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Can farmers adapt to higher temperatures? Evidence from India

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ABSTRACT

Projections suggest that the damages from climate change will be substantial for developing countries. Understanding the ability of households in these countries to adapt to climate change is critical in order to determine the magnitude of the potential damages. In this paper, I investigate the ability of farmers in India to adapt to higher temperatures. I use a methodology that exploits short-term weather fluctuations as well as spatial variation in long-run climate. Specifically, I estimate how damaging high temperatures are for districts that experience high temperatures more or less frequently. I find that the losses from high temperatures are lower in heat-prone districts, a result that is consistent with adaptation. However, while adaptation appears to be modestly effective for moderate levels of heat, my results suggest that adaptation to extreme heat is much more difficult. Extremely high temperatures do grave damage to crops, even in places that experience these temperature extremes regularly. The persistence of negative impacts of high temperatures, even in areas that experience high temperatures frequently, underscores the need for development policies that emphasize risk mitigation and explicitly account for climate-change-related risks.

1. Introduction

According to the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC), it is virtually certain that average temperatures worldwide will increase by the end of the 21st century, and very likely that the frequency and duration of heat waves will increase (IPCC, 2013). Developing countries are likely to suffer substantial damages from these higher temperatures, for three reasons. First, many developing countries are located in low latitudes that will likely experience heat extremes first (Harrington et al., 2016). Second, many households in developing countries rely on agriculture, forestry, or fisheries for their livelihoods. Thus their livelihoods inherently are dependent on the climate. Third, many of these households have limited access to assets and infrastructure that could protect them against climate change.

Looking at agriculture in particular, researchers predict significant climate-induced agricultural damages in developing countries (Auffhammer & Schlenker, 2014; Dell, Jones, & Olken, 2012; Mendelsohn, 2008). The preferred methodology for estimating agricultural climate damages uses short-term weather fluctuations to construct a temperature–yield relationship that is then extrapolated using climate change projections (Auffhammer & Schlenker, 2014; Schlenker & Roberts, 2009). However, the reliance on short-term fluctuations does not allow for longer-run adaptations that agents may undertake in the face of sustained climate change. The literature to date has provided limited evidence on the extent to which farmers can temper the temperature–yield relationship. Insight into how elastic this relationship is to human decisions is critical for shaping expectations over how dramatic a problem climate change may be for agriculture and food security.

In this paper, I exploit spatial and temporal variation in the incidence of high temperatures in India to estimate the extent to which farmers have adapted to high temperatures. I use a fixed effects framework to investigate whether farmers in heat-prone areas are adapted to high temperatures and have lower heat-induced yield losses. I also explore the extent to which this adaptation occurs via inter- or intra-crop farmer behaviors and the role of groundwater aquifers.

I use panel data on agricultural yields for 286 Indian districts during the period 1979–2011, merged with a daily gridded weather data set. I use a flexible temperature-binning approach to measure the impact of higher temperatures on agricultural yields. I first estimate the effect of higher temperatures on agricultural yields, while controlling for district-level unobservables, employing a fixed effects strategy that is common in the literature (Burgess, Deschenes, Donaldson, & Greenstone, 2017; Deschenes & Greenstone, 2007; Schlenker & Roberts, 2009). I next divide the

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sample into two groups: districts with long-run average temperature above the median, and districts with long-run average temperatures below it. I then repeat the fixed effects estimation of temperature impacts, but now allow impacts to vary depending on whether a district is above or below the median temperature. If farmers in districts where hot days are common are adapted to high temperatures, then a single hot day should be less harmful to yields in the hotter districts than in the colder districts. The difference between the impacts across the hotter versus colder districts is an estimate of adaptation.[1]

I find four main results. First, higher temperatures are significantly harmful to yields in all districts. For example, relative to a day in the 12–15 °C range, having a *single* additional day with the daily temperature in the range of 27–30 °C reduces yields by 0.99%.[2] Second, evidence suggests that farmers in the hotter districts are effectively adapted to moderate ranges of heat. In particular, yield losses are about 50% lower in the hotter districts compared to the colder districts, for temperatures ranging from 18 °C to 27 °C. Third, temperatures over 30 °C are equally harmful for both the hotter and the colder districts, suggesting that adaptation to extremely high temperatures may be very costly. Fourth, I find evidence of both intra-crop and inter-crop adaptations. Farmers in the hotter districts appear to be protected from moderate heat both because of the types of crops that they choose to grow (inter-crop adaptation) and because of the practices they use to grow those crops (intra-crop adaptation).

This paper contributes to the interdisciplinary development literature on climate change adaptation.[3] This literature has analyzed many factors, including the role of crop and labor diversification (Asfaw, Pallante, & Palma, 2018); interactions between adaptation and gender (Bhattarai, Beilin, & Ford, 2015); the importance of forests in supporting adaptation (Fisher, Chaudhury, & McCusker, 2010); the role of local seed banks and seed markets (Maharjan & Maharjan, 2018; Nordhagen & Pascual, 2013); and the function of microfinance, agricultural extension, and education (James, 2010). This literature has emphasized the broader context in which adaptation occurs, using theoretical lenses that include adaptation governance (Agrawal, 2010); multi-scalar pathway approaches (Burnham & Ma, 2017); and analyses of autonomy, authority, and control (Christoplos, Ngoan, Sen, Huong, & Nguyen, 2017; Funder, Mweemba, & Nyambe, 2017).

Methodologically, my work relates most closely to the strand of literature that uses the long-run frequency of events to estimate potential adaptation.[4] Researchers have used this approach to study the relationship between temperature and economic growth (Dell et al., 2012), agricultural yields (Butler & Huybers, 2012), mortality (Barreca, Clay, Deschênes, Greenstone, & Shapiro, 2015), and labor productivity (Behrer & Park, 2017). My paper also relates to the work on climate change impacts on Indian agriculture (Auffhammer, Ramanathan, & Vincent, 2011; Burgess et al., 2017; Gupta, Sen, & Srinivasan, 2014).

My paper makes several contributions to the adaptation literature. I provide the first set of estimates of agricultural adaptation of crops to higher temperatures in India. Earlier work on agricultural adaptation in India has focused primarily on adaptation to rainfall (Fishman, 2018; Taraz, 2017). In addition, this study is the first to use the long-run frequency approach to estimate agricultural adaptation in a developing country. Also, this paper provides crop-specific estimates of the impact of temperature on yields. Earlier work using the temperature binning approach in India has focused on the effect of heat on aggregate (rather than crop-specific) yields (Burgess et al., 2017). Finally, my focused analysis of high-temperature impacts is a valuable complement to work that has analyzed broader, more holistic measures, such as economic vulnerability (Cariolle, Goujon, & Guillaumont, 2016) or sustainable livelihoods (Shah, Angeles, & Harris, 2017).

This study has significant policy implications. The persistent and substantial damages from high temperatures, even in areas that experience high temperatures frequently, suggests that adaptation to these temperatures is extremely difficult, given the current set of technologies and policies available in India today. This suggests a critical role for the government and private sector to advance the set of available technologies and policies, so as to make adaptation to extreme temperatures feasible. And, considering India's overall development strategy more broadly, my results underscore the need for adaptive development: development policies that emphasize risk mitigation and explicitly account for climate-change-related risks, while continuing to promote growth, equity, and sustainability (Agrawal & Lemos, 2015).

The remainder of this paper is organized as follows. Section 2 gives background on Indian agriculture and agricultural adaptation. Section 3 describes the conceptual framework for temperature binning. Section 4 describes the data sources, gives summary statistics, and runs a balance test to verify that the hotter and colder districts are balanced across other observable characteristics. Section 5 describes the strategy for estimating adaptation. Section 6 presents the regression results. In Section 7, I run a series of robustness tests, discuss the limitations of my study, and explore the implications of my findings for future climate change. In Section 8, I consider policy implications and suggest directions for future research.

2. Background on Indian agriculture and agricultural adaptation

Agriculture is the primary livelihood for India's rural population, employing more than 50% of the rural workforce (India Ministry of Agriculture, 2015). Agriculture contributes roughly 12% of the gross domestic product (GDP) of the country's economy (India Ministry of Agriculture, 2015). The fraction of GDP that comes from the agricultural sector is steadily declining as the country grows economically, but the proportion of the population reliant on agriculture remains high. The primary crops grown in India are rice and wheat, with sorghum, groundnut, maize, and sugarcane also significant. Indian farmers increasingly rely on irrigation, but, as of 2010, only about 30% of all agricultural land was reliably irrigated (World Bank, 2017). The typical farm size is very small, with the average land holding at about 1.3 hectares (Lowder, Skoet, & Raney, 2016). The primary, or *kharif*, growing season is June through September, with crops from this season being harvested anywhere from October to February, depending on the crop. The secondary, or *rabi*, growing season runs from October through March (Krishna Kumar, Rupa Kumar, Ashrit, Deshpande, & Hansen, 2004). Wheat is the main crop grown during the *rabi* season.

The climate of India is diverse, but the majority of the country has a tropical climate (Pant & Kumar, 1997). The southern peninsular region is hotter than the northern region, as seen in Fig. 1, which shows the average annual temperature for each district. The majority of rainfall occurs during the summer monsoon season, which is June through September (Pant & Kumar, 1997). Low rainfall is detrimental for crops, as are high temperatures (Kumar, Kumar, Parikh, & Parikh, 2001).

[1] Interpreting the difference between the hotter versus colder districts as adaptation requires that these two groups of districts be otherwise similar. I run a balance test on observables to verify this in Section 4.3.

[2] The range 12–15 °C corresponds to 53.6–59 °F, and 27–30 °C corresponds to 80.6–86 °F.

[3] Carstensen (2014) and Castells-Quintana, del Pilar Lopez-Uribe, and McDermott (2018) provide helpful review articles.

[4] Hsiang (2016) provides a typology of adaptation models and refers to the approach of this paper as "time-series variation with stratification."