}$. Thus, we can substitute this into the maximization problem to get

$$\max_{l^{farm}\, l^{off}} U[Pq(l^{farm}, R, \overline{K}) + \overline{w}l^{off}, T - l^{farm} - l^{off}] \tag{4}$$

We consider the case where rural households allocate time for both farm and non-farm activities. In this case, the first order conditions of the optimization problem (4) are given by

$$u^{'}(c)\left(P\frac{\partial q}{\partial l^{farm}}\right) - \propto = 0 \tag{5}$$

$$u^{'}(c)\overline{w} - \propto = 0 \tag{6}$$

where $u^{'}(c)$ is the marginal utility of the consume and $\propto$ is the marginal utility of leisure.

From conditions (5) and (6), one may verify that

$$\left(P\frac{\partial q}{\partial l^{farm}}\right) = \overline{w} \tag{7}$$

Condition (7) indicates that, on optimum, the farm wage is equal to the wage paid by non-farm activities. To ensure a globally concave objective function, and thus, a unique optimum, we assume that

$$\left[u''(c)\left(P\frac{\partial q}{\partial l^{farm}}\right)^{2} + P\frac{\partial^{2} q}{\partial l^{farm^{2}}}u^{'}(c)\right]u^{''}(c)\overline{w}^{2} > \left[u^{''}(c)\overline{w}\left(P\frac{\partial q}{\partial l^{farm}}\right)\right]^{2} \tag{8}$$

We are interested in the effect that weather shocks have on the optimal level of both farm and non-farm labor. That is, how would we expect an adverse weather shock to affect the rural household labor decision? They would use non-farm labor as a mitigation strategy to weather shocks? These questions lead us to our two testable hypothesis:

- Proposition 1: Negative rainfall shocks decrease household farm labor supply.

Proof. From the first order condition:

$$\frac{\partial l^{farm}}{\partial R} \cong \overbrace{-\,u''(c)\bar{w}^2 u'(c)P\frac{\partial^2 q}{\partial l^{farm}\partial R}}^{(+)} \tag{9}$$

Farm work has a positive relationship with R. In other words, an increase (reduction) in R implies in increasing (decreasing) farm labor. In this model, there is only one way that weather shocks affect the choice of farm work. When a drought is faced, the marginal productivity of agricultural labor will reduce, which implies a diminishing in the return of farm labor. Thereby, agricultural activities become less attractive. Household will allocate less time to farm labor, thus reducing l^{farm}. However, positive rainfall shocks increase the benefit to farm working, agricultural wage rises and household will increase farm labor supply

- Proposition 2: Negative rainfall shocks increase household non agricultural labor supply.

Proof. From the first order condition, we can derivate the effect of weather shocks on the optimal choice of non-farm working:

$$\frac{\partial l^{off}}{\partial R} \cong \overbrace{-\,u''(c)P\frac{\partial q}{\partial R}\bar{w}u'(c)P\frac{\partial^2 q}{\partial l^{farm^2}} + u''(c)\bar{w}^2 u'(c)P\frac{\partial^2 q}{\partial l^{farm}\partial R}}^{(-)} \tag{10}$$

Weather shock has two effects on the optimal level of non-farm labor. First, a drought decreases both farmland productivity and the value of agricultural work, which affect the benefit of time spent in farm labor. Thus, non-farm labor becomes more attractive, and household will increase l^{off}. Second, droughts decreases the value of marginal productivity of farm labor. Since the marginal return associated to non-farm activities is higher, the household could choose non-farm labor above the optimal level, leading to rising the total income, and mitigating the shocks effect.

2.4 Data and Empirical Strategy

2.4.1 Household data

Our basic source for labor market outcomes in the rural Northeast is from the Brazilian Household Survey (PNAD). Every year since 1967, the Brazilian Bureau of Statistics (IBGE) has implemented the PNAD throughout Brazil during the month of September.[9] It is nationally and regionally representative, and contains detailed information on socio-economic and demographic characteristics. Since its implementation in 1967, PNAD passed through many methodological alterations along the years. Thus, we restrict our analysis to the period between 2001 and 2014, for which questionnaires and consistent sampling methodologies were maintained.

Importantly for our study, the PNAD asks whether respondents work with agriculture, are self-employed, wage-employee, employers, or whether they grow for their own consumption. In addition, respondents are asked to provide information about the number of jobs they have, and the amount of hours usually spent in each job per week. This allows us to calculate the participation of each job on the total of hours worked. The rural sample is comprised of 145,425 individuals from 40,519 households in 150 municipalities. Employment data are available for 92,006 individuals, among which 47,295 are the head of household.[10]

We restrict the sample to those living outside of urban areas because our causal factor of interest, rainfall, should mainly have an effect in rural areas. We also restrict the sample to individuals aged 10 to 70. The householder's characteristics, just as gender, age, years of schooling, and family size, are also collected from the PNAD. Our main outcomes of interest include probability of have more than one job, ratio of farm work on the total worked, share of secondary job on the total of hours worked, and likelihood of at least one family member being employed in nonagricultural work (non-farm likelihood). Table 1 presents summary statistics of these variables.

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[9] Except in the Brazilian Censuses years, that is conducted of each ten years.

[10] The basic idea underlying our empirical approach is to compare householders who experienced different climatic conditions in a given moment in time. Using different rounds of the PNAD, we can compare families (individuals) in different moments in time and place, so that there is a great amount of variation across municipalities and years in weather conditions and our dependent variables. PNAD is not longitudinal, so we are unable to observe the same individuals in different years. However, this does not jeopardize our empirical approach. Our identifying assumption is that, conditional on municipality and year fixed effects, weather shocks are orthogonal to other determinants of the variables of interest. This plausible assumption is sufficient to estimate the impact of weather shocks on our labor outcomes. Thereby, the relevant source of variation in our study is at the municipality-level.

In rural Northeastern, more than 70% of individuals report agriculture as their principal economic activity. Most of them are self-employed, while 25% help another member of the household and do not receive any salary. On average, only seven percent of individuals are employed in more than one job (not shown in the table), and the share of time spent on these secondary occupations of the total hours worked is 2,82%.

2.4.2 Climate data

Weather data are based on a reanalysis model, ERA-Interim. The ERA-Interim database provides daily temperature and precipitation information with horizontal and vertical resolution of 12 Km and covers the period from 1 January 1979 onwards. We use a geo-spatial software to aggregate the data to the municipality level and calculate an average of the points located inside the municipality limits.[11] We make use of this daily data in order to calculate summary measures and construct annual shocks.

To analyze the effect of weather on rural labor allocation, we construct several measures of drought shocks. Our first measure is the Standardized Precipitation Index (SPI).[12] The SPI calculation is based on the long-term precipitation record for a desired period. This long term-record is fitted to a probability distribution, which is then transformed into a normal distribution (Mckee et al., 1993). Its probabilistic nature gives it historical context, and since it is spatially consistent, it allows for comparisons between different locations, both are well suited for decision-making. Negatives SPI values indicate less than median precipitation and characterizes a drought. The drought intensity depends which value SPI reaches. Whether it reaches until -0.99 is within the "mild dryness" category, from -1 to -1.49 is "moderate dryness", if it is between -1.50 and -1.99 "severe dryness" and from -2 onwards is "extreme dryness" category. Any value above zero is not considered an negative rainfall event. Figure 2 presents the yearly averages for SPI.

To calculate the SPI index, we first aggregate weather data to the municipality-by-month-by-year level. These collapsed data contain total precipitation and average temperature for each municipality in a given month and year. We then define drought as equal to 1 if SPI is below -1 and 0 otherwise for a given month in each municipality.

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[11] Considering the small grid used, almost all municipalities (1,485 of an total of 1,794) have had points inside their limits. For those that have had not, we use the four closest points on the grid to the center of the municipality, using the linear distances from the municipality's centroid to each node as weights.

[12] See Mckee et al. (1993) for more details.

This definition is similar to the one employed by employed by Kaur (2013), Rocha and Soares (2015) and Shah and Steinberg (2017). Having defined a drought month, our final measure of exposure to droughts is computed as the number of months that each municipality faced a drought shock over the 12 months prior to PNAD survey month. Figure 3 reports the time series for the drought variable, indicating the percentage of municipalities with SPI below -1. One can see that there are periods with no municipality facing a drought, and others with drought heating 90 percent of the municipalities. This shows how the intensity of negative shocks varies geographically within a given month.

Our second measure of drought shock is the longest consecutive dry days (CDD). Consecutive dry days is the greatest number of consecutive days for the period over the twelve months prior the survey, with daily precipitation amount below 1 mm. Figure 4 portrays the CDD in 1979 and 2016, respectively, for entire Northeastern Brazil. It shows that drought shocks at a point in time are not homogenous throughout the Northeastern region. Some areas may be suffering harsh rainfall conditions, spending more than three hundred days without rain, while others may not be.

2.4.3 Empirical strategy

To identify the impacts of weather shocks on rural household labor allocation, we estimate the following model:

$$H_{ijt} = \alpha + \beta_1 D_{jt} + \beta_2 X_i + \omega T_{jt} + \theta_j + \varphi_t + \varepsilon_{ijt} \tag{11}$$

where H_{ijt} is the labor outcome of interest for individual i, in municipality j and year t. The labor outcomes in this study are the number of jobs, ratio of farm work on the total worked and share of secondary job on the total of hours worked. We also consider these outcomes at the family level, since literature suggests that time allocation is as a household decision-making process rather than an individual one.[13] In particular, we consider a dummy indicating whether at least one household member is mainly employed in the non-farm market. D_{jt} is a drought shock measure (either the longest consecutive dry days in the 12 months prior to survey or the number of drought months

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[13] See, for example, Démurger et al. (2010); Ellis (2000); Janvry and Sadoulet (2001); Jonasson and Helfand (2010); Mishra and Goodwin (1997); Vergara et al. (2004).

in the same period) in year t and municipality j, which is our regressor of interest. We also control for householder's characteristics, just as gender, age, race and family size, by including the vector X_i. T_{jt} is the average temperature in the municipality j, on year t.[14]

The model includes municipality fixed effects (θ_j), which absorb any unobservable time invariant factors, including initial conditions and persistent municipality characteristics such as geography. Year fixed effects (φ_t) capture aggregate shocks impacting all Northeast region, including aggregated demand shocks, and regional policies and programs. Standard errors are clustered at the municipality level to account for serial correlation (Bertrand et al., 2004; Wooldridge, 2003).[15]

The parameter of interest β_1 measures the relationship between rainfall shocks and labor market outcomes. The identifying assumption underlying this statistical approach is that, conditional on municipality and year fixed effects, there are not determinants omitted of labor market outcomes correlated with the incidence of weather shocks. This seems plausible, given that the occurrence of extreme weather event at a given moment in time and place is unpredictable. Thus, our approach exploits arguably random fluctuations in rainfall from municipality-specific deviations in long-term rainfall after controlling for all seasonal factors and common shocks to all municipalities.

Although much of the variation in rainfall shocks over time within municipalities appears to be idiosyncratic, an identification issue could arise when following this specification. In particular, one may be concerned whether rural families respond migrating away from areas affected by extreme droughts. This would be problematic only if families that migrate in response to an extreme rainfall shock are different to families who do not. We address this issue in two way. First, we estimate the main regressions considering only families that live for at least five years in the current municipality. If regression results are similar to the ones derived from the baseline, we would be more confident that selective migration is unlikely to be a major issue. Second, we explore whether rainfall shocks are associated with predetermined individual or household characteristics. If different families are more likely to respond to rainfall shocks by migrating, one would expect to see significant effects of rainfall

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[14] We also control for bins of temperature in order to capture its nonlinear impacts. The results were the same, with temperature presenting no statistical significance.

[15] We also compute standard errors clustered at micro and macro-region level. Our results are robust to these standard errors.

shocks on predetermined characteristics. As we shown below, there is very little evidence that this is the case. Perhaps, this is not very surprisingly, given we are exploiting temporary deviations in rainfall from the historical norm. Migration is likely to be a more salient issue in the case of prolonged and permanent changes in rainfall.

2.5 Results

2.5.1 Effects of Drought Shocks on Rural Labor Allocation

We begin by examining the effects of drought shocks on income. Table 2 presents the results from estimating equation (11) for the primary and secondary income. All regressions results are based on a specification that adjust for municipality fixed effects, year fixed effects, a set of demographic characteristics of the household head. Sample sizes and R-squared's of the regressions are shown at the bottom of the table.

Column (1) explores the effects of extreme negative rainfall shocks on income derived from the main job. The results indicate that negative rainfall shocks are significantly associated with lower income derived from the main job, especially for those engaged with farm activities (column 2). This is what one would expect given that a considerable fraction of population in this region depends on farming and related agricultural activities for living. The fact that we observe significant reductions in income associated to extreme droughts is reassuring given that data on income are generally measured with substantial error in household surveys.

Column (3) investigates the effects on income derived from secondary jobs. The point estimate of the coefficient of interest is 0.0251 (standard error =0.0119), which statistically different from zero at the 5 percent level of significance. This estimate suggests that drought shocks are associated with higher income from secondary jobs. An increase of one drought per year implies an increase of 5.45 percent in the dependent variable. We interpret this result as preliminary evidence that rural families respond to negative rainfall shocks by increasing the supply of secondary jobs. In particular, this evidence is consistent with a mitigation response to reduced income from cash crops due to water scarcity.

Having established that drought shocks affect rural household income, we turn to the analysis of labor supply responses. We present estimates of equation (1) for a series of labor outcomes in Table 3.[16] Panel A presents the results from using drought shocks based on Standardized Precipitation Index (SPI) as our key independent variable. Instead, Panel B considers the longest consecutive dry days (CDD) as the rainfall shock measure. The first three columns show results for outcomes measures for the head of household, while the last three consider labor allocation outcomes measures at household level, which assume that labor allocation is a collective decision rather than an individual one. We present results with sampling weights, which ensure that our final follow-up database is representative of the entire initial study population, although the results are very similar when ignoring sampling weights.

Panel A, column (1) shows that there is a positive and statistically significant relationship between drought and the number of jobs. One more drought shock per year increases by 5.63 percent the likelihood of being employed in more than one work. Column (2) looks at the share of farm job as main source of income on the total hours worked. The results suggest that there is a statistically significant negative effect of drought on the supply of farm work. The coefficient on ratio of agricultural activities on the total work is -0.567. Relative to mean of 69, this suggests an small decrease of 0.82 percent. But note that the estimate in column (3) implies an effect that is an increase of 6.6 percent in the share of hours worked in secondary job, relative to mean of 4.7. These results may indicate that they offer more hours to non-farm activities not trough a large decrease of farm labor supply but increasing the total amount of worked hours. This way they can compensate the loss of farm income, and mitigate the shock.

Columns (4) to (6) explore the effects of drought shocks on the outcomes measures at the family level. In columns (4) and (5), the results are qualitatively similar to the ones observed at the head of household level. In column (6) we find a statistically insignificant relationship between drought shocks and the likelihood of at least one family member chooses non-farm as main occupation. In addition, the estimated coefficient are very small in magnitude. For instance, the estimated coefficient of interest is -0.0004, which means that, one more drought month implies an effect that is 0,10% of the average and 0,0005% of the standard deviation in our dependent variable. In Panel B, we present analogous results using CDD as the independent variable. The qualitative patterns are similar – indicating in this case that droughts shocks are

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[16] We also estimate regressions with the Terrestrial Air Temperature and Terrestrial Precipitation: 1900–2010 Gridded Monthly Time Series data base. The results are similar to ones find with ERA-Interim data base. Results available upon request, not shown here due to space limitation.

associated with rural households labor allocation – though the quantitative patterns are smaller. This difference might be due to rainfall characteristic, not normally distributed, and to the fact that SPI take this in account. Couttenier and Soubeyran (2013) have argued that several alternative measures of water stress are more efficient than the linear rainfall measure, and the SPI is one version of these measures. In light of the results from Table 3, we concentrate from now on, on the sum of drought months based on SPI as our preferred independent variable.

To assess potential heterogeneities of the effects of negative rainfall shocks we stratify the sample according to level of municipality GDP per capita. Exploring GDP is of special interest since it is a reasonable proxy for local development. It seems to reasonable to expect smaller impacts of extreme droughts on income and thus on time labor allocation in more developed areas where there are often higher access to credit markets, more formal social safety net programs, and where the capacity of adaptation is higher. Figure 5 portrays the coefficients, 90 and 95 percent confidence intervals from estimating equation (1) for both municipalities with low and high GDP per capita separately. If the municipality is characterized by GDP per capita at the 50th percentile of the Northeast GDP distribution it is considered a low GDP municipality, otherwise it is a high GDP one.

In Panel A, we regress labor outcomes of the head of household on drought shocks. One can see how the effect of negative rainfall shocks changes with income per capita. Lower income seems to be associated with higher impacts of rainfall variation. When we compare the likelihood of being employed in more than one work, one can observe a positive significant effect of drought shocks in municipalities with low GDP per capita and a statistically insignificant effect in those with high GDP. Individuals faced a drought shock in the previous year are 0.67 percentage point more likely to report having more than one job in the survey month, this is an increase of 5.58 percent from a mean of 0.12. While one more drought shock is not statistically significant to impact the share of farm work in high GDP municipalities, for those whom live with low income the point estimate of the coefficient of interest is -0.74 (standard error =0.29), which statistically different from zero at the 5 percent level of significance. The effect is larger in the share of secondary employment, increasing 7.5 per cent relative to a mean of 4.82. Panel B plots our baseline model for dependent variables at the family level. The qualitative and quantitative patterns are similar to ones find in Panel A. The results show that individuals with lower income are more vulnerable to weather shocks, and confirm the importance of adjustments in labor allocation to protect income due to decreasing in agricultural productivity.

The Northeastern presents vast variation in precipitation within year and between municipalities. One might expect there to be significant heterogeneity according to prevailing rainfall patterns. So we asses if drought shocks will have the same impacts on labor outcomes where rainfall levels are bellow 50th percentile of historical average (low rainfall patterns) as they would in areas that are above the median (high rainfall patterns). In Table 4, we regress labor outcomes on weather shock, as well as their interaction with a dummy indicating whether the municipality is low or high rainfall pattern. The interaction term indicates whether the effect of the drought shock depends on more general climate conditions. This is similar to the strategy employed in (Blakeslee and Fishman, 2014). The drought variable shows similar coefficients to those found before, and the drought shock interaction term are small and not significant. Thus, there is no evidence that the effect of negative rainfall shocks is mitigated by higher median rainfall levels.

2.5.2 Alternative rainfall measures

Considering the agricultural channel for the observed drought effects on labor allocation, we test if those shocks occurring during the pivotal monsoon season are more relevant in order to determine farmers job allocation response. To do this, we disaggregate our annual measure of drought shock into a specific period within the agricultural season and evaluate the impact of this shock on labor allocation. The period considered is the rainy season of current year *t* (February-April), which impact the production of the crops that are planted around December of year *t*-1 and January of year *t*.[17] In Appendix, table A1 reports the estimated impacts of monsoon drought shocks on labor outcomes. The results show that negative rainfall shocks during the rainy period reduce agricultural labor by 5.45 percent for the head of household and also increase by 34 percent his share on non-farm activities, relative to mean of 4.7. For family level, the results are pretty much the same, however, we do not find that the share of household farm employment is statistically sensitive to monsoon season

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[17] The most important crops (corn, rice, beans and sugarcane) are cultivated in this season.

shocks. Perhaps this happens because farmers may be compensating for a negative shock by increasing family labor and decreasing hired labor.

We also investigate if the consecutive occurrence of negative rainfall shocks has substantial impact on labor outcomes. We compute the longest consecutive number of months that each municipality faced a drought shock over the 12 months prior to PNAD survey month. Then, we create a dummy equal to one if the municipality faces two or more consecutive drought shocks and equal to zero otherwise. In appendix table A2, we follow our baseline model and regress labor outcomes on 2-or more consecutive drought shocks. The estimates reported in table A2 show that consecutive drought shocks have a significant effect on probability of being employed in more than one job (20 percent increase, relative to mean of the dependent variable). The impact is also statistically significant on the share of farm employment on the total of hours worked for the head of the family. The coefficient is -1.737, which relative to mean of 69, suggests a decrease of 2.49 percent on the ratio of agricultural activities. In column (3), the results show that consecutive drought shocks lead to a meaningful increase on hours spend at non-agricultural work (20 percent relative to its mean). The effect is similar to the outcomes at household level, for both variables (columns (4) and (5)).

One might expect that consecutive dry months have greater impact on labor outcomes than isolated drought shocks during the year. To verify this assumption, we compare the magnitude of the coefficients on the drought indicator in table 3, with the coefficients in appendix table A2. We find that a standard deviation increase in the number of drought months increases the likelihood of the head of household has more than one work by 8.5 percentage points. Whereas a standard deviation increase in two or more consecutive drought shocks enhances the probability of being employed in more than one job by 8.9. For one standard deviation in the number of drought months, the rate of farm work declines by 1.2 percentage points and the share of non-agricultural activities increases by 9.8 percentage points. When we look at a standard deviation increase in two or more consecutive dry months the values are basically the same (decrease of 1.1 percentage points on farm work and a raise of 9.2 percentage points on non-agricultural job). The magnitude is also similar when comparing the coefficients at family level.

2.5.3 Further Results

As mentioned before, we expect that much of the variation in rainfall shocks over time within municipalities is idiosyncratic, but an identification issue could arise whether rural families respond to rainfall shocks by migrating away from areas affected by extreme droughts. We assess on this issue in two way. First, in Appendix table A3 we replicate the baseline specification using only the rural households that live for at least five years in the current municipality. As can be seen from the table A3, the results are very similar to the baseline. We obtain the same order of magnitude for all estimated coefficients, as well as for standard errors. The only exception is share of hours spent in agricultural main job on the total, where the estimated coefficients of interest are not significant. However, this result may be due to low statistical power given the reduced sample size. Point estimates are fact very similar to the baselines and we cannot reject the null hypothesis that both estimates are the same.

Second, as discussed above, if different families are more likely to respond to rainfall shocks by migrating, one would expect to see significant effects of rainfall shocks on predetermined characteristics. To explore this issue, Table A4 estimates whether rainfall shocks are associated with any individual or household characteristics for all economically active population in our sample. All regressions results are based on a specification that adjust for municipality fixed effects, year fixed effects and are clustered at the municipality level. Columns (1) to (3) assess estimates of the effect of rainfall negative shocks on the head of household characteristics such as age, gender and education. Column (4) shows estimates for family size as dependent variable. Out of four estimated coefficients of interest, none is statistically significant. Thus, there is little evidence that our baseline results are in fact driven by migration.

Rainfall variation across space and time should generate corresponding variation in agricultural output and thus should mainly have a bigger effect in rural areas rather than urban. To assess if this occur in Northeastern Brazil, we examine the effect of drought shocks on labor outcomes of urban households. Table A5 presents the estimates for this subsample. As can be seen from the table, there is no significant effect of negative rainfall shocks on urban labor outcomes; most effects are concentrated in rural areas.

2.6 Concluding Remarks

It is already well documented in the literature the acute vulnerability of developing countries to extreme weather events. Water scarcity is a major problem for a large fraction of the rural population in these countries. Climate change is likely to make it an even more recurrent phenomenon in the coming decades. Considering the economic situation of most rural households in developing countries, adaptation will play a limited role in mitigating the impacts of climate change on agricultural production. Thus, this paper investigates the effects of drought shocks on rural household non-agricultural labor supply.

Reducing the variability of agricultural income streams is of paramount importance to improve welfare of rural dwellers. Given the constraints faced in the insurance and credit markets by most rural families in developing countries, labor reallocation can be one of the main channels by which poor rural households mitigate negative rainfall shocks. Engaging in non-farm labor market might help households to smooth consumption.

The strategy outlined here presents evidence of a relationship between negative rainfall events and labor time reallocation. We find that drought shocks are significantly associated with lower income derived from the main job. This is especially true when we consider income derived from farm activities. Moreover, higher incidence of drought shocks are significantly associated with increased income from secondary jobs. Our results show that droughts affect negatively hours spent on farm work, whereas lead to increased supply of non-agricultural job. One can also observe stronger effects among families residing in municipalities with lower per capita income. Taken together, our findings suggest that rural families adjust labor supply as an autonomous strategy in order to mitigate the income effects of water scarcity.

Table 1. Summary statistics: rural Northeastern Brazil, 2001-2014.

	Mean	Std. deviation	Min	Max	Number of observations
Household characteristics:					
Gender	0.52	0.50	0	1	145,425
Age	33.90	18.37	10	70	145,425
Years of studies	4.81	3.62	1	17	145,425
Number of household members	4.46	2.08	1	17	145,425
Employment characteristics:					
More than one job	0.07	0.25	0	1	92,006
Farm work as main %	0.73	0.44	0	1	92,006
Share of farm job	70.43	44.38	0	100	92,006
Share of secondary job	2.82	11	0	97.82	92,006
Non-farm (likelihood)	0.42	0.49	0	1	92,006
Agriculture wage job	0.22	0.41	0	1	65,790
Agriculture self-employed	0.28	0.45	0	1	65,790
Agriculture employer	0.02	0.13	0	1	65,790
Agriculture unpaid	0.25	0.43	0	1	65,790
Agriculture own consumption	0.24	0.42	0	1	65,790
Non-farm wage job	0.63	0.48	0	1	26,216
Non-farm self-employed	0.27	0.44	0	1	26,216
Non-farm employer	0.01	0.12	0	1	26,216
Non-farm unpaid	0.05	0.23	0	1	26,216

Notes: This table shows summary statistics from PNAD database.

Table 2: Effect of drought shocks on rural household income

	(1) Main Income (log)	(2) Main Income Agr. (log)	(3) Secondary Income (log)
Drought (SPI)	-0.0141 [0.0081]*	-0.0193 [0.0097]**	0.0251 [0.0119]**
Mean of dep. variable	5.4	5.17	0.46
Basic controls	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes
N	39720	21937	39720
R-sq	0.303	0.304	0.111

Notes: All outcomes are measured in log. Each coefficient is from a different regression. All regressions control for municipality and year fixed effects. We exclude observations in the top percentile of total income. Basic controls include gender, age, race and family size. Temperature control includes the average temperature at municipality level. The number of observations differs in column (2) because it only considers households with agricultural job as main source of income. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Effect of drought shocks on rural household labor outcomes

	(1) Number of Jobs	(2) Share of farm employement	(3) Share of secondary employment	(4) Share of household farm employment	(5) Share of household secondary employment	(6) Non-farm employment
Panel A						
Drought (SPI)	0.0062	-0.5673	0.284	-0.4492	0.2152	-0.0004
	[0.0031]*	[0.2570]**	[0.1248]**	[0.2709]*	[0.0990]**	[0.0029]
Panel B						
CDD	0.0003	-0.0267	0.01	-0.0291	0.009	0.0002
	[0.0001]*	[0.0179]	[0.0057]*	[0.0184]	[0.0046]*	[0.0002]
Mean of dep. var.	0.11	69.5	4.37	65.9	3.47	0.37
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	40006	40006	40006	42952	42952	47295
R-sq	0.129	0.177	0.121	0.182	0.122	0.116

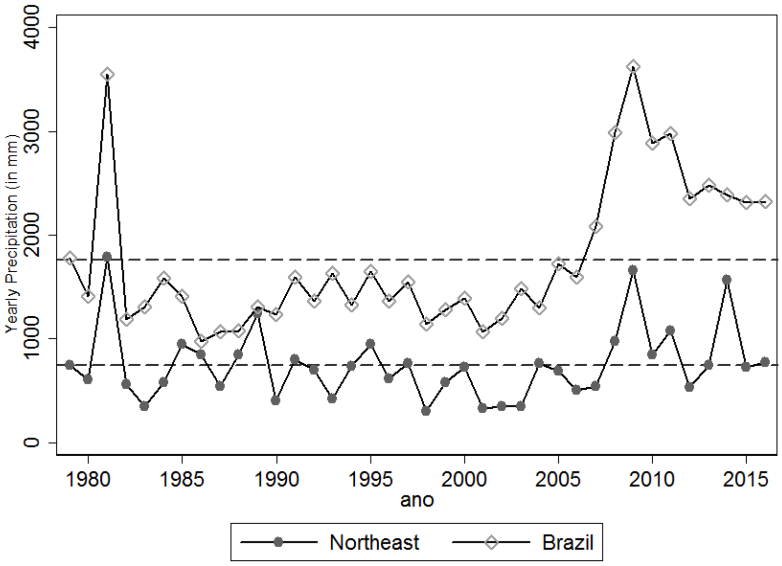
Notes: Each coefficient is from a different regression. Each panel corresponds to a different independent variable. All regressions control for municipality and year fixed effects. Columns (1) to (3) measure the outcomes at the head of household level, while in columns (4) to (6) the outcomes are at the household level. Each dependent variable in columns (2) to (5) refers to the share of the mentioned work on the total of hours worked. Basic controls include gender, age, race and family size. Temperature control includes the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4. Effect of drought shocks on rural household labor outcomes by rainfall level

	(1) Number of Jobs	(2) Share of farm employement	(3) Share of secondary employment	(4) Share of household farm employment	(5) Share of household secondary employment	(6) Non-farm employment
Drought (SPI)	0.0075	-0.546	0.3448	-0.5214	0.2698	-0.0004
	[0.0038]**	[0.3033]*	[0.1536]**	[0.3263]	[0.1276]**	[0.0033]
Drought x low rainfall	-0.003	-0.0465	-0.1331	0.1569	-0.1185	-0.0001
	[0.0031]	[0.2889]	[0.1353]	[0.3074]	[0.1025]	[0.0031]
Mean of dep. var.	0.11	69.5	4.37	65.9	3.47	0.37
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
N	40006	40006	40006	42952	42952	47295
R-sq	0.129	0.177	0.121	0.182	0.122	0.116

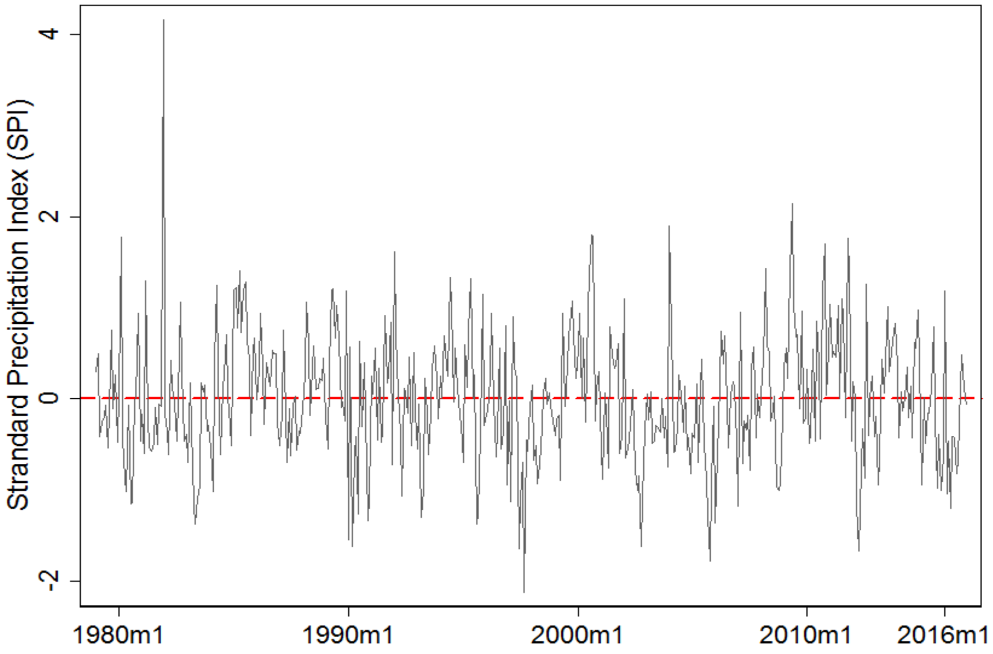
Notes: Each coefficient is from a different regression. All regressions control for municipality and year fixed effects. Columns (1) to (3) measure the outcomes at the head of household level, while in columns (4) to (6) the outcomes are at the household level. Each dependent variable in columns (2) to (5) refers to the share of the mentioned work on the total of hours worked. Basic controls include gender, age, race and family size. Temperature control includes the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * p < 0.10, ** p < 0.05, *** p < 0.01.

Figure1. Yearly precipitation in Northeastern Brazil and in the rest of the country



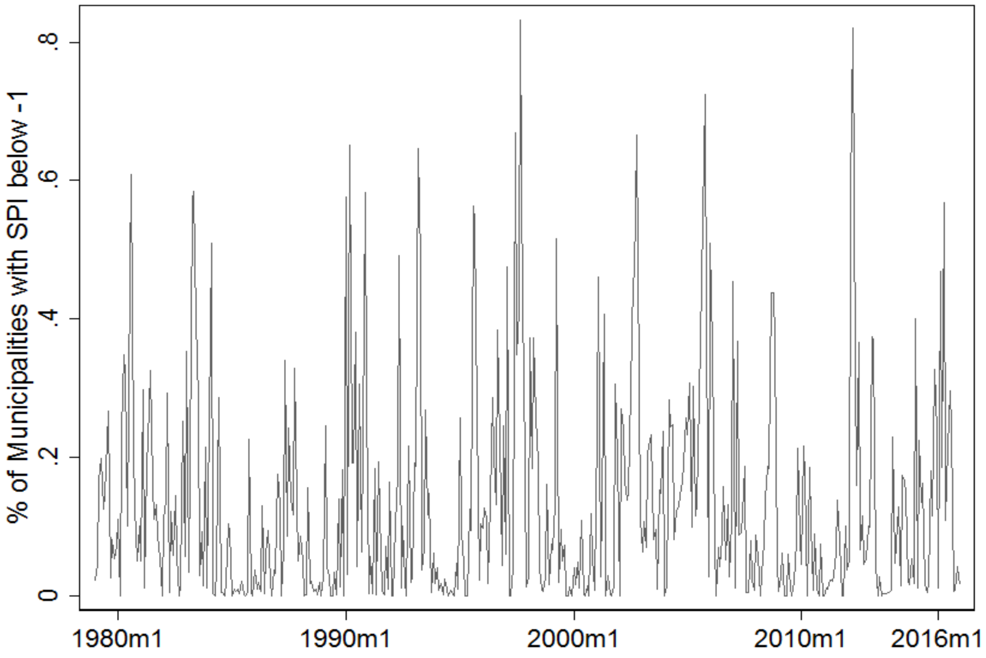
Notes: Author's calculation based on data from ERA-Interim, 1979-2016.

Figure 2. Standard Precipitation Index (SPI) yearly average



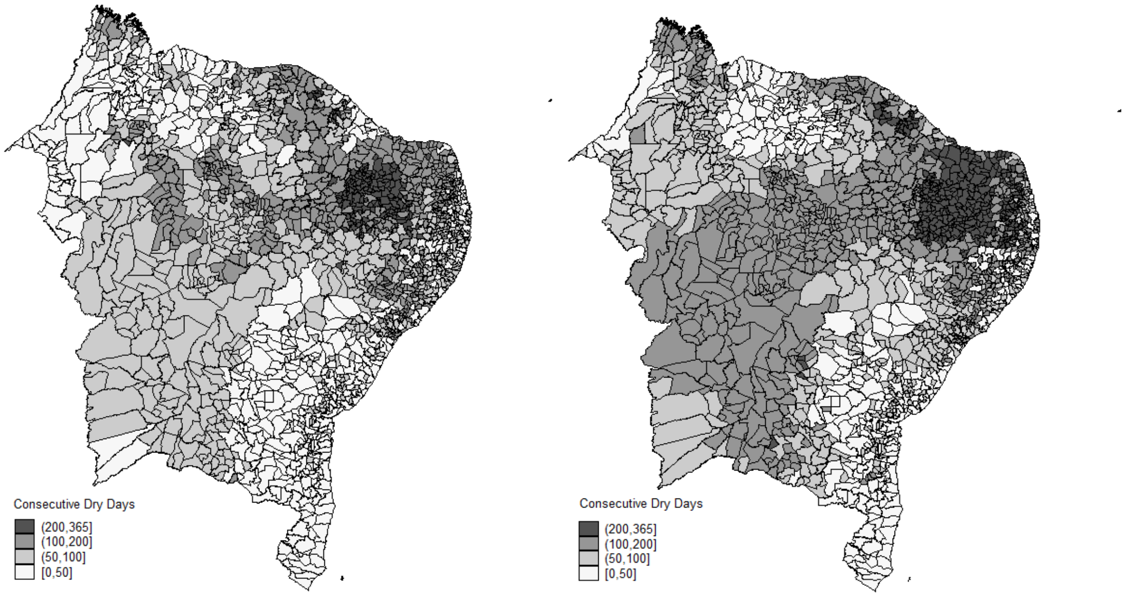
Notes: Municipality averages. Author's calculation based on data from ERA-Interim, 1979-2016.

Figure 3. Drought (SPI) time series



Notes: Author's calculation based on data from ERA-Interim, 1979-2016.

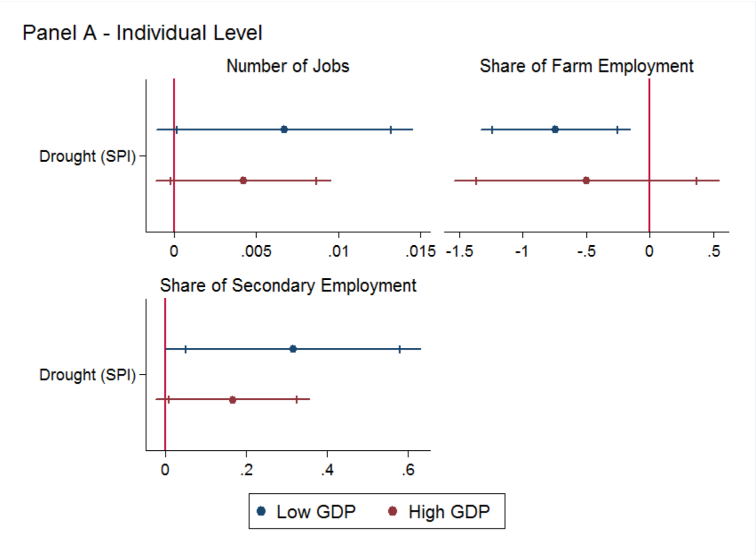
Figure 4. Consecutive Dry Days, Northeastern Brazil - 1979 and 2016.

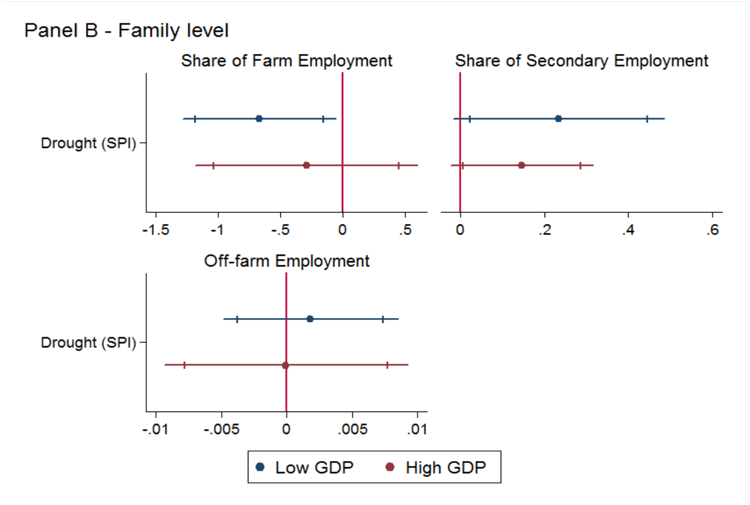


a) 1979 b) 2016

Source: ERA-Interim database.

Figure 5. Effects of drought shocks on labor outcomes by GDP per capita level





Notes: This is an event-study created by regressing labor outcomes on drought shocks and on a set of controls. The controls include municipality and year fixed effects, individual and household characteristics such as gender, age, race and family size. Temperature control include the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level.

APPENDIX A

Table A1. Effect of drought shocks on rural household labor outcomes

	(1) Number of Jobs	(2) Share of farm employement	(3) Share of secondary employment	(4) Share of household farm employment	(5) Share of household secondary employment	(6) Non-farm employment
Drought shock	0.0303	-3.7929	1.5246	-2.2129	1.21	0.0093
(SPI) Feb/April	[0.0211]	[1.4891]**	[0.8157]*	[1.5053]	[0.6598]*	[0.0172]
Mean of dep. Var	0.11	69.5	4.37	65.9	3.47	0.37
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
N	40006	40006	40006	42952	42952	47295
R-sq	0.129	0.176	0.121	0.181	0.123	0.116

Notes: Each coefficient is from a different regression. All regressions control for municipality and year fixed effects. Columns (1) to (3) measure the outcomes at the head of household level, while in columns (4) to (6) the outcomes are at the household level. Each dependent variable in columns (2) to (5) refers to the share of the mentioned work on the total of hours worked. Basic controls include gender, age, race and family size. Temperature control includes the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A2. Effect of consecutive drought shocks on rural household labor outcomes

	(1) Number of Jobs	(2) Share of farm employement	(3) Share of secondary employment	(4) Share of household farm employment	(5) Share of household secondary employment	(6) Non-farm employment
2-or more consecutive drought shock	0.0218	-1.7375	0.9026	-1.582	0.6522	0.0028
	[0.0079]***	[0.8566]**	[0.3240]***	[0.8891]*	[0.2599]**	[0.0086]
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
N	40006	40006	40006	42952	42952	47295
R-sq	0.129	0.177	0.121	0.182	0.122	0.116

Notes: Each coefficient is from a different regression. All regressions control for municipality and year fixed effects. Columns (1) to (3) measure the outcomes at the head of household level, while in columns (4) to (6) the outcomes are at the household level. Each dependent variable in columns (2) to (5) refers to the share of the mentioned work on the total of hours worked. Basic controls include gender, age, race and family size. Temperature control includes the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A3. Effect of drought shocks on labor outcomes for rural household living at least five years in currently municipality

	(1) Number of Jobs	(2) Share of farm employement	(3) Share of secondary employment	(4) Share of household farm employment	(5) Share of household secondary employment	(6) Non-farm employment
Drought (SPI)	0.0068 [0.0031]**	-0.2467 [0.3763]	0.2926 [0.1189]**	-0.294 [0.4557]	0.2254 [0.0921]**	-0.0029 [0.0046]
Mean of dep. var.	0.11	65.4	4.55	61.67	3.62	0.41
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
N	11048	11048	11048	12012	12012	13166
R-sq	0.146	0.248	0.136	0.251	0.137	0.158

Notes: Each coefficient is from a different regression. All regressions control for municipality and year fixed effects. Columns (1) to (3) measure the outcomes at the head of household level, while in columns (4) to (6) the outcomes are at the household level. Each dependent variable in columns (2) to (5) refers to the share of the mentioned work on the total of hours worked. Basic controls include gender, age, race and family size. Temperature control includes the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A4. Effect of drought shocks on rural households predetermined characteristics

	(1) Age	(2) Gender	(3) Education	(4) Family Size
Drought (SPI)	-0.0227 [0.0488]	-0.0024 [0.0029]	-0.0032 [0.0155]	-0.0164 [0.0135]
Temperature control	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	92006	92006	92006	92006
R-sq	0.017	0.008	0.084	0.061

Notes: Each coefficient is from a different regression. All regressions control for municipality and year fixed effects. Temperature control includes the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A5. Effect of drought shocks on urban households

	(1) Number of Jobs	(2) Share of farm employement	(3) Share of secondary employment	(4) Share of household farm employment	(5) Share of household secondary employment	(6) Non-farm employment
Drought (SPI)	0.001 [0.0009]	-0.043 [0.1839]	0.0318 [0.0372]	-0.0258 [0.1675]	0.0242 [0.0285]	0.0016 [0.0015]
Mean of dep. Var	0.06	8.29	2.31	6.92	2.06	0.81
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	123292	123292	123292	145416	145416	170024
R-sq	0.023	0.149	0.02	0.123	0.02	0.122

Notes: Each coefficient is from a different regression. All regressions control for municipality and year fixed effects. Columns (1) to (3) measure the outcomes at the head of household level, while in columns (4) to (6) the outcomes are at the household level. Each dependent variable in columns (2) to (5) refers to the share of the mentioned work on the total of hours worked. Basic controls include gender, age, race and family size. Temperature control includes the average temperature at municipality level. Robust standard errors (reported in brackets) are clustered at the municipality level. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3 Drought Shocks and School Performance in Brazilian Rural Schools[18]

Abstract

This paper aims at assessing the impact of drought shocks on the performance of students enrolled in Brazilian Northeastern rural schools. In particular, we assess how droughts may affect student achievement as measured by Prova Brasil, a national standardized exam. Our results show that drought shocks are associated to lower scores on both mathematics and Portuguese exams. By investigating the potential transmission mechanisms underlying the relationship between weather shocks and school performance, we observe that exposure to a negative rainfall shock increase the hospitalization rate among children. In addition to that, severe droughts are also associated to higher probability of child work. Both health and job-market related effects may be associated to lower school attendance and therefore contribute to poor student achievement. Finally, our results provide suggestive evidence that drought tends to be more harmful to children that study in schools with no cistern or other water storage devices. Therefore, investing in basic infrastructure like cisterns is a low-cost policy strategy that may offset the negative the effects of droughts and considerably improve school performance in Brazilian semiarid rural areas.

Keywords: extreme weather events; droughts; school performance.

3.1 Introduction

A consolidated body of research suggests that the risk of extreme events will rise with the increasing global average temperature (Coates et al., 2014; IPCC, 2013; Kreft et al., 2014; Marengo, 2009). Further, higher temperature variability could amplify the magnitude of climate shocks. Changes in the frequency and level of these events may cause severe damages in regions that are vulnerable to harsh climate scenarios (Hallegatte et al., 2007). In particular, weather shocks can have serious welfare

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consequences in both the short and the long runs if it affects education production, children's schooling, and accumulation of human capital.

This study examines how weather shocks, more specifically drought shocks, affect educational outcomes of children attending schools in rural Northeastern Brazil. In particular, we assess how droughts may affect students achievement measured by Prova Brasil scores in math and language, a national standardized exam. We believe that focus on Northeastern Brazil provide a compelling setting to investigate the potential impacts of extreme weather events. This is the driest Brazilian region and it has long been subject to harsh climatic conditions, with recurrent events of drought and rising temperatures (Ab'Sáber, 1999; Marengo, 2009). Brazilian Northeast is one of the most populated semi-arid area of the world, where more than 23.5 million inhabitants (12% of the Brazilian population) are living (Ab'Sáber, 1999; Correia et al., 2011; Insa/MCTI, 2014). Moreover, there is plenty of anecdotal evidence showing that schools in rural semiarid areas are forced to temporally cease activities due to lack of water storage infrastructure. It is estimated that approximately 40.5% of all public schools have no water storage devices such as water tanks and cisterns (Cipola, 1998). Such disruptions may hamper school attendance and therefore contribute to poor students achievement. Furthermore, this region has limited social safety nets, consequently households face credit constraints and they do not have access to the portfolio of adaptation strategies available in more developed regions.

We hypothesize that drought shocks have negative impact on students achievement. There are different mechanisms through which climate change may affect child schooling. One can have a direct effect, known as "thermal stress", which can cause cognitive impairment, discomfort and fatigue (Zivin et al., 2018; Zivin and Shrader, 2016). Another potential mechanism is school supply. Drought shocks may lead schools to close or cease activities due to lack of water for consumption and hygiene, decreasing the educational provision and making impossible for the children attend school. As an attempt to prevent this, the governors should investing in basic infrastructure like cisterns. Such improvement could maintain schools open, enriches learning and nurturing the environment of disadvantaged children.

Second, we assess whether the scarcity of water could drive children to become sick. Previous studies have documented the relationship between weather shocks and health outcomes. Heat waves and cold waves, for instance, could directly affect cardiovascular stress, respiratory diseases, and cerebrovascular diseases (Deschênes and

Moretti, 2009). Also, indirect impacts could be associated to scarcity and lack of adequate water supply, leading to disruption on agricultural production, reducing food availability and increasing malnutrition (Rocha and Soares, 2015). The lack of drinkable water increases the risk of infectious diseases, such as diarrheal diseases. One estimated 94% of the diarrheal disease burden in developing countries are associated with risk factors such as unsafe drinking water, lack of sanitation and poor hygiene (WHO, 2008). Furthermore, extreme events could contribute to the persistence of infectious endemic diseases, such as dengue and leptospirosis, enhancing the region's vulnerability (Souza et al., 2013). If drought shocks lead to higher incidence of particular diseases, this could reduce school attendance, hindering students learning and delaying their progress in school.

As the last mechanism, we investigate whether the drought shocks are associated with increased child labor. According to the luxury axiom (Basu and Van, 1999), the reduction in the household income should increase child labor. A negative rainfall shock could affect agricultural production leading to a drop in family income. As a consequence, parents may need to increase their use of child labor, typically by having children substitute adult labor in household chores or farm work, for instance. On the other hand, the drought shock could reduce the opportunity cost of studying. In this case, parents may reallocate the child's time endowment to human capital accumulation rather than to labor market activities. Whether the income or substitution effect prevails is an empirical question.

Identification requires that weather shocks, conditional on municipality and year fixed-effects, are not correlated with other latent determinants of students achievement. We argue that this is plausible insofar as parents are unlikely to anticipate precisely a rainfall shock at a given moment in time and place. One potentially important concern is that if for some reason the drought shocks lead only the low-performing students to take the exam, the estimated effect of drought on achievement at the end of the year may not capture the causal impact of negative shocks on learning. We address this issue and there is very little evidence that this is the case. We make use of high frequency gridded information on precipitation and temperature to construct a municipality-by-year weather dataset which then is combined with Prova Brasil microdata and Educational Census by using place and exam month.

We focus our analysis on young students (fifth and ninth graders) from schools located in rural areas. We provide evidence for both grades that students from schools that are exposed to drought shocks perform worse on standardized math and Portuguese exams. A one standard deviation increases in the number of drought months per academic year leads to a reduction of 0.39 and 0.27 percentage points in math and Portuguese scores, respectively, for fifth graders. For the ninth grade students, the effect of drought on math and language achievement are -0.29 and -0.24 percentage points, respectively. Our results also suggest that the shock effect seem to be more detrimental for girls and those students with lower educated mothers. We also find suggestive evidence that drought tends to be more harmful to children that study in schools with no cistern or other water storage device. Therefore, investing in basic infrastructure is a low-cost policy strategy in rural areas that may considerably improve school performance. The results do not seem to be driven by student selection and are robust to placebo tests. In particular, we find no association between drought that occurs after the exam and performance at the exam.

By investigating the potential transmission mechanisms linking weather shocks to school performance, we find that the impact of negative rainfall shocks on child health is an important mechanism driving our results. Exposure to a drought shock increase the hospitalization rate among children. For instance, the estimate suggests that one more negative shock per year increases by 2,6 per cent the hospitalization rate by infectious and parasitic diseases per 1,000 inhabitants, relative to mean of 0.46. In addition to that, one more drought shock per year is associated to a 4.24% increase in the likelihood of a child being employed. Both health and job-market related effects may be associated to lower school attendance and therefore contribute to poor student achievements.

Recent papers have addressed the relationship between general shocks (such as accidental crop loss, reduction in crop prices, economic crises) and children's schooling. Kruger et al., (2012) find that exogenous shocks to local economic activity are associated with increased child labor and reduced schooling, in Brazil. They also stress out that these shocks have even more strength in children living in rural areas. Duryea et al., (2007) also analyze the impact of household economic shocks on schooling and employment transitions of young people living in Brazilian metropolitan areas. They show that an unemployment shock significantly increases the probability that a child enters the labor force, drops out of school, and fails to advance in school. Guarcello et al., (2003) observe a similar response for households in Guatemala, and also point out that child labor has a high degree of persistence because children who are sent to work are subsequently less likely to return to school. de Janvry et al., (2006) show that economic shocks have large effects in taking children out of school and induce they to increase their work participation in Mexico. They also find that the conditional transfers help protect enrollment, but do not refrain parents from increasing child work in response to shocks.

Our results contribute to an emerging literature that documents the relationship between specific weather-related events and educational outcomes. Boutin, (2014) finds no relationship between climate change and school attendance in Malawi. However, she observe that climate vulnerability negatively affects child labor incidence and intensity, while has no significant impact on household chores. Shah and Steinberg, (2017) investigate positive rainfall shocks in India and show that going from regular rainfall to a positive rainfall shock increases wages by 2%, decreases school attendance by 2 percentage points, and decrease the probability that a child is enrolled in school by 1 percentage point. We contribute to this literature by documenting that changes in health conditions could be an important mechanism through which rainfall shocks affect human capital.

The rest of the study is organized as follows. The next Section presents the conceptual issues. Section 3.3 describes database construction and the econometric specification. Section 3.4 presents the results on the relationship between droughts and school performance, the robustness checks, as well as the discussion on the potential transmission mechanism underlying this relationship. Finally, Section 3.5 summarizes the main conclusions and presents some policy recommendations.

3.2 Conceptual issues

The modeling of the cognitive achievement production function is often based on the idea that knowledge acquisition is a cumulative process by which current and past family and school inputs are combined with child's innate characteristics to produce a cognitive outcome (Todd and Wolpin, 2007, 2003). Cognitive achievement production functions typically consider achievement for child i residing in household j at age a, S_{ija} to be a function of an initial child's endowed mental capacity μ_{ij0}, as well as the history of family and school inputs, respectively, $F_1, ..., F_a$, $T_1, ..., T_a$, and exogenous environmental factors Z. Other cognitive achievement determinant of importance includes student health H. Following Todd and Wolpin (2007, 2003) a model of education production function can be expressed as:

$$S_{ija} = s(\mu_{ij0}, F_1, \ldots, F_a, T_1, \ldots, T_a, Z, H) \quad (12)$$

Drought shocks may have direct effects on learning through heat stress that may affects physiology in ways that can be detrimental to cognitive performance or reduced expected productivity (Park, 2018; Wargocki and Wyon, 2007; Zivin et al., 2018; Zivin and Shrader, 2016). We also hypothesize that the shocks may have disruptive effects on school routine. As supported by several reports in the media, extreme weather events can affect the school routine by causing temporary school closings and interruption of classes, due to lack of water for consumption and hygiene. As a result, student achievement could suffer as classes are discontinued (Grogger, 1997).

Poor health in childhood may also be an important mechanism through which water scarcity affects education; thus, "if poor health among school aged children has an effect on the acquisition of skills, it is more likely to come through impairing children's ability to learn while they are in school" (Currie, 2009). The literature suggests that in developing countries children who are in poor health tend to have lower educational attainments (Bleakley, 2007; Miguel and Kremer, 2004). Bleakley (2007) provides evidence that the eradication of hookworm in the American South had a significant effect on school enrollment, school attendance, and that in addition, literacy increased markedly.

In this paper, we do not attempt to estimate tightly the education production function specified in (12) once that initial endowments are not observed and we also do not observe past family and school inputs and test scores. Instead, to arrive at an empirically implementable specification, we propose a reduced-form strategy that relies on the evidence that variation in rainfall levels within municipalities over time is orthogonal to any other past and contemporaneous latent determinants of learning. Our empirical strategy is detailed in next section.

3.3 Methods

3.3.1 Educational data

To assess the impact of drought shocks on student achievement, this paper uses two different databases, Prova Brasil microdata and Educational Census, both developed and coordinated by Instituto Anísio Teixeira (Inep). These datasets provide information at the level of the school, the teacher, and the student. The Prova Brasil is a national standardized exam applied each two years to all fifth and ninth graders students. The student scores on exam are our main outcome variables. All students from public schools with at least twenty students enrolled in each grade are required to take this test. The Prova Brasil exam is applied at the same day in all schools in November, and it is composed of two parts, language (Portuguese) and math. The fifth grade students have to answer twenty-two questions, while the ninth grade ones need to answer twenty-six questions. The score is calculated separated for language and math, and only for those students who answered more than 3 questions in each portion. In addition, students also respond to a socioeconomic survey, and teachers and principals provide information on their experience and school routine.

The exam has been applied since 1995, but it was only in 2007 that rural schools were included. We restrict our analysis to the period between 2011 and 2015, when it is possible to compare the scores, and to schools situated in rural areas, because rural population is more likely to suffer insults due to drought shocks than urban ones. Before 2010, elementary School in Brazil had two possible systems, but after this year, all Brazilian schools have implemented the Law nº 11,274/2006. This law institutes the nine years primary School, with the compulsory inclusion of six-year-old instead of seven-year-old children, and it also reorganized school curriculum.[19] In panel A of table 5, we report summary statistics for fifth graders who take the Prova Brasil exam, while panel B provides statistics for ninth grade students. For fifth grade, our analysis sample consists of 350,838 students from 6,098 elementary schools. The numbers for ninth grade are slightly smaller, comprising 253,946 students from 3,977 primary schools.

Although Prova Brasil database provides some information at school level, it does not contain details on schools or teachers. We thus use the Educational Census to complete the information about school infrastructure and teachers' characteristics. The

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[19] We also thought to estimate separately for the period 2007-2009, but it is not possible considering that the number of schools that took the exam in 2007 was too low.

dataset is annual and every school receives an unique identification code. Since 2009, this number has been the same to identify the school on both Educational Census and Prova Brasil, which allows us to merge them and to link teachers to schools that took the exam over time. Panel C of table 5 reports the summary statistics for the teachers in our sample.

3.3.2 Weather data

We use the latest global atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), the ERA-Interim data, to build a series for temperature and precipitation. ERA-Interim provides worldwide estimates for weather conditions at the 0.1 × 0.1 degree latitude/longitude grid and covers the period from 1 January 1979 onwards. To construct a municipality-by-month of weather panel we use a geo-spatial software to aggregate the data to the municipality level and calculate an average of the points located inside the municipality limits. Considering the small grid of the dataset, almost all municipalities (1,485 of an total of 1,794) have had points inside their limits. For those that have had not, we employ the same approach as (Rocha and Soares, 2015). We compute the centroid for each of the 309 remaining municipalities and then locate the four closest nodes to build a monthly series as the weighted average of estimates related to these four nodes. We use the inverse of the distance to each node as weight. We make use of this data to construct our measure of drought shock.

An episode of drought is defined when the following condition holds

$$r_{jm} < \left(\overline{r_j} - r_j^{SD}\right) \tag{13}$$

where r_{jm} indicates the monthly rainfall in municipality j and calendar month m. $\overline{r_j}$ is the average historical monthly rainfall in municipality j, and r_j^{SD} is the historical monthly standard deviation of rainfall for municipality j, both calculated over the 1979-2016 period. Thus, an episode of drought occurs always that rainfall in a given month was more than one standard deviation below the historical average for municipality j. Then our measure of drought shock is computed as the fraction of drought months occurring in the current year up to the month when Prova Brasil exam takes place. For example, if the exam was made in November 2005, then the drought shock is computed as the share of drought months between January and November 2005.

3.2.3 Other data

To explore potential mechanisms, we use data from the Brazilian Household Survey (PNAD). The PNAD is nationally and regionally representative, and contains detailed information on socio-economic and demographic characteristics. We use data from 2001 to 2014, for which consistent sampling methodologies and questionnaires were maintained. The input we examine is child labor, the PNAD asks whether children from age 10 work or not, thus we restrict our analysis to children ages 10-16, to keep the sample similar to the students who take the Prova Brasil exam. On one hand, facing a negative rainfall shock could decrease the opportunity cost of studying. In this case, parents may reallocate the child's time endowment to human capital accumulation rather than to labor market activities. On the other hand, due to a drop in income, parents may need to increase their use of child labor, typically by having children substitute adult labor in household activities or farm work, preventing children from attending school; or yet, children could work off parents establishments to improve family income. Thus, to test in which direction this mechanism would be acting, we exploit whether water scarcity affect the likelihood of a child being or not employed.

We also construct a dataset on infant health by using microdata from the Brazilian National System of Hospital Information (Datasus/SIH). The database records every hospitalization by hospital units participating in the Brazilian Health Unique System (SUS)[20] and provides information on, among other things, the municipality of residence, years of age and sex. Thus, we are able to build a municipality-by-month on hospitalization panel over the 2008-2016 period. The region of interest is Northeastern Brazil and we restrict our sample to children aged 9 to 15, because our main sample on educational data. The municipality of reference in the panel is the municipality where the child lives, so that we are able to capture the shock that she was subject to.

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[20] This involves all public hospitals and some private hospitals which are associated to SUS.

3.3.4 Variation in drought shocks and outcomes

Because the statistical approach of this study relies on within-municipality variation, we confirm that there is in fact substantial within-municipality variability in the data for identification. To evaluate the within-municipality variability in the data more formally, we regress drought measure on a full set of municipality and year fixed effects. The residual variation in this regression is a direct measure of within-municipality variability. Thus, the further R-squared is from 1 the greater is the within-municipality variation. We find that about 77 percent of the total variation in our drought shock exposure cannot be explained by this set of fixed effects, a substantial within-municipality variation.

We also evaluate the within-municipality variability in the main outcomes of interest, language and math scores for fifth and ninth grade students. For fifth graders, we find that a substantial portion of the total variation in math and language scores is due to within-municipality differences, about 87 and 88 percent, respectively. For ninth grade students, municipality and year fixed effects cannot explain 93 percent of the variation in math score, and the value does not change when we look to language score variation. In summary, this analysis shows that there is meaningful variation the data for identification.

3.3.5 Empirical Strategy

In order to identify the impacts of drought shocks on student achievement, we estimate the following regression

$$S_{ihmt} = \propto + \beta_1 D_{mt} + \beta_2 X_i + \beta_3 Y_h + \omega T_{mt} + \theta_m + \varphi_t + \varepsilon_{ihmt} \qquad (14)$$

where S_{ihmt} is the learning outcome of student *i*, enrolled at school *h* in municipality *m* and surveyed in year *t*. Learning is measured by Prova Brasil scores in math and language. The variable of interest is D_{mt}, that is the number of drought months in *m* from January to November (the month in which the exam is taken) of the current year, *t*. The β_1 is the key parameter of interest, it captures the effect of current-year droughts on math and language test scores. We also control for child socioeconomic characteristics, by including X_i, just as students' gender, age fixed effects, mother's education, race, a dummy for whether the student has ever dropped out in previous years and a dummy for whether the student has ever repeated a grade. School's characteristics are also accounted by including the vector Y_h (whether the school has water storage facilities, computer lab, free lunch and offers free transport for students). These controls were add in order to absorb confounding effects driven by within-school heterogeneity. The term T_{mt} is the average temperature in the municipality m, on year of survey t. It allows us controlling for other climatic variations possibly correlated with droughts also occurring at the municipality level.

The term θ_m is a vector of municipality fixed effects, which absorb any unobservable time invariant factors at the municipality level, including initial conditions and persistent municipality characteristics such as geography. The model also includes year of survey fixed effects (φ_t), that capture aggregate shocks impacting all Northeast region, including demand shocks, labor market conditions and educational policies and programs. This specification allows us to compare children from the same municipality who take the Prova Brasil exam in different years. Standard errors are clustered at the municipality level to account for serial correlation.

The identifying assumption underlying this statistical approach is that, conditional on municipality and year fixed effects, there are not omitted determinants of children's education correlated with the incidence of weather shocks. This seems plausible, given that the occurrence of extreme weather event at a given moment in time and place is unpredictable. Thus, our approach exploits arguably random fluctuations in rainfall from municipality-specific deviations in long-term rainfall after controlling for all seasonal factors and common shocks to all municipalities. If this assumption holds, we are able to identify the causal impact of drought shocks on student achievement.

Although much of the variation in rainfall shocks over time within municipalities appears to be idiosyncratic, an identification issue could arise when following this specification. A potential problem in our analysis concerns student selection at the Prova Brasil exam. For instance, if for some reason the drought shocks lead only the low-performing students to take the exam, the estimated effect of drought on achievement at the end of the year may capture the worsening of the pool of students rather than the causal impact of shocks on learning. We address this issue in section 3.4 and there is very little evidence that this is the case.

3.4 Results

3.4.1 Impact on student achievement

In table 6 we report the results from equation (14) estimating the impact of contemporaneous drought shocks on students achievement. Panel A displays the results for fifth graders. In columns 1 and 3 we estimate our simplest specification, which include only year and municipality fixed effects. Columns 2 and 4 present our full specification, which we add controls for student and school characteristics in order to absorb confounding effects driven by observed heterogeneity in students' background and school infrastructure.

In panel A of table 6, column 1 reports a significant negative relationship between drought and math achievement. The coefficient rises slightly as we move from column 1 to 2. It appears that the heterogeneity in students and school characteristics plays a restricted role in generating the noticed correlation between drought shocks and math scores. In columns 3 and 4 we estimate the impact of drought shocks on fifth graders Portuguese score. We also find a significant negative correlation between drought and language achievement. Besides, when we control for observed students and school characteristics the coefficient is pretty much the same (column 4).

Panel B of table 6 repeats the same sequence of specifications for ninth grade students. When we move from column 1 to column 2, there is no striking differences between the coefficients, and it remains negative and statistically significant at the 5% level. This result indicates that the effect of water scarcity on math achievement is important for the older children as well. For language scores, the point estimates basically does not change, as we move from columns 3 to 4, remaining negative and statistically significant.

Column 2 and column 4 of table 6 are our preferred specifications, and are the ones we use in the remainder of the paper, for both fifth and ninth grade students. The magnitudes are similar in size. A one standard deviation increases in the number of drought months per academic year leads to a reduction of 0.39 and 0.27 percentage points in math and Portuguese scores, respectively, for fifth graders. For the ninth grade students, the effect of drought on math and language achievement are -0.29 and -0.24 percentage points, respectively. Overall, we find a negative and statistically significant impact of drought shocks on both math and language achievement.

3.4.2 Heterogeneities

In appendix table B1, we look at the heterogeneity of drought impact by students' socioeconomic characteristics. In each column we regress students achievements on the drought shock, as well as its interaction with different student characteristics. Panel A shows the results for fifth grader students, while panel B presents the coefficients for ninth graders. Columns 1 and 5 replicates our benchmark specification, respectively, for math and Portuguese, without interaction terms. In the rest of the columns, we add interaction terms between the drought indicator and a dummy for white, for boys and low-educated mother (student's mother is illiterate or has not completed elementary school), respectively.

Panel A of table B1 provides evidence for fifth graders. Overall, we find that differential effects are in general statistically significant, for both math and language test scores, with exception of race. The results show that the effects of water scarcity on school achievement seem to be larger for girls. Furthermore, the shocks tend to be more detrimental to those students with lower educated mothers. In this period children may benefit from instruction at home. Moreover, better educated parents may react differently to the drought shock than less educated ones. The observed concentration of damage among children with lower educated mother is consistent with a larger compensatory response by high-education parents compared to low-education parents. In other words, higher educated mothers might know better ways to mitigate the effects of the shock. Panel B documents there is little evidence for a differential response to drought shock according to students' socioeconomic characteristics for ninth graders, with the only exception being gender.

Table B2 of the appendix examines heterogeneity in the effect of drought shocks by school's infrastructure. Each column presents the result from our main specification, added by an interaction term between the drought indicator and a different school characteristic. Panel A shows the results for fifth graders, while panel B repeats the exercise for ninth grade students. Columns 1 and 4 show the results for our preferred specifications, without interaction terms. In columns 2 and 5, we add an interaction term between the shock and a dummy for schools with cistern. Column 3 and column 6 add an interaction term for a variable that indicates if the school provides transportation for children to attend the classes. The results provide suggestive evidence that drought tends to be more harmful to children that study in schools with no cistern. In years of negative rainfall shocks, rural schools may cease activities due to lack of adequate water for consumption and hygiene, decreasing the educational provision and making more difficult for the children attend to school. As an attempt to prevent this, cisterns should be installed to store water. Such improvement could helps on the functioning, enriches learning and nurturing environments of disadvantaged children.

3.4.3 Effects of shocks before and after the Prova Brasil year

In appendix table B3, columns 1 and 4 replicates our benchmark specification, respectively, for math and Portuguese performance. In column 2 and 5 we assess the extent to which droughts have either persistent or transitory effects on learning, by exploring the relationship between math and language achievement and our benchmark indicator of drought shock for the previous two school years. In the remainder columns we provide a natural placebo test. We regress students performance in math and language on our drought measure computed in the following academic year. As before, panel A shows the results for fifth graders and panel B for ninth grade students.

According to the results of table B3, there is no evidence of a significant association between math and Portuguese test scores and past drought shocks. Other studies in the literature have found that intervention programs, violence and temperature effects on test scores "fade out" over time, especially in earlier grades (Andrabi et al., 2011; Cascio and Staiger, 2012; Deming, 2009; Monteiro and Rocha, 2017; Shah and Steinberg, 2017). The interpretation that the effect of drought shocks on learning is only transitory should be taken with attention. Although test score impacts often fade over time, their effects on knowledge is more persistent (Cascio and Staiger, 2012). Furthermore, drought may affect student attainment through its effects on learning, which may affect completed years of schooling in the long run. Also, as expected, the placebo test shows that there is no relationship between water scarcity during the following year and test scores in the current year.

3.4.4 Student selection

The primary concern for our main results in table 6 is self-selection of students at the Prova Brasil exam. If Prova Brasil data is sampling a different set of children in schools when experiencing droughts relative to a set when the shock does not occur, this may bias our estimates. Specifically, if higher-ability children are less likely to take the exam when rainfall is low, the estimated effect of droughts on students achievement may capture the worsening of the pool of students rather than the causal impact of weather shock on learning.

In order to address this issue, table 7 examines for student selection at the Prova Brasil exam. Panel A shows the results for fifth graders, while panel B provides evidence for ninth grade students. First, we regress some socioeconomic characteristics of the students who take the exam on the drought shock during the school year. In the first column we regress on drought a dummy variable indicating gender equal to male. The results show that a shock during the school year is not significantly associated with a higher probability of observing a male in the sample of students taking the exam, for both fifth and ninth grade. In the columns 2 to 4, we repeat the same specification for race (white), mother's education (student's mother is illiterate or has not completed elementary school) and student age, respectively. The coefficients on below are typically small and statistically insignificant, with the only statistically significant coefficient plausibly arising due to sampling error. The remaining column examines the relationship between drought shocks and participation rate of students who take the exam. The point estimate for the fifth graders is negative but statistically insignificant, and for ninth grade students is positive but insignificant either. Thus, we observe no significant association between water scarcity and the number of students taking the Prova Brasil exam.

3.4.5 Mechanisms

In this section, we try to uncover the specific mechanisms linking negative rainfall shocks to students achievement. This relationship can be driven by a variety of channels. In the context of Northeast Brazilian, we may think in three main potential channels acting in our setting. First potential connection is through school supply. Negative rainfall shocks may lead schools to close or cease activities due to lack of water. Second, we assess whether the scarcity of water could cause children to become sick and attend school less. Finally, we examine whether, due to a drop in family income, the drought shocks are associated with increased child labor and reduced school attendance.

3.4.5.1 School supply

We analyze if drought shocks may lead to disruption of regular classroom routines and procedures due to lack of water for consumption and hygiene, decreasing educational provision and affecting children learning. As a result, student achievement may suffer as classes are discontinued.

To investigate the effects of the drought shocks on the school supply, we use a survey answered by principals in Prova Brasil editions. This survey investigates several aspects of the school's routine. Table 8 presents the results from estimating drought events for school routine. In column 1, we regress a dummy variable indicating whether the principal reported any interruption of school activities for any reason. We find no relationship between the shocks and this variable. In the following columns, we estimate other binary dependent variables: student and teacher absenteeism, both reported by principals. The ideal it would be have information about daily student and teacher attendance, but this is not available. Point estimates are small and not statistically significant at the conventional levels of significance. Importantly, note that these results are not driven by large standard errors. This suggests that teachers absenteeism do not increase noticeably in drought years.

3.4.5.2 Infant health

If drought shocks lead to higher incidence of particular diseases, this could cause children to attend school less during drought years, and thus doing worse on Prova Brasil exam. A series of studies have documented the relationship between weather shocks and health outcomes. Precipitation is crucial for agricultural productivity, thus water scarcity may be associated with lower agricultural production, higher food prices and, therefore, lower nutrient intake, which could rise de incidence of nutritional diseases. Also, it may be related with lack of adequate drinkable water, which increases the risk of infectious diseases (Bandyopadhyay et al., 2012; Burgess and Deschenes, 2011; Carlton et al., 2013; Carrillo, forthcoming; Rocha and Soares, 2015; WHO, 2016, 2008).

To investigate the effects of drought shocks on infant morbidity, we use a municipality-by-month on hospitalization panel from January 2008 to October 2016, with children between 9 and 15 years old. We estimate the following equation:

$$H_{jmt} = \propto + \beta_1 R_{jmt} + \omega T_{jmt} + \theta_j + \varphi_t + \mu_m + \delta_{mt} + \varepsilon_{jmt} \tag{15}$$

where H_{jmt} is the infant hospitalization rate per 1,000 inhabitants in municipality j, on month m and year t. R_{jmt} is our drought indicator, a dummy equal one if rainfall over month m in year t was more than one standard deviation below the historical average for municipality j. T_{jmt} is the average temperature in the municipality in the same month. We also control for municipality (θ_j), year (φ_t), month (μ_m) and month-by-year (δ_{mt}) fixed effects. Standard errors are clustered at the municipality level.

The results are reported in table 9. Column 1 estimates the impact of drought shock on children aged 9 to 15. We find that exposure to negative rainfall shocks increase the hospitalization rate among children in 0.83 percent. In columns 2 and 3, we report these coefficients separately estimated for children aged 9–11 and aged 12–15 in order to observe if the effect is concentrated in an specific group. As in the first column, the results are positive and statistically significant, but the effect appears to be slightly larger for the younger children (1 percent) than to older ones (0.72 percent). This result supports the view that infant health in the Northeast region are affected by rainfall fluctuations.

In order to examine a little deeper on the impact of drought shocks on infant health, we look at causes of hospitalization. We group our sample into four categories: infectious and parasitic diseases, malnutrition, respiratory infections, and all other diagnoses. In contexts of water scarcity, these are consider the main drivers of infant morbidity and mortality. Diarrhea is caused mainly by pathogens that are ingested from contaminated water (for consumption and hygiene) and food. Through reduced capacity to absorb nutrients, diarrhea can also lead to increased malnutrition. Rainfall scarcity also facilitates the irritation of the airways. A drier environment leaves children more susceptible to nasal bleeding and coughing due to the concentration of dust in the air. For those who already suffer from respiratory diseases, drought shocks increase the risk of having a crises (Fewtrell et al., 2007; Rocha and Soares, 2015; WHO, 2016, 2008).

In panel A of table 10 we report the results from equation (3) estimating the impact of negative rainfall shocks on hospitalization by cause of children aged 9–11. The first column presents the effect on hospitalization rate by infectious and parasitic diseases. The point estimate of the coefficient of interest is 0.0116, which is statistically different from zero at the 5 percent level of significance. This estimate suggests that one more shock per year increases by 2,6 per cent the hospitalization rate by infectious and parasitic diseases per 1,000 inhabitants, relative to mean of 0.46. The coefficient for malnutrition (column 2) is also statistically significant. One more drought shock per year is associated with an increase of 5 per cent in hospitalization by malnutrition for children aged 9-11. Column 3 shows that respiratory diseases are positively related with water scarcity, increasing by 3.23 per cent with to one additional drought shock, relative to mean of 0.61. In Panel B, we present these coefficients estimated for children aged 12-15. Most of the magnitudes are similar in size, although the effect of rainfall negative shocks on malnutrition is not statistically different from zero for the older children. Overall, the results show that health may be one of the mechanisms through which drought shocks affect students achievements.

3.4.5.3 Child labor

The impact of drought shocks on agricultural production is straightforward. Almost all of the total area sown in Northeastern Brazil is rainfed. Only 2 percent of net area is irrigated. Therefore, we would expect rainfall to be an important driver of agricultural productivity and household income. According to the literature, family wealth is associated with child labor, as poorest the family as higher the chance of a child works (Baland and Robinson, 2000; Basu and Van, 1999; Kruger et al., 2012). For example, facing a negative rainfall shock could lead parents increase their use of child labor, typically by having children substitute adult labor in household activities or farm work, preventing children to attending classes or diminishing time devoted to school activities (Bar and Basu, 2009; Beegle et al., 2006); or yet, children could work off parents establishments to improve family income. This would reduce school attendance and consequently contribute to poor students achievement. On the other hand, decreasing agricultural revenues may diminish the opportunity cost of school attendance. In this sense, negative shocks could be associated to school performance improvements. The answer to the question whether the effects of weather shocks are positive or negative to school achievement is a priori ambiguous.

To analyze the effects of drought shocks on the likelihood of a child being or not employed, we specify the following regression equation:

$$W_{imt} = \propto + \beta_1 D_{mt} + \beta_2 X_i + \omega T_{mt} + \varphi_t + \theta_m + \varepsilon_{ihmt} \qquad (16)$$

where W_{ihmt} is equal to one if child i works and zero otherwise, in municipality m and surveyed in year t. The variable of interest is D_{mt}, that is the number of drought months in m from January to September (the month in which the survey is made) of the current year, t. The β_1 is the key parameter of interest, it captures the effect of current-year droughts on . We also control for child socioeconomic characteristics, by including X_i, just as students' gender, age fixed effects, race and the number of family members. The term T_{mt} is the average temperature in the municipality m, on year of survey t. It allows us controlling for other climatic variations possibly correlated with droughts also occurring at the municipality level. The model also includes year of survey fixed effects (φ_t) and municipality fixed effects θ_m. Standard errors are clustered at the municipality level to account for serial correlation.

The coefficient from Table 11 refers to the effect of the drought shocks on the likelihood of child working. The point estimate is positive and statistically significant at the 5 percent level of significance. One more drought shock per year is associated with a 4.24% increase in the likelihood of a child being employed. Therefore, we find suggestive evidence that infant labor is a mechanisms through which drought shocks may reduce student achievement. Overall, the finding in this section is consistent with the evidence that the poorest agricultural families tend to increase the supply of child labor in order to substitute adult labor or improve family wealth (Bar and Basu, 2009; Beegle et al., 2006; Bhalotra and Heady, 2003; Boutin, 2014; Hyder et al., 2015).

3.5 Concluding Remarks

In this paper, we tried to shadow some light on rural school issues. The Brazilian public debate is dominated by urban-related educational themes, mainly focused on enhancing teaching quality. Little attention is devoted to rural schools, which suffer from basic infrastructure problems, high dropout rates and poor student achievement.

This study provides evidence that drought shocks have negative impact on the performance of students from rural schools located in the Northeastern Brazil. We assessed how droughts may affect student achievement as measured by Prova Brasil scores, a national standardized exam. Our results show that drought shocks are associated to lower scores on both mathematics and Portuguese exams, for fifth and ninth graders. However, schools equipped with cisterns seem to be able mitigate the negative effects of droughts. Cisterns may prevent water scarcity problems that could eventually force schools to temporarily cease their activities. Therefore, investments in this low-cost water storage device may bring considerable benefits to rural children, improving school attendance and education supply.

We also find that the effect of drought is transitory, although this result should be taken with caution. Although test score impacts often fade over time, their effects on knowledge is more persistent. Furthermore, drought may affect student attainment through its effects on learning, which may affect completed years of schooling in the long run.

We are able to provide evidence for two mechanisms through which adverse rainfall shocks affect students achievement. Water scarcity increases the hospitalization rate among children, specially by specific causes as malnutrition, respiratory diseases, infectious and parasitic diseases. In addition to that, droughts are also associated to higher probability of child labor. Both health and job-market related effects may be associated to lower school attendance and therefore contribute to poor student achievement.

In order to intervening on the health-related transmission mechanism, governmental policy could focus on improving water and sanitation infrastructure. Many rural areas lack access to safe drinking water especially during drought years. Improving access to safe drinking water may reduce waterborne diseases like diarrhea and improve school attendance;

Finally, conditional cash transfers could be an effective way to improve school attendance in rural areas. By conditioning eligibility to the income supporting program to school attendance, the government may reduce the incentives for rural households replacing the workforce by child labor during drought seasons. In this sense, the Bolsa Família Program seems to be playing an important role by listing school attendance as an eligibility criteria.

Table 5. Summary Statistics

	Rural schools		
	Mean	SD	N
Panel A - Prova Brasil takers - 5th graders			
Portuguese score	167.56	42.05	326433
Math score	181.98	42.95	326433
Age	11.27	1.39	326433
% white	0.23	0.42	278508
% boys	0.52	0.50	326433
%low educated mother	0.64	0.48	210799
% low educated father	0.65	0.48	178181
% have repeated a grade	0.45	0.50	318991
% have dropped out	0.16	0.36	319933
Observations			326433
Panel B - Prova Brasil takers - 9th graders			
Portuguese score	228.52	43.43	162828
Math score	233.11	42.99	162828
Age	14.36	0.66	162828
% white	0.20	0.40	144723
% boys	0.41	0.49	162828
%low educated mother	0.64	0.48	131364
% low educated father	0.73	0.44	108588
% have repeated a grade	0.27	0.45	162037
% have dropped out	0.05	0.21	162240
Observations			162828
Panel C - Teacher-level variables			
Age	36.50528	8.803206	251906
Male	0.329967	0.470202	251906
White	0.253986	0.435291	251906
BA diploma	0.621282	0.485069	251906
Pos diploma	0.002777	0.052624	251906
Observations			251906

Notes: This table provides summary statistics of students characteristics.

Table 6. Drought shocks effects on student achievement

	1 Math score	2 Math score	3 Portuguese Score	4 Portuguese score
Panel A - Prova Brasil takers - 5th graders				
Drought shock	-0.61	-0.65	-0.51	-0.53
	[0.3371]*	[0.3248]**	[0.3088]*	[0.2974]*
N	326433	326433	326429	326429
R-sq	0.192	0.238	0.169	0.248
Panel B - Prova Brasil takers - 9th graders				
Drought shock	-0.72	-0.81	-0.67	-0.67
	[0.3352]**	[0.3512]**	[0.3971]*	[0.4029]*
N	162828	162828	162838	162838
R-sq	0.133	0.167	0.122	0.17
Basic controls	No	Yes	No	Yes
Temperature control	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes

Note: Basic controls include students' sex, race, age fixed effects, dummy for level of mother’s education, and dummy for level of father's education, also some school characteristics as dummies indicating whether there is a computer lab, science lab, cistern and free transportation for students. We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 7. Student selection

	1	2	3	4	5
	Male	White	Low educated mother	Age	Rate of participation in Prova Brasil exam
Panel A - Prova Brasil (5th grade)					
Drought shock	-0.0004	-0.0013	0.0013	-0.0014	-0.0322
	[0.0019]	[0.0017]	[0.0018]	[0.0082]	[0.2664]
N	327824	327824	327824	327824	27080
R-sq	0.031	0.023	0.178	0.106	0.97
Panel B - Prova Brasil (9th grade)					
Drought shock	0.003	-0.0035	-0.0018	-0.0107	0.0784
	[0.0025]	[0.0019]*	[0.0023]	[0.0068]	[0.3473]
N	163243	163243	163243	163243	20552
R-sq	0.027	0.037	0.177	0.071	0.959
Temperature control	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes

Note: Basic controls include students' sex, race, age fixed effects, dummy for level of mother's education, and dummy for level of father's education, also some school characteristics as dummies indicating whether there is a computer lab, science lab, cistern and free transportation for students. We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ****p* < 0.01, ***p* < 0.05, **p* < 0.1.

Table 8. School routine

	1 Interruption of classes	2 Teacher Absenteeism	3 Student Absenteeism
Drought shock	0.0025 [0.0086]	0.0054 [0.0068]	0.0113 [0.0078]
Temperature control	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes
N	15259	15259	15259
R-sq	0.154	0.149	0.114

Note: Basic controls include some school characteristics as dummies indicating whether there is a computer lab, science lab, cistern and free transportation for students. We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 9. Drought effect on infant hospitalization rate

	Dependent variable: hospitalization rate		
	1 Ages 9-15	2 Ages 9-11	3 Ages 12-15
Drought shock	0.032 [0.0129]**	0.019 [0.0088]**	0.013 [0.0076]*
Temperature control	Yes	Yes	Yes
Month FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes
N	450394	450394	450394
R-sq	0.48	0.424	0.365

Note: The dependent variable is infant hospitalization rate per 1,000 inhabitants. We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 10. Drought effect on infant hospitalization rate by cause

	1 Infectious and parasitic diseases	2 Malnutrition	3 Respiratory diseases	4 Other causes
Children aged 9-11				
Drought shock	0.0116 [0.0050]**	0.0033 [0.0013]**	0.0197 [0.0059]***	-0.0125 [0.0048]***
N	450394	450394	450394	450394
R-sq	0.389	0.135	0.347	0.144
Children aged 12-15				
Drought shock	0.0097 [0.0031]***	0.0011 [0.0007]	0.0079 [0.0023]***	-0.0052 [0.0041]
N	450394	450394	450394	450394
R-sq	0.352	0.097	0.283	0.115
Temperature control	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Month-by-year FE	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes

Note: The dependent variable is infant hospitalization rate per 1,000 inhabitants. We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 11. Drought shocks and child labor

	Child labor
Drought shock	0.0106 [0.0049]**
Temperature control	Yes
Month FE	Yes
Year FE	Yes
Municipality FE	Yes
N	28665
R-sq	0.214

Note: We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

APPENDIX B

Table B1. Heterogeneity in the drought shocks effect by students' socioeconomic characteristics

	1 Math score	2 Math score	3 Math score	4 Math score	5 Portuguese score	6 Portuguese score	7 Portuguese score	8 Portuguese score
Panel A - Prova Brasil takers - 5th graders								
Drought shock	-0.61	-0.6287	-0.9072	-0.477	-0.5319	-0.4899	-0.813	-0.3124
	[0.3371]*	[0.3243]*	[0.3320]***	[0.3293]	[0.2974]*	[0.2963]*	[0.3224]**	[0.3136]
Drought shock x white		-0.0909				-0.2265		
		[0.1889]				[0.2405]		
Drought shock x boy			0.5306				0.5699	
			[0.1709]***				[0.1904]***	
Drought shock x low educated mother				-0.4435				-0.5778
				[0.1766]**				[0.2213]***
N	326433	326433	326433	326433	326429	326429	326429	326429
R-sq	0.238	0.238	0.238	0.238	0.248	0.248	0.248	0.248
Panel B - Prova Brasil takers - 9th graders								
Drought shock	-0.8114	-0.8417	-1.127	-0.7617	-0.6747	-0.7285	-0.9582	-0.4865
	[0.3512]**	[0.3440]**	[0.3554]***	[0.3658]**	[0.4029]*	[0.3929]*	[0.4092]**	[0.4223]
Drought shock x white		0.2008				0.3566		
		[0.3926]				[0.4124]		
Drought shock x boy			0.784				0.7043	
			[0.2681]***				[0.2695]***	
Drought shock x low educated mother				-0.1088				-0.4126
				[0.2439]				[0.2699]
N	162828	162828	162828	162828	162838	162838	162838	162838
R-sq	0.167	0.167	0.167	0.167	0.17	0.17	0.17	0.17
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table B2. Heterogeneity in the drought shocks effect by school characteristics

	1 Math score	2 Math score	3 Math score	4 Portuguese score	5 Portuguese score	6 Portuguese score
	Panel A - Prova Brasil takers - 5th graders					
Drought shock	-0.6455	-0.8177	-0.574	-0.5319	-0.6994	-0.4953
	[0.3248]**	[0.3249]**	[0.3388]*	[0.2974]*	[0.2978]**	[0.2923]*
Drought shock x cistern		0.9926			0.9655	
		[0.4526]**			[0.4516]**	
Drought shock x transportation			-0.1924			-0.0984
			[0.3728]			[0.3577]
N	326433	326433	326433	326429	326429	326429
R-sq	0.192	0.238	0.238	0.172	0.248	0.248
	Panel B - Prova Brasil takers - 9th graders					
Drought shock	-0.8114	-0.9692	-0.686	-0.6747	-0.8393	-0.6339
	[0.3512]**	[0.3685]***	[0.4152]*	[0.4029]*	[0.4282]*	[0.5108]
Drought shock x cistern		0.955			0.9963	
		[0.5663]*			[0.5899]*	
Drought shock x transportation			-0.2674			-0.087
			[0.4434]			[0.5227]
N	162828	162828	162828	162838	162838	162838
R-sq	0.167	0.167	0.167	0.17	0.17	0.17
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Basic controls include students' sex, race, age fixed effects, dummy for level of mother's education, and dummy for level of father's education, also some school characteristics as dummies indicating whether there is a computer lab, science lab, cistern and free transportation for students. We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table B3. Drought effect on student achievement in different times

	1 Math score	2 Math score	3 Math score	4 Portuguese score	5 Portuguese score	6 Portuguese score
	Panel A - Prova Brasil takers - 5th graders					
Drought shock (current year)	-0.65 [0.3248]**	-0.43 [0.3590]	-0.61 [0.3220]*	-0.53 [0.2974]*	-0.48 [0.3377]	-0.51 [0.2999]*
Drought shock (Lag, Year -1)		-0.01 [0.2867]			-0.13 [0.2402]	
Drought shock (Lag, Year -2)		0.92 [0.4655]**			0.51 [0.3983]	
Drought shock (Lead, Year +1)			-0.34 [0.2747]			-0.28 [0.2360]
N	326433	326433	326433	326429	326429	326429
R-sq	0.238	0.238	0.238	0.248	0.248	0.248
	Panel B - Prova Brasil takers - 9th graders					
Drought shock (current year)	-0.81 [0.3512]**	-0.80 [0.4022]**	-0.81 [0.3396]**	-0.67 [0.4029]*	-0.60 [0.4634]	-0.68 [0.3889]*
Drought shock (Lag, Year -1)		0.13 [0.3512]			-0.12 [0.3429]	
Drought shock (Lag, Year -2)		-0.28 [0.5027]			-0.13 [0.5444]	
Drought shock (Lead, Year +1)			-0.05 [0.3215]			0.07 [0.3209]
N	162828	162828	162828	162838	162838	162838
R-sq	0.167	0.168	0.168	0.17	0.17	0.17
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature control	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Basic controls include students' sex, race, age fixed effects, dummy for level of mother's education, and dummy for level of father's education, also some school characteristics as dummies indicating whether there is a computer lab, science lab, cistern and free transportation for students. We report robust standard errors clustered at the municipality level (in brackets). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

4. Concluding Remarks

The two essays presented in this thesis have investigated two important issues in economic development and weather shocks. As a whole, the essays are intended explore the possible impacts of drought shocks and develop a understanding of the mechanisms behind these relationships, in order to contribute to our ability to mitigate and to prevent for the negative impacts of extreme weather-related events.

The first essay contributes to understand the relationship between rainfall shocks and household's labor allocation in the Northeastern Brazil. We discovered that negative rainfall shocks are significantly associated with lower income derived from the main job, especially for those engaged with farm activities. This is what one would expect given that a considerable fraction of population in this region depends on farming and related agricultural activities for living. We also find that drought shocks are associated with higher income from secondary work in the non-agricultural sector.

Having established that drought shocks affect rural household income, we turn to the analysis of labor supply responses. We find that an additional drought shock per year is associated with greater likelihood of have more than one job, lower share of farm activities on the total hours worked, and a higher offer of time in secondary work in the non-agricultural sector. These results are consistent with a response to reduced agricultural profitability due to water scarcity and show the importance of non-agricultural activities as an autonomous mitigation mechanism.

Reducing the variability of agricultural income streams is of paramount importance to improve welfare of rural dwellers. Given the constraints faced in the insurance and credit markets by most rural families in developing countries, labor reallocation can be one of the main channels by which poor rural households mitigate negative rainfall shocks. Engaging in non-farm labor market might help households to smooth consumption.

Continuing on the theme of extreme weather-related events, the second essay examined an important economic development issue: human capital accumulation. We tried to shadow some light on rural school issues. The Brazilian public debate is dominated by urban-related educational themes, mainly focused on enhancing teaching quality. Little attention is devoted to rural schools, which suffer from basic infrastructure problems and poor student achievement. this paper aimed at assessing the impact of drought shocks on the performance of students from rural schools located in the Brazilian Northeast. We assessed how drought shocks may affect student achievement as measured by Prova Brasil, a national standardized exam.

The results show that show that drought shocks are associated to lower scores on both mathematics and Portuguese exams, for fifth and ninth graders. However, schools equipped with cisterns seem to be able mitigate the negative effects of droughts. Cisterns may prevent water scarcity problems that could eventually force schools to temporarily cease their activities. Therefore, investments in this low-cost water storage device may bring considerable benefits to rural children, improving school attendance and education supply.

We provide evidence for two mechanisms through which drought shocks affect students achievement: infant health and child labor. Water scarcity increases the hospitalization rate among children, specially by malnutrition, respiratory diseases, infectious and parasitic diseases. The effect appears to be more detrimental for the younger children than to older ones. In addition to that, droughts are also associated to higher probability of child labor. Both health and job-market related effects may be associated to lower school attendance and therefore contribute to poor student achievement.

These two essays try to uncover two important issues related to weather shocks. The results of this project provides inputs for a cost-benefit analysis of the impacts of rainfall scarcity in the context of a developing country. Employment policies that do not consider the responses of rural households to weather shocks can overestimate its benefits. In order to intervening on the health-related transmission mechanism, governmental policy could focus on improving water and sanitation infrastructure. Many rural areas lack access to safe drinking water especially during drought years. Improving access to safe drinking water may reduce waterborne diseases like diarrhea and improve school attendance. Policy makers can put policies in place that make mitigation easier. However there are still countless open questions to be investigated, plenty of unresolved issues, and plenty of work still to be done on the topics of economic development and extreme weather-related events.

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