The Impact of Weather Shocks on Employment Outcomes: Evidence from South Africa

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Abstract

As climate change accelerates, the frequency of extreme weather conditions will increase. We assess the impact of rising temperatures and drought on the employment outcomes of working–age individuals in South Africa between 2008 and 2017. We merge high-resolution weather data with panel survey data that contains individual labor market outcomes and estimate causal impacts using a fixed effects framework. We find that drought conditions decrease the likelihood that an individual is employed by approximately 3.2 percentage points. These effects are concentrated in the service sector and in provinces that are more reliant on tourism. The employment outcomes of women, part-time workers, and workers without a high school diploma appear to especially sensitive to drought. Taken together, our results suggest that the impacts of climate change will be felt unequally by South Africa's workers.

JEL Classification: J21, O12, O55, Q54, Q56

Keywords: employment, unemployment, climate change, drought, South Africa

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1 Introduction

A key aspect of economic development is the degree to which an economy's production is independent of environmental volatility (Deryugina and Hsiang, 2017). As economies become wealthier, they are better able to insulate themselves from destabilizing environmental fluctuations through adaptation, technological innovation, and industrial-centered production (Dell et al., 2014).

Despite these efforts to protect themselves, all economies still experience the adverse effects of climate change (Graff Zivin and Neidell, 2014; Colacito et al., 2019). Importantly, many low- and middle-income countries are particularly vulnerable to extreme fluctuations in weather brought on by climate change for reasons including limited adaptive capacity, higher dependency on agriculture, high unemployment, and high poverty levels (Xie, 2021). High temperatures lower aggregate economic output (Hsiang, 2010; Dell et al., 2012; Burke and Emerick, 2016; Deryugina and Hsiang, 2017; Jain et al., 2020), and an increased frequency of heat waves, drought, and other extreme weather conditions may induce significant changes to the workforce in low- and middle-income economies.

South Africa presents a critical study setting for these questions as the country has faced high poverty levels and an unemployment rate of 29.1% in 2019 (Statistics South Africa, 2019). Annual average temperatures have increased by 1.5 times the observed global average of 0.65°C over the past five decades, and extreme weather events such as drought have increased in frequency (Ziervogel et al., 2014). Given the already high rate of poverty and unemployment in South Africa, any additional adverse impacts of weather shocks on employment outcomes are likely to have substantial economic and social welfare costs.

In this paper, we analyze the impact of extreme weather conditions—specifically rising temperatures and drought—on employment outcomes in South Africa. We use high-resolution temperature and precipitation data, which we merge with individual-level panel survey data to evaluate employment outcomes in response to the aforementioned weather shocks. We explore the impacts of weather shocks on general employment outcomes as well as sector-specific employment in the agricultural, manufacturing, and service sectors.

In our background section, we delineate three mechanisms that may link weather shocks to employment outcomes. Temperature and precipitation shocks can affect labor market outcomes via adverse impacts on agricultural production which may spill over to other sectors (Liu et al., 2021). Conversely, temperature and precipitation shocks may directly impact labor productivity, which in turn may effect the demand for labor in the manufacturing sector and other sectors (Graff Zivin and Neidell, 2014; Zander et al., 2015; Adhvaryu et al., 2019). Lastly, in economies highly reliant on tourism, adverse temperature and precipitation shocks may affect the demand for labor in sectors such as the service sector that rely on tourists for revenue (Hoogendoorn and Fitchett, 2018; Dube et al., 2021).

To explore the relationship between weather shocks and employment outcomes, we use individual panel survey data from the National Income Dynamics Study (NIDS) of South Africa. NIDS collects individual employment, income, and consumption data from a representative sample of the South African population at two-year increments starting in 2008. We use all five waves of NIDS, spanning 2008 to 2017. We merge this individual survey data with hourly temperature and precipitation data from the ERA5 reanalysis weather dataset (1979 to present). We aggregate this hourly data to the calendar year level. Spatially, our weather variables capture temperature and precipitation at the district level for each of South Africa's 52 districts – the most spatially granular level possible given the data available.

Our empirical strategy follows the recent climate–economy literature and relies on the quasi-randomness of year-to-year weather fluctuations. We estimate the impact of rising temperatures and drought on the likelihood of sectoral employment among a representative sample of the working-age South African population. Our unit of observation is an individual in a particular year and district. We use a linear probability model with district fixed effects and year fixed effects. In addition to these fixed effects, we control for individual characteristics such as race, gender, and education. Our identifying assumption is that, conditional on these district and year fixed effects, year-to-year variation in weather is essentially random. Hence, we can interpret our estimates as the causal impacts of weather shocks on employment outcomes.

We fail to detect a statistically significant effect of rising temperatures on employment outcomes, both when we use an average temperature specification and a degree day specification. In contrast, we find that drought conditions (during the twelve months prior to the survey interview date) have a statistically significant impact on the likelihood of any employment, decreasing the probability that an individual is employed at all by 3.2 percentage points. These effects are driven by the service sector: drought has a statistically significant negative impact on service sector employment. We fail to detect any impact of drought on the likelihood of employment in the agriculture or manufacturing sectors. Finally, we uncover interesting heterogeneous effects. The negative impacts of drought on employment are concentrated in provinces with a higher reliance on tourism. Furthermore, the negative effects of drought on employment appear to be greater for women, part-time workers, and workers without a high school diploma, suggesting that the most vulnerable segments of the population may be the most adversely effected.

Our results reflect the impact of South Africa's severe El Niño drought that started in 2015 and which has led to official declarations of disaster in all but two of the nine provinces of South Africa over the last 5 years (Agri SA, 2016; Muyambo et al., 2017). The negative effect of drought on employment outcomes in the service sector—the largest employment sector of the South African economy—suggests that a large swath of workers in South Africa are vulnerable to weather shocks. As climate change intensifies, these workers may experience substantial social and economic welfare costs. Our results highlight that climate impacts can be heterogeneous within a country, can depend on the structure of the economy, and can impact certain demographic groups more intensely than others.

We contribute to two strands of the research literature. First, we contribute to the rapidly growing literature on the impacts of climate change on labor markets. Second, we contribute to the more specific literature on the impact of drought on the South African economy. We describe these strands of the literature in more depth in Section 2; here we highlight a few key papers of interest from each strand. Considering the growing literature on the impact of weather shocks on employment outcomes, Graff Zivin and Neidell (2014) find that higher temperatures result in large reductions in U.S. labor supply in industries with high exposure to climate. Similarly, Xie (2021) finds that quarterly heat shocks lead to significant increases in the propensity of manufacturing-worker layoff. Antonelli et al. (2020) find that temperature has a nonlinear effect on labor supply in Uganda, with number of hours worked being optimized at 21.3°C. Shayegh et al. (2020) find that the optimal temperatures for weekly labor supply in South Africa are heterogeneous across different sectors of the economy. Relative to this literature, we make several important contributions. First, we focus our analysis on the impact of drought, whereas the bulk of the existing literature looks at the impact of rising temperatures. Second, we focus on the extensive margin (employment status), which complements existing analyses, such as Shayegh et al. (2020), that focus on the intensive margin (hours worked). Third, we document important impacts of weather shocks on the service sector, whereas the existing literature has largely focused on the agricultural and manufacturing sectors. Finally, our use of detailed micro-data allows us to explore heterogeneous effects by demographic features (gender, education) and by the structure of the economy (reliance on tourism). This analysis of heterogeneity is important, as earlier work highlights that climate change impacts will be highly unequal, even within countries (Park et al., 2018; Winsemius et al., 2018).

Considering the literature on the impact of drought on the South African economy, there are a few key papers of note. Dube et al. (2021) finds that drought reduces tourist arrivals and tourist spending in the Western Cape province. Other work has focused on the impact of drought on the agricultural sector in South Africa (Hlalele et al., 2016; Agri SA, 2016). We make several contributions to this strand of literature. First, we undertake a country-wide analysis, whereas much of the earlier work has focused on a single province or location.

Second, we use detailed micro data with a large sample size, whereas much of the earlier work has relied on qualitative data with relatively small samples. Finally, we look at concrete impacts of drought on service sector employment, whereas much of the earlier literature has focused on the agricultural sector or on specific tourist outcomes (such as arrivals data) instead of directly looking at employment outcomes.

Our results are highly policy-relevant, given South Africa's significant levels of poverty and inequality, and unemployment, as climate change may have significant impacts on worker welfare given the high unemployment and poverty rates.[1] Moreover, assessing the potential costs of climate change in upper-middle-income countries such as South Africa, and the degree to which they can insulate themselves from extreme weather conditions provides an important perspective in the formulation of effective climate mitigation policy in Africa more broadly.

The rest of this paper is organized as follows. Section 2 provides background on the literature on weather shocks and employment and gives context on the South African labor market. Section 3 provides an overview of our data. Section 4 outlines our empirical strategy. Section 5 presents our results. Finally, in Section 6, we conclude.

2 Background

2.1 Weather Shocks and Employment

The climate–economy literature provides evidence that adverse weather conditions can affect a country's economic prosperity by hindering labor productivity, lowering agricultural and industrial output and reducing investment (Acevedo et al., 2020). For example, temperature shocks are found to lower aggregate economic output, inhibit economic growth, and reduce GDP per capita (Hsiang, 2010; Jones and Olken, 2010; Dell et al., 2012; Burke et al., 2015; Jain et al., 2020). Prior literature exploring climate change and labor market dynamics

[1] The most recently reported Gini coefficient and poverty headcount for South Africa are 0.65 (Statistics South Africa, 2020) and 55.5% (World Bank, 2014), respectively.

highlights three primary channels through which weather shocks can impact a country's labor market. The first channel is through agriculture, the second is through direct impacts on labor productivity, and the third is through impacts on the tourism sector.

Regarding the agricultural channel, high temperatures and drought reduce crop yields and negatively impact agricultural productivity (Mendelsohn and Dinar, 1999; Schlenker and Roberts, 2009; Lobell et al., 2011; Taraz, 2018; Vargas et al., 2018). Farmer adaptations to weather shocks, such as investment in irrigation (Taraz, 2017) or diversification (Alfani et al., 2018) may be of limited efficacy in reducing losses. Adverse shocks to agricultural output can affect the labor market in three ways.

First, there may be a direct effect where agricultural firms decrease their demand for agricultural labor. As a result, there will be higher total unemployment driven by the higher unemployment among agricultural workers. Alternatively, agricultural workers, including those who are self-employed, may experience a decline in work hours or wages. Farmers may increase off-farm activities such as casual labor and small business, while decreasing on-farm activities (Dassanayake et al., 2018).

Second, in the presence of intersectoral input-output linkages, a decline in agricultural production could lead to negative fluctuations in industries that use agricultural output in their own production processes (Acemoglu et al., 2012). Thus, there may be an indirect effect whereby labor demand declines in agriculture and other sectors of the economy, such as agricultural-related manufacturing and food processing. This decline in labor demand from both agriculture and related manufacturing could increase the total unemployment.

Third, if there is a decline in agricultural output that decreases agricultural employment, wages, or incomes, there may be a decline in the local demand for manufactured goods and services, especially if there are barriers to internal trade, or if some goods are non-tradable (Henderson et al., 2017; Emerick, 2018; Santangelo, 2019; Liu et al., 2021). If the decrease in local demand for tradable goods and services is substantial, lower agricultural incomes or wages and increased layoffs could reduce local non-agricultural firm revenue and profitability, leading to a decline in labor demand from these sectors.

The indirect effects of adverse weather shocks on non-agricultural firms suggest that non-agricultural sectors may not absorb agricultural workers who have become unemployed or experienced a negative income shock, and may even lay off their own workers, potentially contributing to the total increase in unemployment.

However, an important modulating factor to consider is market integration. Weather-driven agricultural productivity shocks may not increase unemployment in the non-agricultural sector if markets are well-integrated regionally or globally, and if labor markets are flexible (Colmer, 2021). First, if markets are well-integrated, a negative productivity shock to agriculture (holding demand constant) will not change agricultural prices as agricultural imports will fill the supply gap. As a result, non-agricultural firms that use agriculture outputs as inputs will not experience any adverse supply shocks to their production processes. Second, holding the supply of tradable goods and services constant, any decline in local consumer demand resulting from agricultural unemployment or income shocks would be mitigated by global demand and demand from other regions in the country, preventing any negative local demand effects. Therefore, in the presence of well integrated markets, non-agricultural firms could absorb labor that shifts away from agriculture as a result of adverse weather shocks.

The second channel through which weather shocks can impact labor markets is a physiological channel. High temperatures can lower endurance, increase fatigue, and reduce cognitive performance, inhibiting labor productivity (Pilcher et al., 2002; Hancock et al., 2007). Decreased labor productivity can result in declines and agricultural and non-agricultural output (Kjellstrom et al., 2009; Hsiang, 2010; Hsiang et al., 2013; Graff Zivin and Neidell, 2014; Zander et al., 2015; Adhvaryu et al., 2019). For example, Somanathan et al. (2021) find that worker productivity in the Indian manufacturing sector declines by 2% to 4% per degree Celsius above 27°C. In a similar vein, Oliveira et al. (2021) find that higher temperatures reduce non-agricultural wages in Brazil. Furthermore, sustained high temperatures also increase the frequency of worker absenteeism. In the U.S. Graff Zivin and Neidell (2014) find that temperatures above 29°C decrease labor supply in industries with high exposure to climate such as agriculture, manufacturing, and construction. Graff Zivin and Neidell (2014) suggest that these effects will be amplified in low- to middle-income economies.

Therefore, a worker could be laid off due to weather-driven individual productivity declines or reduce their labor supply. These workers may find it difficult to reallocate into a different sector or transition into a different job within the same sector for a number of reasons. For example, if a worker is laid off, other employers may take a layoff to signal that the worker is a "low productivity type" and be reluctant to hire them (Xie, 2021).

Second, workers may experience high transition costs as well as frictions in the job rematching process that prevent them from reallocating their labor. These effects may be exacerbated in low- and middle-income countries where workers experience greater intersectoral reallocation frictions relative to what they would experience in wealthier countries (Goldberg and Pavcnik, 2007; Dix-Carneiro, 2014; Autor et al., 2014).

When upper-middle-income countries that already have a high baseline unemployment rate experience heat-induced labor productivity shocks, these shocks may severely worsen workers' economic welfare and employment outcomes. Consider Brazil, an economy similar to that of South Africa. When Brazilian workplaces experience heat shocks, daily maximum temperatures above 31 °C, the workers in those workplaces experience a greater likelihood of being laid off–an 11% increase in the baseline propensity to be laid off (Xie, 2021). Furthermore, a substantial portion of these manufacturing workers who experience weather-driven layoffs fail to find any formal re-employment within 36 months. Hence, weather-driven layoffs may lead to persistent negative employment outcomes if workers are unable to transition into different jobs.

A third channel by which weather shocks may affect labor markets is via an economy's dependence on tourism. Thomas et al. (2013) give a useful overview of the myriad ways that drought can affect the tourism and recreation sector, emphasizing the importance of three measures: exposure to drought, sensitivity to drought, and adaptive capacity. The authors emphasize that tourism, like agriculture, is a climate-sensitive sector of the economy. Otrachshenko and Nunes (2021) explore the impact of climate-change-induced wildfires on tourism. Hoogendoorn and Fitchett (2018) focus on the African context, and emphasize that changes in temperature and precipitation will have significant impacts on the tourism sector in Africa. The authors emphasize that the lack of capital intensity and technological flexibility of many African countries will heighten the sensitivity of the tourism sector in those countries to drought and other facets of climate change. Mathivha et al. (2017) and Dube and Nhamo (2020) look at the impact of drought in South African on tourist arrivals to Kruger National Park, while Dube et al. (2021) explores the impact of drought on tourism in the Western Cape. In all cases, the authors emphasize that reductions in tourist arrivals and tourist spending are likely to have significant impacts on employment in that sector.

2.2 South African Labor Market

Having considered three major channels by which weather shocks may influence labor market outcomes, we now provide some country-specific context on the South African labor market. Several distinct features of the South African labor market may influence how workers and firms respond to weather shocks, in ways that have not been observed elsewhere. First, South Africa has a large and persistent unemployment rate. In 2020, Q1, unemployment was 30.1% using the narrow definition and 39.7% using the expanded definition to include discouraged workers (Maluleke, 2020). These high unemployment rates may pose a significant challenge to workers displaced by adverse weather shocks in finding re-employment given the large number of job searchers. Second, the South African labor market is relatively rigid given the significant role of trade unions and formal bargaining mechanisms in determining wages (Godfrey et al., 2007). The combination of high unemployment and a rigid labor market may make it difficult for workers to transition between sectors in response to weather shocks, or for sectors to absorb workers in response to such shocks. If sectors of employment such as manufacturing struggle to adapt, the negative weather-driven impacts on labor markets may exacerbate the harmful effects of climate change on the economy at large.

Lastly, many low- and middle-income economies have sizeable informal sectors that can mitigate any significant losses in individual economic welfare as a result of losing formal employment. However, the informal sector in South Africa is relatively small and exhibits high barriers to entry, resulting in a potentially limited capacity of the informal sector to absorb workers displaced from formal employment as a result of a weather shock (Kingdon and Knight, 2007).

Another factor to consider is that, since 2015, South Africa has experienced severe drought, accompanied by stringent water restrictions. One can expect that these conditions have effects, directly or indirectly, on firms' employment decisions across the economy (Baudoin et al., 2017). For example, water restrictions may have hindered the hospitality industry because hotels or restaurants had to reduce how much water they used.

These distinct features suggest that the South African labor market and economy may be particularly vulnerable to adverse weather shocks, and that the impacts may be qualitatively and quantitatively different from that of other upper-middle-income economies.

3 Data

We leverage two data sets to analyze the impact of weather shocks on employment in South Africa. We use high frequency and high resolution climate data and we also use detailed panel survey data containing individual labor market outcomes. From these data, we create a balanced panel where the unit of observation is an individual in a particular district in a particular year. Table 1 presents the summary statistics of the weather and employment variables discussed in the following subsections.

3.1 Weather Data

We use hourly temperature and precipitation data from the ERA5 data set. This data set provides a spatially complete record of global climate on a 0.25-by-0.25 degree resolution grid from 1979 to 2020. We use a subset of this weather data, spanning the years 1997 to 2018, and construct district-level temperature and precipitation measurements for all 52 districts of South Africa. We construct these district-level weather data using the weighted average of all grid points within 100 kilometers of each district's center (centroid). We use weights that are the inverse of the squared distance between the grid point and the district centroid. At the spatial level of the district, we aggregate the hourly temperature and precipitation measurements to the calendar year level.

We create a twelve-month drought variable at the district level. This binary dummy variable is equal to one if rainfall levels in a particular year are in the bottom 20th percentile, relative to a given district's historical distribution of precipitation. For temperature, we create two sets of temperatures variables. The first is an average temperature variable that measures the average temperature over the calendar year for every district between 1997 and 2018. These variables are measured in degrees Celsius (°C). Table 1 shows that the average annual temperature is approximately 17.51 °C. Our second set of temperature variables capture the effects of extreme heat days, using a degree days specification. We construct two degree day variables, using thresholds of 28 °C and 31 °C, respectively. We define our degree day measures as:

$$DD^k(T) = \sum (T - k) \times 1(T > k),$$

where T is the observed daily temperature and k is the threshold above which temperatures are detrimental. Daily values are summed over the past twelve months. Degree days effectively capture the nonlinear impacts of high temperatures on the agricultural sector (D'Agostino and Schlenker, 2016).

For our drought and temperature measures, we construct variables based on the twelve months prior to the interview survey date. Panel B of Table 1 provides summary statistics for our weather variables. To complement this, Figure 1 displays the spatial variable in temperature and precipitation for the 52 districts of South Africa.

3.2 Employment Data

We use individual panel data on employment from the National Income Dynamics Study (NIDS) of South Africa. NIDS collects representative household and individual employment, income, and consumption information at two-year increments starting in 2008. We use all five waves of NIDS: 2008, 2010, 2012, 2015, and 2017. To determine whether an individual is employed, we construct a binary employment variable where being employed is defined as being a working-age (age 15 or older) individual who is earning a regular wage from a formal source of employment. We exclude from our sample those who are not economically active and those who had less than three successful survey interviews (i.e., those who were present for less than three waves of NIDS). We classify a person as not economically active if any of the following conditions is met: the person is retired, is institutionalized, is a student, is unemployed and has not made an attempt to find any form of work though the five waves of NIDS, or is outside of working age.

In total, we have 7,498 unique, economically active individuals in our sample. In addition to those individuals who are employed, our sample of economically active individuals includes those who are unemployed and discouraged, which is defined as being unemployed, having a desire to work but have not searched for work. Our sample also includes those who are strictly unemployed, which is defined as being unemployed, having a desire to work, and having searched for work within at least four weeks prior to the time of the survey. In addition to our general employment variable, we construct binary employment variables by sector for the agricultural, manufacturing and service sectors respectively. These variables are coded as one if an individual is employed within the particular sector or zero otherwise.

While the agricultural and manufacturing sector variables are already present in NIDS, we construct the service sector employment variable by combining all the tertiary sectors in our sample, which include community and social services; private households; wholesale and retail; transport and communication; and finance, real estate and business services.[2]

Panel A of Table 1 shows that over the nine years NIDS covers, 55% of our sample are employed, which is approximately representative of the country employment rate (using the broad definition of unemployment). 7% of our sample are employed in agriculture, 6% in manufacturing, and 37% in the service sector.

3.3 Tourism Data

To categorize provinces as highly or less highly reliant on tourism, we use data on each province's share of total tourist arrivals from Department of Tourism, South Africa (2019). We scale these tourist arrival shares by the population share of each province. We define tourist-reliant provinces to be those provinces whose ratio of tourist share to population share exceeds one (Free State, Gauteng, Limpopo, Mpumalanga, and Western Cape). And, similarly, less tourism-reliant provinces are those provinces whose ratio of tourist share to population share is less than one (Eastern Cape, KwaZulu-Natal, North West, and Northern Cape).

4 Empirical Strategy

We use a linear probability model with year and district fixed-effects as our baseline empirical framework to explore the impact of rising average temperatures and drought on individual employment outcomes. We estimate

$$Z_{ijmt} = f(w_{jmt}) + \gamma_i + \alpha_j + \alpha_m + \alpha_t + \epsilon_{ijmt}. \quad (1)$$

[2]The definitions of these sectors can be found at https://www.datafirst.uct.ac.za/dataportal/index.php/catalog/88/download/1032.

In our main specification, looking at worker i in district j in month m in year t, Z_{ijmt}, is one of four binary outcome variables: first, a binary variable that the worker is employed in **any** sector; second, a binary variable that the worker is employed in the agricultural sector; third, a binary variable that the worker is employed in the manufacturing sector; and, fourth, a binary variable that the worker is employed in the service sector. The term γ_i represents a set of individual-level demographic controls, specifically a series of dummies for race, gender, and education level. The term α_m is a month fixed effect that controls for any seasonality in employment. The terms α_j and α_t represent district fixed effects and year fixed effects. The district fixed effects control for time-invariant district-level characteristics. The year fixed effects control for time-varying shocks that occur nationwide. The last term is the stochastic error term, ϵ_{ijmt}. The term $f(w_{jmt})$ is a function of drought and temperature, that is based on the twelve previous months to the month of the survey interview. In our first specification, it is function of drought and average temperature:

$$f(w_{jmt}) = \beta_1 drought_{jmt} + \beta_2 average\, temperature_{jmt} \tag{2}$$

We also explore the impact of degree days on the probability of employment. In this specification, the function of weather is

$$f(w_{jmt}) = \beta_1 drought_{jmt} + \beta_2 DD^k_{jmt} \tag{3}$$

where $k \in \{28, 31\}$ is the temperature threshold used for our degree day measure.

In all regressions, standard errors are clustered at the district level to account for serial and spatial correlation.

5 Results

Using the data and empirical strategy outlined in sections 3 and 4, we examine the effects of rising temperatures and drought on employment outcomes of working-age individuals in South Africa. We analyze the effects of these weather shocks on the individual likelihood of employment across the economy, as well as the likelihood of employment in particular sectors of the South African labor market, specifically, the agricultural, manufacturing, and service sectors.

Table 2 presents our main results. In Panel A we present a specification that uses drought and average temperature. In Panels B and C we present specifications that use drought and degree days, with thresholds of 28°C and 31°C. In all three panels, we fail to detect a statistically significant impact of temperature on overall employment, or on employment in agriculture, manufacturing, or services. This result is surprising since earlier work in other country context has found significant impacts of temperature on labor market outcomes (Graff Zivin and Neidell, 2014; Colmer, 2021; Liu et al., 2021; Xie, 2021). One possibility for this discrepancy may be South Africa's relatively milder climate, compared to India (studied by Colmer (2021) and Liu et al. (2021)) and Brazil (studied by Xie (2021)).[3] Relative to results on temperature and labor supply in the U.S. (Graff Zivin and Neidell, 2014), we may be failing to detect an effect because we are looking at the relatively coarse binary measure of employed or not employed, whereas Graff Zivin and Neidell (2014) explore detailed time-use data and look at the intensive margin of employment, rather than the extensive margin.

However, despite these null results for temperature, we do detect large, significant, and robust results for the impact of drought on employment. In Panel A, while controlling for average temperature, we find that the presence of drought conditions in the twelve months prior to the survey interview decreases the probability of overall employment by 3.2 percentage points, an effect that is significant at the 5% level. In Panels B and C, where we control

[3] South Africa's mean annual temperature for 1991-2020 was 18.3°C, compared to 24.7°C for India and 25.5°C for Brazil (World Bank, 2021).

for degree day temperature specifications, we find coefficients on drought that are very similar to magnitude and significance level to our coefficient in Panel A. For this reason, and given our null results for temperature, in subsequent tables we will focus on the specification that controls for average temperature and drought only, and we will focus our interpretation on the drought coefficients.

Table 2 also delivers interesting results of the impact of weather shocks on sectoral employment. As with overall employment, we do not find statistically significant impacts of temperature on sectoral employment in any of three panels. Looking at drought however, we do find a statistically significant relationship with sectoral employment, specifically in the services sector. We that that drought conditions in the past twelve months reduce the probability of service sector employment by 2.8 percentage points, an effect that is significant at the 5% level. In Panels B and C, where we control for degree day specifications, we find coefficients on drought that are very similar to magnitude and significance level to our coefficient in Panel A.

These sectoral results are slightly surprising, since the agricultural sector is often presumed to be more climate-exposed than the service sector, and hence we might expect to see larger effects on agricultural employment (Hlalele et al., 2016; Schreiner et al., 2018). On the other hand, the service sector is substantially larger than the agricultural sector in South Africa (Table 1), which may be why we are better able to detect an effect for services. In addition, if service sector employment in part relies on tourism/recreation, then that channel may explain these results (Hoogendoorn and Fitchett, 2018).

To explore the tourism mechanism further, in Table 3, we repeat our main specification, but divide our sample into districts that have a higher or a lower reliance on tourism, based on the ratio of tourist arrival shares to population shares of each province. In Panel A, we look at individuals living in provinces with a higher reliance on tourism. For these individuals, we find that drought has an even larger impact on overall employment than it did in the full sample: drought conditions in the twelve months prior to the survey date reduce the probability that an individual is employed by 7.3 percentage points, a result that is significant at the 1% level. Looking at sectoral employment in the tourism-reliant provinces, we find that drought in the previous twelve months decreases the probability of being employed in the service sector by 5.3 percentage points.[4] Turning to Panel B, when we look at the provinces with a lower reliance on tourism, we detect no statistically significant effect of drought on either overall or sectoral employment. Indeed, the point estimates for drought for overall employment and service sector employment are small and positive. Taken as a whole, Table 3 provides suggestive evidence that the impacts of drought that we are detecting on overall and service sector employment are driven in part by the tourism sector.

Having found a link between drought and employment, and a possible mechanism (tourism) we now explore how different types of workers may be differentially affected by drought. In Table 4, we explore how hours worked (conditional on being employed) responds to drought. We find no statistically significant effect of drought on overall hours worked. However, when we look at the service sector we find that, conditional on being employed, drought *increases* the hours worked each week, by 1.3 hours. This suggests that the drought-induced reduction in service employment may be driven in part by part-time workers; hence, when these part-time workers leave the pool of the employed, we see average hours of those who remained employed increase slightly.

Next we split our sample by various demographic variables to get further insight into different impacts of drought on employment. In Table 5, we separate our sample by gender. In Panel A, looking at males, we find a negative impact of drought on overall employment, but it is smaller in magnitude than our estimate for the full sample (2.6 versus 3.2) and only significant at the 10% level. We fail to detect a significant effect of drought on service sector employment for males. Turning to Panel B, which focuses on females, we detect a negative impact of drought on overall employment with a point estimate that is larger than

[4] In Panel A, we also find some counterintuitive coefficients on temperature: higher temperatures increase overall employment and service sector employment in the tourism-reliant provinces. While not consistent with earlier research, it is possible these results are driven by South Africa's mild climate, whereby higher temperatures may actually be beneficial for the economy and for labor markets.

our overall sample (3.8 versus 3.2), but as with males it is only significant at the 10% level. Looking at the service sector however, we find a negative impact of drought on service sector employment with a point estimate that is larger than the point estimate for our full sample (3.7 versus 2.9), and significant at the 5% level. Taken as a whole, the results in Table 5 suggest that the negative impacts of drought on employment may be intensified for women in the service sector.

In Table 6, we explore the heterogeneity of our results with respect to education levels. In Panel A, we look at individuals who have completed high school, and in Panel B we look at individuals who did not complete high school. We do not detect any statistically significant effects of drought on overall or sectoral employment for individuals who completed high school. On the other hand, when we look at individuals who did not complete high school, we find that drought reduces overall employment and service sector employment, with both coefficients significant at the 5% level. An important caveat to Table 6, is that the sample size for Panel A is smaller than the sample size for Panel B, and that may perhaps be why we fail to detect an effect in Panel A. For example, looking at the service sector, the coefficients on drought in Panels A and B are both negative and of comparable magnitude. Thus, as a whole, Table 6 provides suggestive but not definitive evidence that the impacts of drought on employment are concentrated on individuals with less education.

Finally, in Table 7, we test for heterogeneous effects by race, by breaking our sample into African (Panel A), Coloured (Panel B), and White (Panel C).[5] When we split the sample this way, we do not detect a statistically significant effect of drought on overall or sectoral employment for any of the racial groups.

[5]The other racial group listed in NIDS, Asian/Indian, has a relatively sample size, and hence we omit it from this analysis.

6 Conclusion

Anthropogenic climate change poses significant challenges to labor markets in developing countries, especially as countries are projected to experience higher temperatures, greater weather variability, and drought (IPCC, 2014). In this paper, we examine the impact of rising temperatures and drought on individual employment outcomes in South Africa. We look at the effect of these weather shocks on the likelihood that an individual has any employment across the economy, and how these weather shocks affect employment in the agricultural, manufacturing and service sectors respectively.

We find that drought negatively impacts the likelihood of employment in any given sector by 3.2 percentage points, and that the most significantly affected sector is the service sector. Meanwhile, we find no effect of drought on employment in the agricultural or manufacturing sectors, and temperature shocks have no impact on employment outcomes in any sector. The negative effect of drought on the service sector and on overall employment suggests that drought may have permanent adverse effects on employment outcomes. As South Africa has experienced severe drought during the time period of our analysis, this weather shock to employment may have significant negative effects on worker welfare, particularly in an economy like South Africa's where unemployment is already high. Our results on the negative impact of drought on labor market outcomes complement existing work that has found negative impacts of drought on human capital and cognitive development (Joshi, 2019; Nübler et al., 2020).

Our paper is one of the first to offer insight into the direct effects of climate change on the labor market in South Africa. We have begun to identify the vulnerability of the workforce in South Africa, the sectors in which workers may be vulnerable, and the types of environmental changes they might be most susceptible to. These findings are important as South Africa faces significant socioeconomic challenges such as high unemployment and poverty levels, as well as slow economic growth, all of which climate change may exacerbate.

Thus, our findings can begin to inform a more comprehensive cost assessment of climate change damage to the South African economy. We also open avenues for further research into understanding the dynamics between climate change and the labor force in South Africa, as well as the type of climate-change-adaptation policy interventions that could alleviate the negative impacts of rising temperatures and drought. Not only will this be helpful for policy formation in South Africa, but for climate–change policy in other African countries, as well as other upper-middle-income countries.

Competing Interests

The authors declare no competing interests.

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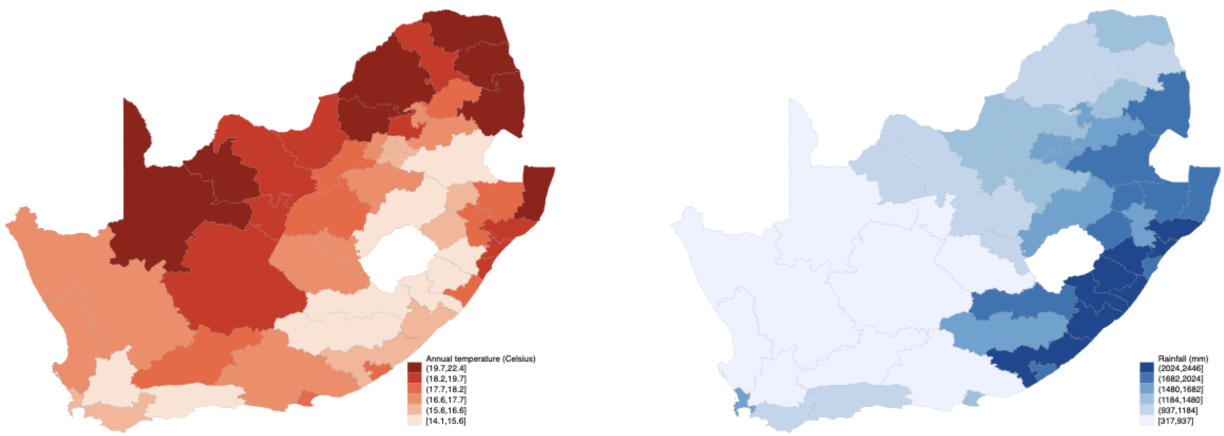
Figures



(a) Annual average temperature

(b) Annual total precipitation

Figure 1: Annual average temperature and annual total precipitation for South African districts.

Tables

Table 1: Descriptive Statistics

Panel A: Weather Data	Observations	Mean	Std. Dev.	Min.	Max.
Annual average temperature	23831	17.51	1.91	13.40	23.04
Annual total precipitation	23831	1445.45	597.24	136.35	2981.50
Drought (indicator)	23831	0.35	0.48	0.00	1.00
Harmful degree days (28°C threshold)	23831	259.22	226.86	13.03	1107.27
Harmful degree days (31°C threshold)	23831	83.28	107.47	0.00	585.57
Panel B: Employment Data	Observations	Mean	Std. Dev.	Min.	Max.
Employed	23831	0.71	0.45	0.00	1.00
Unemployed (discouraged)	23831	0.05	0.22	0.00	1.00
Unemployed (strict)	23831	0.23	0.42	0.00	1.00
Share of workers in agriculture	23831	0.09	0.28	0.00	1.00
Share of workers in manufacturing	23831	0.07	0.26	0.00	1.00
Share of workers in services	23831	0.47	0.50	0.00	1.00
Weekly hours (primary occupation)	16491	40.94	14.62	0.00	168.00
Panel C: Demographic Data	Observations	Mean	Std. Dev.	Min.	Max.
Female	23831	0.54	0.50	0.00	1.00
Completed high school	23831	0.40	0.49	0.00	1.00
African	23831	0.78	0.42	0.00	1.00
Asian or Indian	23831	0.01	0.10	0.00	1.00
Coloured	23831	0.18	0.39	0.00	1.00
White	23831	0.03	0.17	0.00	1.00

Note: The table presents summary statistics for our sample. There are 7,498 different individuals over 9 years across the 52 districts in South Africa. This sample is restricted to those who are of working age and economically active.

Table 2: The effect of drought on the likelihood of employment in any sector and in specific sectors

Panel A: Average temperature	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	0.0134	-0.0093	0.0072	0.0137
	(0.0205)	(0.0087)	(0.0076)	(0.0208)
Drought	-0.0322**	0.0080	-0.0035	-0.0294**
	(0.0136)	(0.0076)	(0.0066)	(0.0133)
Observations	23831	23831	23831	23831
R^2	0.106	0.187	0.037	0.113
Panel B: Degree days (28C)	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Degree day (28)	0.0001	-0.0000	0.0000	0.0002
	(0.0001)	(0.0000)	(0.0000)	(0.0001)
Drought	-0.0336**	0.0067	-0.0021	-0.0322**
	(0.0141)	(0.0076)	(0.0065)	(0.0130)
Observations	23831	23831	23831	23831
R^2	0.107	0.187	0.037	0.113
Panel C: Degree days (31C)	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Degree day (31)	0.0002	-0.0000	-0.0001	0.0003
	(0.0002)	(0.0001)	(0.0001)	(0.0002)
Drought	-0.0319**	0.0067	-0.0009	-0.0309**
	(0.0137)	(0.0075)	(0.0063)	(0.0127)
Observations	23831	23831	23831	23831
R^2	0.106	0.187	0.037	0.113

Note: In column 1, the dependent variable is a binary variable coding whether an individual has any formal employment or not in the South African economy. In the remaining 3 columns, the dependent variable is the binary variable coding whether an individual's primary employment is in agriculture, manufacturing or services. All columns include district and year fixed effects. All weather variables are defined over the 12 months prior to the month of the particular individual's interview. Drought is defined by rainfall in the bottom 20th percentile for each district. Panel A controls for average temperature, Panels B and C control for degree days with thresholds of 28°C and 31°C, respectively. We restrict our sample to individuals who were successfully interviewed in at least 3 waves, and control for individual characteristics such as gender, race and education level. We present robust standard errors clustered at the district level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: The effect of drought on the likelihood of employment: By province's level of tourism dependence

Panel A: Higher reliance on tourism	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	0.0386**	-0.0135	0.0070	0.0512***
	(0.0170)	(0.0150)	(0.0115)	(0.0164)
Drought	-0.0737***	0.0047	-0.0060	-0.0531***
	(0.0176)	(0.0139)	(0.0118)	(0.0188)
Observations	12660	12660	12660	12660
R^2	0.105	0.225	0.033	0.104
Panel B: Lower reliance on tourism	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	0.0157	-0.0017	0.0029	0.0049
	(0.0335)	(0.0119)	(0.0100)	(0.0304)
Drought	0.0019	-0.0014	-0.0012	0.0027
	(0.0197)	(0.0094)	(0.0071)	(0.0167)
Observations	11171	11171	11171	11171
R^2	0.100	0.152	0.046	0.122

Note: In column 1, the dependent variable is a binary variable coding whether an individual has any formal employment or not in the South African economy. In the remaining 3 columns, the dependent variable is the binary variable coding whether an individual's primary employment is in agriculture, manufacturing or services. All columns include district and year fixed effects. All weather variables are defined over the 12 months prior to the month of the particular individual's interview. Drought is defined by rainfall in the bottom 20th percentile for each district. Panel A looks at individuals in provinces that are more reliant on tourism (Free State, Gauteng, Limpopo, Mpumalanga, and Western Cape), while Panel B looks at individuals in provinces that are relatively less reliant on tourism (Eastern Cape, KwaZulu-Natal, North West, and Northern Cape). Tourism reliant provinces are those provinces whose relative share of annual tourists exceeds their relative share of population. We restrict our sample to individuals who were successfully interviewed in at least 3 waves, and control for individual characteristics such as gender, race and education level. We present robust standard errors clustered at the district level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: The effect of drought on hours of employment

	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	-1.9924	-1.8676	0.4411	-2.6214*
	(1.2668)	(2.1821)	(1.7687)	(1.3978)
Drought	0.7663	-0.5599	-2.0549**	1.3234**
	(0.5774)	(1.6983)	(0.8645)	(0.6482)
Observations	16491	2022	1672	10880
R^2	0.073	0.121	0.107	0.076

Note: In column 1, the dependent variable is the number of hours worked (in any sector). In the remaining 3 columns, the dependent variable is the number of hours worked in agriculture, manufacturing or services. All columns include district and year fixed effects. All weather variables are defined over the 12 months prior to the month of the particular individual's interview. Drought is defined by rainfall in the bottom 20th percentile for each district. We restrict our sample to individuals who were successfully interviewed in at least 3 waves, and control for individual characteristics such as gender, race and education level. We present robust standard errors clustered at the district level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: The effect of drought on the likelihood of employment: By gender

Panel A: Males	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	-0.0004	-0.0139	0.0221	-0.0102
	(0.0216)	(0.0127)	(0.0146)	(0.0168)
Drought	-0.0263*	0.0056	-0.0103	-0.0222
	(0.0136)	(0.0099)	(0.0083)	(0.0153)
Observations	10978	10978	10978	10978
R^2	0.109	0.236	0.040	0.120

Panel B: Females	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	0.0269	-0.0076	-0.0076	0.0424
	(0.0270)	(0.0091)	(0.0098)	(0.0297)
Drought	-0.0377*	0.0082	0.0033	-0.0374**
	(0.0199)	(0.0087)	(0.0089)	(0.0184)
Observations	12853	12853	12853	12853
R^2	0.111	0.145	0.040	0.106

Note: In column 1, the dependent variable is a binary variable coding whether an individual has any formal employment or not in the South African economy. In the remaining 3 columns, the dependent variable is the binary variable coding whether an individual's primary employment is in agriculture, manufacturing or services. All columns include district and year fixed effects. All weather variables are defined over the 12 months prior to the month of the particular individual's interview. Drought is defined by rainfall in the bottom 20th percentile for each district. Panel A looks at men while Panel B looks at women. We restrict our sample to individuals who were successfully interviewed in at least 3 waves, and control for individual characteristics such as race and education level. We present robust standard errors clustered at the district level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: The effect of drought on the likelihood of employment: By education level

Panel A: Completed high school	(1)	(2)	(3)	(4)
	All	Agriculture	Manufacturing	Services
Average temperature	0.0083	-0.0105	0.0042	0.0294
	(0.0240)	(0.0083)	(0.0129)	(0.0275)
Drought	-0.0281	0.0075	0.0094	-0.0325
	(0.0181)	(0.0076)	(0.0078)	(0.0220)
Observations	9535	9535	9535	9535
R^2	0.087	0.047	0.051	0.078
Panel B: Did not complete high school	(1)	(2)	(3)	(4)
	All	Agriculture	Manufacturing	Services
Average temperature	0.0176	-0.0070	0.0104	0.0034
	(0.0234)	(0.0117)	(0.0103)	(0.0225)
Drought	-0.0385**	0.0053	-0.0103	-0.0305**
	(0.0155)	(0.0105)	(0.0088)	(0.0142)
Observations	14296	14296	14296	14296
R^2	0.112	0.211	0.044	0.077

Note: In column 1, the dependent variable is a binary variable coding whether an individual has any formal employment or not in the South African economy. In the remaining 3 columns, the dependent variable is the binary variable coding whether an individual's primary employment is in agriculture, manufacturing or services. All columns include district and year fixed effects. All weather variables are defined over the 12 months prior to the month of the particular individual's interview. Drought is defined by rainfall in the bottom 20th percentile for each district. Panel A looks at individuals who have completed high school while Panel B looks at individuals who did not complete high school. We restrict our sample to individuals who were successfully interviewed in at least 3 waves, and control for individual characteristics such as gender, race and education level. We present robust standard errors clustered at the district level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: The effect of drought on the likelihood of employment: By race

Panel A: African	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	0.0054	-0.0091	0.0114	0.0092
	(0.0245)	(0.0095)	(0.0077)	(0.0262)
Drought	-0.0249	0.0061	-0.0038	-0.0200
	(0.0178)	(0.0078)	(0.0085)	(0.0147)
Observations	18530	18530	18530	18530
R^2	0.099	0.155	0.032	0.108
Panel B: Coloured	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	-0.0157	0.0032	-0.0023	-0.0134
	(0.0453)	(0.0161)	(0.0236)	(0.0463)
Drought	0.0050	-0.0279	0.0141	-0.0004
	(0.0313)	(0.0321)	(0.0196)	(0.0304)
Observations	4352	4352	4352	4352
R^2	0.082	0.253	0.083	0.150
Panel C: White	(1) All	(2) Agriculture	(3) Manufacturing	(4) Services
Average temperature	-0.0280	0.0212	-0.0164	-0.0413
	(0.0336)	(0.0289)	(0.0378)	(0.0683)
Drought	0.0002	-0.0337*	0.0272	-0.0274
	(0.0203)	(0.0197)	(0.0410)	(0.0459)
Observations	697	697	697	697
R^2	0.162	0.373	0.123	0.198

Note: In column 1, the dependent variable is a binary variable coding whether an individual has any formal employment or not in the South African economy. In the remaining 3 columns, the dependent variable is the binary variable coding whether an individual's primary employment is in agriculture, manufacturing or services. All columns include district and year fixed effects. All weather variables are defined over the 12 months prior to the month of the particular individual's interview. Drought is defined by rainfall in the bottom 20th percentile for each district. Panel A looks at individuals in the African racial group, Panel B looks at individuals in the Coloured racial group, and Panel C looks at the white racial group. The Asian/Indian racial group is omitted due to its small sample size. We restrict our sample to individuals who were successfully interviewed in at least 3 waves, and control for the individual characteristics of gender and education level. We present robust standard errors clustered at the district level in parentheses.
* p < 0.10, ** p < 0.05, *** p < 0.01.