Drought adaptation and development: Small-scale irrigated agriculture in northeast Brazil

Abstract

Water scarcity has intensified in northeast Brazil over the past decade. The same period has brought economic growth, aggressive government-funded social support programs, and technological advancements. These latter factors have led to widespread, successful, and largely unintended adaptation to increasing climatic stress. With specific focus on the experience of irrigated farmers in Pernambuco during the 2011-2013 drought, the worst in a half century, in this article we examine how Brazil's societal changes have led to the emergence of unique climate adaptation strategies. To put this into context, income diversification, particularly in the form of employment in clothing production, provides a stable back-up income for farmers amidst environmental uncertainty. Aggressive poverty alleviation programs, foundational to the Lula da Silva and Dilma Rousseff presidential administrations, have had the spillover benefit of decreasing climate vulnerability. Efficient irrigation technology, which farmers have adopted primarily in an effort to decrease erosion and labor needs, saves water and decreases drought vulnerability. In summary, we find that the study area serves as a global example that economic, political, and social developments not aimed at climate adaptation can inadvertently facilitate it and decrease drought vulnerability.

Keywords: adaptation; vulnerability; Latin America; water management; climate change

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Introduction

From large-scale farmers in California, to cattle ranchers in the Australian Outback, to subsistence farmers in northeast Brazil, it seems that few parts of the world have remained unaffected by drought in recent years. Throughout history, northeast Brazil has experienced devastating droughts that have led to disrupted livelihoods, economic losses, mass migrations, and, in the most severe cases, widespread mortality (Nelson and Finan 2009). Between 2011 and 2013 northeast Brazil experienced its worst drought in a half century, affecting an estimated 20 million people (NOAA 2012). This study is focused on the ways that irrigated farmers maintained their livelihoods and adapted to conditions during this drought. From this study, we draw broader conclusions about how economic and technological development and government assistance create opportunities for climate adaptation.

Many reports suggest that climate change has had, and will continue to have, a major impact on water availability. For example, the 2013 IPCC Working Group II report demonstrates with high agreement that climate change will significantly reduce renewable water resources and increase the frequency of droughts, especially in dry subtropical regions such as northeast Brazil (IPCC, 2013). Mekonnen and Hoekstra (2016) find that two-thirds of the global population faces severe water scarcity at some point in the year. As irrigation is one way that people adapt to challenging environmental conditions, climate change will increase irrigation water demand. The study of irrigation is particularly important as irrigation accounts for approximately 70% of total global water withdrawals and production of 40% of the world's food crops (Vital Signs, 2012).

In northeast Brazil, state actors, civil society groups, and farmers have pursued several different approaches to reducing agricultural drought vulnerability. Throughout most of the 20th century, public officials understood drought as an issue of water scarcity, which led the state and federal government to generally approach the problem by building dams (Lemos and De Oliveira, 2004). With the election of populist President Luiz Inácio Lula da Silva in 2003, the technical focus of federal and state government drought programs began including preemptive social support programs as part of broader redistribution policies (Soares, 2012). Economic growth and social support programs have led to the share of Brazilians living below the extreme poverty line of R$70 per month (about US$30) decreasing from 10.5% in the early 2000s to 4.7% in 2011 (World Bank, 2013). By another metric, between 2002 and 2012, the poorest 50% in Brazil had an income increase of 68% (BBC, 2012). Studies on drought and water management in northeastern Brazil to date have mainly been focused on Ceará state (see for example Eakin and Lemos, 2006; Lemos and De Oliveira, 2004; Nelson and Finan, 2009) with far less work occurring in other northeastern states, such as Pernambuco, where this study is focused.

The combination of global attention to climate adaptation in agriculture, projected climatic change, the mounting importance of irrigation, and the policy significance of Brazil's social support programs and economic growth set the backdrop for the present study. We argue that northeast Brazil can serve as a policy example of a region where aggressive government-funded social support programs, paired with economic growth, and technological advancements, have led to successful climate adaptation over the past decade.

Theoretical context: Climate vulnerability and adaptation

Definitions of vulnerability vary among scholars. The most influential is probably that of the IPCC, which defines it as "characteristics of human or social-ecological systems exposed to hazardous climatic or non-climatic events and trends" (IPCC, 2013). Due to the socioeconomic nature of vulnerability, it is geographically and socially differentiated and thus should not be analyzed at a national, regional, or even local scale, but rather in terms of specific populations and their social relations (Brooks, Adger, & Kelly, 2005). Even though people may experience the same physical hazard, such as low rainfall, the impacts differ. In this context, vulnerability to drought is understood not solely as a climate related issue but rather as embedded in overlapping economic, social, and political contexts (Liverman, 1990).

Like vulnerability, adaptation is a concept that can be interpreted in various ways. The IPCC (2013) defines it as "adjustments in response to climate, either actual or expected, aimed at decreasing harm or increasing benefits." In climate literature it is generally linked to vulnerability as the set of processes that change a system and its vulnerability (Smit and Pilifosova 2001). Adaptive capacity is the "potential ability of a system to cope with climate-related risks and opportunities" (Smit and Pilifosova 2001). While most authors tend to agree on the broad factors that increase adaptive capacity, the process of improving adaptive capacity in real-world settings is less clear (Eakin and Lemos, 2006). There are proxies for predicting adaptive capacity but they are often not clear until a system experiences a stressor (Brooks, Adger, and Kelly 2005). Burney et al. (2014) contends that since effective adaptation happens at local levels, more studies should collect data directly from field surveys, taking a 'bottom-up' approach. These combined factors make it particularly important to undertake local-level studies in regions such as northeast Brazil that have recently experienced major stressors.

Adaptation strategies: Economic development, irrigation technology, and infrastructure projects

Throughout history and today, governments have overwhelmingly tended to prioritize the economy over environmental concerns. As such, it is critical that studies of climate adaptation account for economic development. Leichenko and O'Brien (2008), in their conceptual framework of 'double exposure,' contend that globalization and climate change act together to increase inequality, exacerbate vulnerability, and decrease sustainability. However, several scholars have argued that climate adaptation does not need to be, nor should be, approached separately from economic development. For example, Ziervogel et al. (2010) argue, based on a study in Cape Town, that the most effective way to facilitate adaptation is to address areas where issues of both development and climate change overlap. With this approach, climate adaptation does not compete with development but rather is facilitated by it. Similarly, in a study in the Philippines, Lasco et al. (2013) argue that national priorities are biased towards issues deemed more significant than climate and as such integration with broader development policies could provide an entry point for climate adaption. With regard to irrigation as an adaptation strategy in developing countries, Nelson and Finan (2009) found that irrigation constituted a positive adaptation to drought compared to rain-fed farming in northeast Brazil. Conversely, studies in rural Mexico (Liverman, 1990; Eakin, 2003) found that irrigation can increase drought vulnerability, particularly when drought lasts for multiple years and reservoirs dry up. Lindoso et al. (2013) found that while

irrigation as an adaptation strategy is risky, efficient irrigation technology can reduce the dependence of production on climate. Gujja et al. (2009) and Yu et al. (2009), find in studies of water management in India and China respectively that decentralized adaptation measures by farmers are often preferable to large, new infrastructure investments.

An example of the detrimental impacts of large-scale infrastructure is Brazil's infamous 'drought industry,' the tradition of local elites using power over infrastructure and resources to exploit water scarcity to their own advantage (Lemos & De Oliveira, 2004). More recently, the Brazilian government has spearheaded the multi-billion dollar *Transposição do Rio São Francisco* (inter-basin transfer), which will transfer water to approximately 12 million people in 4 states and include 620 km of canals, costing US$3.7 billion (BBC, 2010). While large infrastructure projects are an important climate adaptation strategy, they can also cause environmental degradation, reinforce social inequalities, and require major investments in maintenance and energy (see for example Lemos & De Oliveira, 2004; Nelson and Finan, 2009). The collection of climate adaptation strategies addressed in this study was chosen from those broadly outlined by Eakin and Lemos (2006), as adapted from Smit and Pilifosova (2001): material resources and infrastructure, information and technology, political capital, wealth and financial capital, human capital, organization and social capital, and institutions and entitlements. We specifically focus on the use of efficient irrigation technology, social support programs, and income diversification because these strategies emerged most prominently during field work.

Research design

The study is based on field research conducted by the first author. We examine the institutional, infrastructural, cultural, political, and economic factors surrounding irrigation water management and climate adaptation and seek to better understand how these factors converge to affect drought vulnerability. To operationalize this, the basic research question addressed is:

> *How are climate adaptation strategies of irrigated farmers affected by the political, economic, and technological context of northeast Brazil and how do these strategies affect drought vulnerability?*

Investigating this question involved asking irrigation farmers about: (1) how farmers themselves and people that they know were impacted by the recent drought and previous droughts; (2) the availability of alternative sources of income, in the form of government social support programs and alternative economic opportunities; and (3) types of irrigation infrastructure and technology used and their characteristics.

Methods

The first author undertook fieldwork during June-August 2013 in the upper Capibaribe River basin, conducting in-depth semi-structured qualitative interviews with 32 irrigation farmers, seven rainfed farmers, four agricultural extension workers, four current and former Secretaries of Agriculture, and six environmental activists and other experts. The interviews with irrigation farmer were more structured while those with other community members were mainly aimed at providing context.

Interviews were conducted and audio-recorded by the first author in Portuguese, with a local translator present at all times for clarification. Each interview lasted from 30 minutes to several hours, guided by a list of 60 questions. Questions were split evenly between short answer

and open-ended. GPS coordinates were documented at each farm to reference location, precipitation, and altitude characteristics.

Many farmers were approached at the recommendation of a former Secretary of Agriculture, who provided their contact information. Some farmer respondents were found at the agricultural extension office and the Rural Workers Union. From these farmers, snowball sampling was used. These strategies led to some selection bias as farmers interviewed were often those most engaged in the agricultural community.

All farmers included in the study, (1) resided in one of the two study municipalities; (2) were the primary farmer in their household; and (3) farmed on parcels less than 15 hectares. No specific age, gender, or tenure length was required. However, due to demographic characteristics of farmers in the area, all were male and most were middle-aged or seniors. The sample size was determined by data saturation and research time available. Data saturation was determined when categories and relationships between answers had been repeated many times. The data were analyzed by both coding to classify responses and repeatedly reading interview transcripts to allow themes to emerge. Percents were calculated for answers to short answer and yes-no questions by dividing the number of respondents who gave a certain answer to a question by the number who were asked the question. Given that the sample was small and non-random, the percentages mentioned in this paper are meant to support the qualitative data and provide general context; due to the small, non-random sample, these percentages cannot be generalized to the population of farmers as a whole.

The study focused on small-scale irrigation farmers. The majority of agriculture practiced in the study area is rainfed due to the lack of surface water sources and aquifers. In Pernambuco, only 9% of farms, accounting for 3% of agricultural land, practice irrigated agriculture (IBGE, 2006). Although irrigation farmers are in the minority and often more financially privileged this study was aimed at them due to the mounting global importance of irrigation, increased number of adaptive decisions facing them (e.g. what land, when, and how much to irrigate), and the risks created by irrigation (Eakin, 2003). The study focused on small-scale farmers because they make up the majority of farmers in the region and are generally poorer and thus more vulnerable to drought than large-scale farmers. The median amount of irrigated land among irrigation farmers interviewed was 2.25 ha, the average was 3 ha, the maximum was 8 ha, and the minimum was 0.5 ha.

The majority of irrigation farmers interviewed (60%) retrieved water from shallow lined wells (*poços amazonas*), averaging 10 meters deep, located in the center of streams and rivers that draw base flow from sedimentary alluvial deposits. Farmers pump water directly from the stream or river when it is flowing (usually for about three months per year in the study area) and then begin pumping from the *poço amazona* when the river stops. The rest of the farmers drew directly from streams and rivers (20%), springs (10%), dams (7%), and artesian wells (3%).

Study area

According to all commonly-used measures, poverty has been decreasing in Brazil since 2003, and social support programs have played a significant role (Higgins, 2012). The most widely used program is *Bolsa Familia*, a federally funded social support program that provides monthly payments to about a quarter of Brazil's population (Soares, 2012). *Bolsa Familia's* expenditures

on a national scale have been relatively small, costing less than 0.4% of national annual GDP (Soares, 2012), yet the program is credited with between 16 and 21% of the total fall in Brazilian inequality since 2001 (Higgins, 2012). Northeast Brazil receives 50% of *Bolsa Familia* expenditures while having 25% of the population (Lindoso, 2013). Recipients in rural northeast Brazil also automatically receive extra payments during droughts. The impact of the program has been much greater in rural areas, like the study area, due to a failure to account for cost of living differences.

Despite significant government investment and rapid economic growth, the nine states that comprise northeast Brazil remain the poorest region of the country with the largest concentration of rural poverty in Latin America (IFAD, 2011). The percentage of the population living below the poverty line in Pernambuco is twice that of Brazil as a whole (World Bank, 2013). Some of this poverty can be attributed to harsh environmental conditions. While Brazil holds more fresh water than any other country in the world, the semi-arid northeast possesses only three percent of these water resources , with a per capita water availability of approximately $500m^3$ per year, far below the United Nations definition of water scarcity of $1{,}000m^3$ per capita (Montenegro & Ragab, 2012). Biophysical vulnerability is compounded by the predominance of crystalline bedrock that makes groundwater storage almost nonexistent in the region and erratic precipitation patterns, with 60% of all rainfall coming during one quarter of the year (Montenegro & Ragab, 2012).

The study focused on two municipalities -- Brejo da Madre de Deus and Santa Cruz do Capibaribe (Figure 1). They are located at the headwaters of the Capibaribe River basin.We chose to focus on the upper basin because it is the driest and poorest portion. The average annual rainfall in the study area is 450 mm compared to 2,300 mm in the lower basin while the average monthly income is R$345 (US$155) compared to R$1640 (US$755) in the lower basin (IBGE, 2006).

Figure 1: Study area

Results

In the following section we present empirical results on the climate adaptation strategies of irrigation farmers in the study area. We will first discuss the role of government social support and drought response programs, then turn to efficient irrigation technology, and finally address economic development and income diversification.

The role of government social support and drought response programs

Interviews confirmed that social support programs in Brazil are widely available. In addition to programs aimed at general poverty throughout Brazil, such as the popular and extensively used *Bolsa Familia* program, there are many schemes directly aimed at farmers and drought in the northeast. These programs include drought response programs, such as increased welfare payments, subsidized cattle feed, and drinking water distribution as well as longer term agricultural risk reduction measures such as crop insurance, loans to build small dams or purchase efficient irrigation systems, and subsidized rainwater cisterns.

Of farmers who expressed an opinion on these government social support programs that specifically targeted drought, sentiments were about evenly split between positive and negative. Most farmers interviewed (56%) said that they did not use them. There are several reasons for

this, the most prevalent being excessive bureaucracy. With regard to subsidized cattle feed, farmers said that they did not use it due to the required paperwork and unfair distribution:

> "I traveled for two hours and waited in Cauraru [for subsidized maize] but didn't get any because they lost my documents. Those who didn't need the help got it instead."

This farmer and others explained that those farmers who did manage to receive the subsidized cattle feed resold it to other farmers at a higher price. Another farmer recounted that the assistance arrived too late:

> "Maize for animals was subsidized and sold for R$18 per sack. Some people bought the maize but I didn't because it took so long to get here, by the time it was here my cows had already died."

With regard to loans, one farmer who had recently constructed a small dam for himself and his neighbors with a government loan explained that it took 20 years for him to work through the bureaucracy and receive the loan. Another farmer lamented, "It's not worth it to apply for government loans, they are too hard to get. You shouldn't rely on the government for anything." Opinions on crop insurance were similar, as one farmer stated, "Garantia Safra [crop insurance] is not offered in my region and I wouldn't use it even if it was. It's not worth it to use anything from the government."

Fear of being unable to pay back loans was also a major factor impeding their use. In the 2006 Agricultural Census farmers cited similar reasons for not obtaining government financing: fear of incurring debts (26%), bureaucracy (8%), and a lack of ability to repay loans (4%). There was a serious case of a government loan gone wrong in the study area. In 1994, a co-op of 111 farmers took out a government loan for farm improvements. Everything went well until a severe drought occurred in 1998 and the farmers could no longer afford to make payments. Further, the loan was taken out just as the *real* replaced the *cruzeiro* as the Brazilian currency and so the cost was over-valued. As of 2013, two farmers had paid in full, nine had died, and 100 had accrued debts of R$20,000 (about US$8,600) each to the bank. By law the bank cannot take the farmers' land as payment but the bank is now suing the farmers. This case shows that government loan programs, while aimed at decreasing vulnerability, can be disastrous.

Negative sentiments toward social support programs also stem partially from general mistrust for the government. One farmer explained that he believed that government officials chose to provide short-term support rather than long-term solutions, such as dams, because they wanted to keep people dependent upon them, possibly a residual sentiment from the 'drought industry.' Farmers generally perceived dams as a long-term solution as opposed to social support programs which they perceive as making them dependent upon the government.

Some contended that there was no government assistance; for example, one explained: "The government didn't do anything for anyone during the drought. Nothing, nothing, nothing." Other farmers emphasized their religious faith over faith in the government, "Only God helps, not the government," and "Almost nothing is lucrative here because we don't have financial help from anyone, only from God---the help from the government is weak." Along these lines, religion was integral to all aspects of drought experience. Many farmers made statements such as, "There's nothing more the government can do for us, it only depends on God," "I don't pay much attention to the climate, God is taking care of it," and "When it's dry, it's dry for everyone. When God

sends rain, he sends it for everyone." In this way, faith served to alleviate discontent with the government.

While these quotes convey that there have been many problems with drought specific programs, the general social support program *Bolsa Familia*, through significantly decreasing rural poverty, has had a substantial impact in decreasing drought vulnerability. The program has served to make individuals more resilient to drought, creating a livelihood buffer for the climatic extremes that occur in the region. Historically, droughts led to hunger, thirst, mortality, and forced migrations yet today these impacts are less common. One farmer noted:

> "Lots of people migrated out of the region as a result of drought before *Bolsa Familia* but now there are lots of social programs and opportunities here."

The former president, who created the program, is given credit for this, as one farmer explained:

> "Before Lula people were going to the city, the cities were swelling, people were leaving the countryside but now people who were in the city are coming back [to the countryside]."

In this way, government social support programs allow farmers to maintain their traditional livelihoods and continue producing food for their families and the region.

In some ways, social support programs are a less sustainable alternative to government-funded construction of dams and reservoirs, which several farmers suggested would provide a longer term solution to drought and would decrease dependence on government hand-outs. However, social support programs are necessary because while dams can only reach a localized group of people, social support programs are open to more people, making them a wider-reaching adaptive measure. The shortcomings of social support programs demonstrate that they are not sufficient alone in addressing drought. They are best used in combination with economic and technical strategies, which brings us to the next section.

Efficient irrigation technology and income diversification

While social support programs are a climate adaptation measure instigated by the government, efficient irrigation technology and income diversification are ways that individual farmers decrease their vulnerability. These two adaptation measures were highly interconnected in the study area.

Among irrigation farmers, the majority were using efficient micro-sprinkler or drip irrigation (66%) while some continued to use only (comparatively less efficient) sprinkler irrigation (33%). Of those farmers who used micro-sprinkler or drip, about half (52%) continued to use sprinkler for certain crops. Several (14%) said that they received their efficient irrigation systems from the government. All of the farmers interviewed who had adopted drip and micro-sprinkler irrigation systems did so between 2000 and 2011. This rapid and widespread adoption of efficient irrigation seemed self-perpetuating. One farmer explained how the technology spread:

> "We change according to what our neighbors are doing, we always imitate our neighbors. We see our neighbor spending less and we want to spend less too. The agricultural extension office does orientations but people don't believe it will work until they see a neighbor doing it. There needs to be one person who takes a risk for everyone to take a risk."

Efficient irrigation technologies mitigated the impacts of drought for irrigation farmers. Several farmers explained that prior to switching to efficient irrigation technology water levels in their wells would decline faster during droughts. Farmers stated that micro-sprinkler used from 20% to 80% of the water, while drip ranged from 20% to 30% of the water, compared to what sprinkler systems used. This compares to scientific calculations for irrigation efficiency of 70% for sprinkler, 87.5% for surface drip, and 87.5% for micro-sprinkler (Salas et al. 2006).

Yet while most farmers interviewed said that efficient systems decreased the negative impact of drought, water conservation was not usually the primary reason for switching. When asked to list the reasons why they chose to switch to drip or micro-sprinkler from sprinkler irrigation systems three reasons were cited: to save time and decrease labor needs (57%), to conserve water (47%), and to decrease erosion and soil compaction (29%).These reasons at first seem counterintuitive for a region where water scarcity is such a major source of livelihood insecurity. However, if we unpack the social context of the region, the reasoning becomes clearer.

Drip and micro-sprinkler are 'fixed,' meaning that they are left in one place in fields at all times and farmers do not need to move them. In contrast, with sprinkler systems farmers usually only own a few sprinkler heads and hoses which they move around the fields throughout the day. This means that efficient irrigation systems require less labor to operate. Farmers explained that in the past they would spend half a day moving their irrigation equipment. Decreasing on-farm labor needs is more than an issue of convenience or finances in the study area -- it's critical to a farms survival. Over the past two decades clothing manufacture has exploded in the region making labor more valuable than ever before. Clothing production now accounts for 98% of the income of Santa Cruz do Capibaribe (Prefeitura de Surubim, 2011). The municipality is the home of *Moda Center*, which produces 700 million garments, amounting to US$2 billion, per year with small-scale producers representing 90% of production. The growth of the clothing industry has been part of broader economic development in Brazil -- between 2002 and 2012 the *real* doubled in value and the country's GDP grew by 15% (BBC, 2012).

There is a major shortage of labor in the study area. Over the past decade, family members who once helped with farm operations, mainly wives and children, have begun sewing full-time instead. Non-family members who previously worked as farm laborers have also largely switched to sewing. One farmer explained that it was easier to find the money to pay a farm worker than to find a farm worker and others lamented that they did not know who would take over the family farm, as their children had sought employment with clothing production. Several farmers explained that up until the 1980s they had plentiful labor but low profits. At that time farmers generally did not have the money to purchase fixed irrigation equipment but they had a large available labor force and thus were able to pay workers to move sprinkler systems around the field.

Much of the clothing production in the region is done within homes rather than in large factories. Most of the families interviewed both farmed and sewed, a method of income diversification which increased their resilience to drought as clothing production is often more lucrative and stable than farming. As one farmer explained:

> "My wife probably makes more money sewing than I do farming, but I have the land so I choose to use it."

Many farmers lamented the fact that their children chose to work in the clothing industry rather than farming. Another explained how the lack of labor impacted his farm:

> "It's hard to find workers here […] someday there will be no one left to work […] everyone wants to work with clothing manufacture […] we have to find ways that we don't depend on this workforce."

Some farmers also explained that decreased labor availability was due to migration to cities, yet the clothing industry seemed to make up a larger portion of off-farm income than migration and remittances. This is confirmed by census data reports that only 1.4% of farmers in Pernambuco receive extra money from friends and family, while about 35% of the total regional population work in the clothing industry (IBGE, 2006).

During drought, the back-up income provided by the clothing industry can be a life-saver. However, paradoxically, the clothing industry also leads to a shortage of labor which can increase vulnerability among farmers. Further, not planning to pass the farm on to future generations can disincentivize farmers from taking long-term adaptive measures. Yet, more paradoxically still, farmers have responded to the labor shortage by choosing to use efficient irrigation equipment, which has a secondary benefit of conserving water, and thus causing water resources to last longer during droughts.

Another explanation for farmers prioritizing decreasing labor needs and decreasing land degradation over conserving water is that irrigation water is a communal good, while labor and land are more individual. The communal nature of water was exemplified by a frequent refrain amongst farmers interviewed: "When we have water, everyone has water, and when we don't have water, no one has it." Farmers did not pay for their irrigation water by volume and instead paid only for the energy to pump it, a cost that the majority said did not vary significantly between sprinkler, micro-sprinkler, and drip irrigation systems. While drip irrigation systems use significantly less energy than sprinkler systems, energy was relatively inexpensive in the study area. Free water paired with low energy costs led to little economic incentive to conserve water.

Conversely, erosion is experienced on an individual scale, leading to decreased yield in the short-term as well as long-term land degradation. Given that farmers interviewed all had only small plots of land suitable for irrigation, preserving these plots was a high priority. Further, decreasing the need for paid labor and saving time has clear individual benefits. Despite using less water, some farmers said that micro-sprinkler and drip increased yields compared to sprinkler. Yet no farmers cited yields or energy as a reason for switching systems. In short, the decision to adopt efficient irrigation systems is not the direct result of a desire to economize water. Instead, it is embedded in a more complex social context which includes priorities such as maximizing land and labor efficiency and the consequences of severe droughts.

Discussion and Conclusions

As water scarcity intensifies throughout the world, the question of how governments and institutions can ensure that people successfully adapt to climatic change becomes increasingly critical. This study presents three main findings that contribute to addressing this issue.

Firstly, we find that in the study area, programs aimed at general poverty alleviation were more effective in facilitating climate adaptation than drought-specific programs. Subsidized cattle

feed during drought was made less effective by bureaucracy and profiteering by intermediaries. Farm loans for dams and irrigation infrastructure improvement, aimed at improving water availability during drought, were also unpopular due to fear of credit default. In agreement with these findings, McLeman, et al. (2008) found in a study of the 1930 drought in Oklahoma that the most beneficial government policies for farmers during the drought were not designed for drought relief. In particular, policies aimed at stabilizing commodity prices had the spillover effect of providing income stability for farmers and jobs for the unemployed. In contrast, loans and subsidized cattle feed -- seemingly useful adaptations available to farmers -- were not feasible in practice in the region. Nelson and Finan (2009) contend that in northeast Brazil rural inhabitants are highly dependent upon the state and local elites for relief during drought and that this leads to patronage relationships that constrain adaptation and leave underlying vulnerabilities unchanged. This historical context partially explains farmer skepticism of government drought support programs. The results indicate that drought-oriented social support programs must take into account distrust for the government. Addressing rural poverty as a whole is a far more effective, albeit more complicated, climate adaptation measure than 'band-aid' solutions during droughts.

Secondly, we find that economic development, specifically in the form of a growing clothing industry, had both positive and negative effects on climate adaptation. The industry provides critical back-up income and encourages investments in efficient irrigation technology. Yet it also decreases labor availability and may disincentivize long-term on-farm adaptation measures. For example, Reid et al. (2007) found in a study in Ontario that farmers nearing retirement without children to take over the business had little incentive to invest in long-term climate adaptation strategies. This finding is applicable to the Pernambuco study area, where the children of farmers often choose employment in the clothing industry over agriculture. Further, Leichenko and O'Brien (2002) find that while some farmers may benefit from economic globalization by shifting to production of export commodities, accessing niche markets, or finding alternative sources of income, many others are threatened by low crop prices, removal of subsidies, and competition with cheaper imports. If the clothing industry in Brazil is moved to a less developed country or stops for another reason, rural residents could be in an even worse position than before the industry entered the region. If no other industry entered the region to replace it, residents would be forced to refocus on farming or to migrate. While farmers are benefiting from economic globalization through alternative income sources, the opportunity may increase vulnerability.

Thirdly, this research contributes to literature on technology adoption among farmers. It underscores the benefits of efficient irrigation beyond water savings – including decreasing erosion and labor needs – which is important in understanding the role of irrigation in climate adaptation. It also shows the importance of the cultural, economic, and political context of a society in facilitating or discouraging technology adoption. Nelson and Finan (2009) critiqued the climate-change literature for focusing on technologies and 'large-scale cookie-cutter solutions' at the expense of the role of individuals, cultures, and societies. Culture and climate adaptation are tightly linked, as culture can limit climate adaptation while climate stress can threaten the cultural fabric of communities (Adger et al., 2009; Adger et al., 2012). This paper, speaking to this body of literature, shows that the clothing industry, through its affect on labor availability, has significantly affected adoption of efficient irrigation adoption.

This research is a case study on how farmers in a drought-prone area, specifically Pernambuco state in Brazil, have reacted to drought. The findings do not constitute broad strategy guidance. Nevertheless, findings are relevant beyond the immediate study area. For example, in a study of Canadian agriculture, Smit and Skinner (2002) identified four main categories of adaptation: technological developments, government programs and insurance, farm financial management, and farm production processes. The present study confirms that these first three categories are also the main categories in the study area. The study also raises further questions. Farmers adopt the observed behaviors for non-climatic reasons and as such these behaviors may not technically constitute climate adaptation. They are actions taken for non-climatic reasons that lead to climate-adaptation benefits. Given this, there is a question as to whether these climate adaptive behaviors may be less durable in the face of social and economic change. For example, if the clothing industry in Pernambuco stopped being profitable, people may revert to farming, ceasing the adaptive behavior of diversified incomes.

This case provides useful insights for how government, the private sector, and technology can lead to positive adaptive management (Scott et al., 2013), particularly in other states in semi-arid northeast Brazil. We argue that institutions aimed at decreasing drought vulnerability should condone behaviors such as income diversification and efficient irrigation, especially because these behaviors have benefits beyond serving as climate adaptation (e.g. improved financial security, decreased erosion). Raymond and Robinson (2013) found that in South Australia farmers were more likely to respond to short-term climate stress rather than long-term climate change. Given this preference, facilitating adaptation to long-term climate change among farmers may require using non-climatic incentives. Throughout the world there is more investment in economic and social development than in addressing climate change and protecting the natural environment. By approaching climate adaptation in tandem with strategies that improve other aspects of development and human well-being, it becomes a higher priority.

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