Environment and Development Economics (2023), **28**, 285–305
doi:10.1017/S1355770X22000237

EDE

RESEARCH ARTICLE

The impact of weather shocks on employment outcomes: evidence from South Africa

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(Submitted 7 September 2021; revised 27 June 2022; accepted 18 July 2022; first published online 9 September 2022)

Abstract

Climate change is increasing the frequency of extreme weather events, such as drought and heat waves. In this paper, we assess the impact of drought and high temperatures on the employment outcomes of working-age individuals in South Africa between 2008 and 2017. We merge high-resolution weather data with detailed individual-level survey data on labor market outcomes, and estimate causal impacts using a fixed effects framework. We find that increases in the occurrence of drought reduce overall employment. These effects are concentrated in the tertiary sector, amongst informal workers, and in provinces with a higher reliance on tourism. Taken together, our results suggest that the impacts of climate change will be felt unequally by South Africa's workers.

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

JEL classification: J21; O12; O55; Q54; Q56

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 can better insulate themselves from destabilizing environmental fluctuations through adaptation, technological innovation, and industrial-centered production (Dell *et al*., 2014). Nevertheless, all economies experience the adverse effects of climate change (Graff Zivin and Neidell, 2014; Colacito *et al*., 2019). Low- and middle-income countries are particularly vulnerable to extreme weather, due to limited adaptive capacity, higher dependency on agriculture, persistent unemployment, and elevated poverty levels (Xie, 2021). Heat waves, drought, and other extreme weather conditions can reduce economic output and may cause significant changes to the workforce in low- and middle-income economies (Hsiang, 2010; Dell *et al*., 2012; Deryugina and Hsiang, 2017; Jain *et al*., 2020).

South Africa presents a critical setting for studying these questions as the country has faced high poverty levels and substantial unemployment – the unemployment rate was 29.1 per cent 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 (Munzhedzi *et al.*, 2016; Ayugi *et al.*, 2022). Given the already high rate of poverty and unemployment in South Africa, any 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 the impact of adverse weather shocks on employment outcomes. We explore the impacts of weather shocks on general employment outcomes as well as sector-specific employment in the primary, secondary, and tertiary sectors.

Multiple channels may link weather shocks and employment outcomes. High temperatures and drought can affect labor market outcomes via adverse impacts on agricultural production that may spill over to other sectors (Liu *et al.*, 2022). Conversely, high temperatures may directly impact labor productivity, which in turn may affect the demand for labor in sectors such as manufacturing and construction (Graff Zivin and Neidell, 2014; Zander *et al.*, 2015; Adhvaryu *et al.*, 2019; Xie, 2021). Lastly, in economies that rely on tourism, high temperatures and drought may affect tourism inflows, and subsequently the demand for labor in the service sector that relies on tourists for revenue (Hoogendoorn and Fitchett, 2018; Dube *et al.*, 2022).

To explore the relationship between weather shocks and employment outcomes, we use individual-level panel survey data from the National Income Dynamics Study (NIDS) of South Africa (Southern Africa Labour and Development Research Unit, 2018). NIDS contains individual employment, income, and consumption data from a representative sample of the South African population at roughly two-year intervals 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 (Hersbach *et al.*, 2018), and create district-level weather outcomes for each of South Africa's 52 districts – the most spatially granular level that is possible when using the NIDS publicly accessible data. For each individual, we construct measures of drought and high temperatures for the 12 months prior to their NIDS interview date, based on their district of residence.

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 high temperatures and drought on the likelihood of employment and sectoral employment amongst the NIDS working–age sample population. Our unit of observation is an individual in a particular year, month, and district. We estimate a linear probability model with district, month, and year fixed effects, and we include province-specific linear time trends. We also control for race, gender, age, and age squared. Our identifying assumption is that, conditional on these 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 find four major results. First, drought conditions during the 12 months prior to the survey interview date have statistically significant impacts on overall employment: a one standard deviation increase in our drought variable reduces the overall

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

employment rate by 1.4 per cent.[1] Second, we find that drought reduces tertiary (service) sector employment – a one standard deviation increase in drought reduces tertiary sector employment by 1.7 per cent – but we fail to detect evidence that drought affects primary or secondary sector employment.[2] Third, we find that these effects are concentrated in the informal sector: a one standard deviation increase in our drought variable triggers a 7.8 per cent reduction in (all-sector) informal employment. Fourth, we find that the negative impacts of drought on employment are concentrated in provinces with a higher reliance on tourism, and in the transportation subsector, which relies heavily on tourism.

We contribute to the rapidly growing literature on the impacts of climate change on labor markets. In this literature, 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, such as agriculture, manufacturing, and construction. Similarly, Xie (2021) finds that quarterly heat shocks in Brazil lead to significant increases in the probability of layoffs among workers in manufacturing. Antonelli *et al.* (2021) find that temperature has a nonlinear effect on agricultural labor supply in Uganda, with number of hours worked being maximized at 21.3°C. Shayegh *et al.* (2021) find that high temperatures reduce weekly labor supply for 'low-skill' South African workers more sharply than for 'high-skill' South African workers. Mueller and Osgood (2009) find that drought has long-term effects on rural wages in Brazil.

We provide an important contribution to this literature with evidence that adverse weather shocks, specifically drought, can affect the tertiary sector, whereas the bulk of the existing literature has focused on the primary or secondary sectors. In addition to finding tertiary sector impacts, we also provide insight into the mechanisms driving those impacts – through our analysis of the informal sector, the tourism sector, and the transportation subsector – which further strengthens our contribution. Our results add to the body of literature that demonstrates that climate impacts will be heterogeneous, even within countries (Park *et al.*, 2018; Winsemius *et al.*, 2018; Behrer *et al.*, 2021; Liu *et al.*, 2022).

Our results are highly policy-relevant; given South Africa's significant levels of poverty, inequality, and unemployment, climate change may have significant impacts on worker welfare.[3] Moreover, assessing the potential costs of climate change in an upper-middle-income country such as South Africa – and the degree to which such a country can insulate itself from extreme weather conditions – provides an important perspective in the formulation of effective climate mitigation policy in other upper-middle-income countries more broadly.

This paper is organized as follows. Section 2 provides background on the literature on the climate–employment as well as on South Africa's labor market, tourism sector, and

[1]Our drought variable is the fraction of the 12 previous months that were in drought conditions, where drought conditions are defined as rainfall levels below the 20th percentile for that district-month. Please refer to section 3 for further details of our drought variable.

[2]NIDS defines the primary sector as agriculture and mining; the secondary sector as manufacturing, utilities, and construction; and the tertiary sector as domestic workers, wholesale and retail, transportation and communication, and finance, real estate and business services.

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

recent drought experiences. Section 3 describes our data. Section 4 outlines our empirical strategy. Section 5 presents our results. In section 6, we verify the robustness of our results to specification changes. In section 7, we conclude.

2. Background

2.1 Weather shocks and employment

Research demonstrates that adverse weather conditions can reduce economic prosperity through many mechanisms, including hindering labor productivity, and lowering agricultural and industrial output (Acevedo *et al.*, 2020). For example, high temperatures can lower aggregate economic output, and thereby 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). We highlight three channels through which weather shocks can affect labor markets: an agricultural channel, a labor productivity channel, and a tourism channel.

Regarding the agricultural channel, high temperatures and drought may reduce agricultural output (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.*, 2021), may have limited efficacy in reducing losses. Adverse shocks to agricultural output can, in turn, affect labor markets in three ways. First, adverse weather shocks may directly affect employment if they reduce the demand for agricultural labor, leading to higher unemployment among agricultural workers or reduced agricultural 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, given intersectoral input-output linkages, a decline in agricultural production could reduce labor demand in industries that use agricultural outputs in their production processes (Acemoglu *et al.*, 2012), such as agricultural-related manufacturing and food processing. Finally, weather-induced declines in agricultural output, employment, wages, and incomes may reduce the local demand for manufactured goods and services, especially given any barriers to internal trade (Henderson *et al.*, 2017; Emerick, 2018; Santangelo, 2019; Albert *et al.*, 2021; Liu *et al.*, 2022). If the decrease in local demand is substantial, it may trigger reductions in local non-agricultural firm revenue and profitability, leading to further declines in labor demand. However, if markets are well-integrated regionally or globally and labor markets are flexible, then weather-driven agricultural productivity shocks may not increase non-agricultural unemployment (Colmer, 2021).

The second channel linking weather shocks and labor markets is physiological. High temperatures can lower endurance, increase fatigue, and reduce cognitive performance, which may reduce labor productivity (Pilcher *et al.*, 2002; Hancock *et al.*, 2007) and economic output (Kjellstrom *et al.*, 2009; Hsiang, 2010; Graff Zivin and Neidell, 2014; Zander *et al.*, 2015; Adhvaryu *et al.*, 2019). Graff Zivin and Neidell (2014) find that high temperatures decrease U.S. labor supply in climate-exposed industries such as agriculture, manufacturing, and construction. Somanathan *et al.* (2021) find that high temperatures reduce worker productivity in the Indian manufacturing sector, while Oliveira *et al.* (2021) find that hot days in Brazil reduce non-agricultural wages and increase worker absenteeism. Weather-induced productivity declines may trigger layoffs and workers may find it difficult to transition into new jobs due to transition costs and matching frictions (Dix-Carneiro, 2014; Xie, 2019).

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

A third channel linking weather shocks and labor markets is tourism. Thomas *et al.* (2013) review the multiple 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 (2022) explore the impact of climate-change-induced wildfires on tourism. Hoogendoorn and Fitchett (2018) focus on the sub-Saharan 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) find that drought reduces the number of tourist arrivals to South Africa's Kruger National Park, while Dube *et al.* (2022) find that drought reduces tourist spending and hotel occupancy rates in the Western Cape. In all cases, the authors emphasize that drought-induced reductions in tourist arrivals and spending are likely to have significant impacts on employment in the tourism sector.

2.2 Background on South Africa

Several features of the South African labor market may influence how workers and firms respond to weather shocks. First, South Africa has a large and persistent unemployment rate: 29.1 per cent in Q4 of 2019 (Statistics South Africa, 2019). High unemployment makes it harder for displaced workers to find re-employment, given the large number of job searchers. Second, the labor market is relatively rigid (Fedderke, 2012), with trade unions and formal bargaining mechanisms playing a significant role in wage determination (Godfrey *et al.*, 2007). The rigid labor market may also make it hard for displaced workers to transition to other sectors, potentially intensifying the negative impacts of adverse weather shocks on employment. Finally, relative to many low- and middle-income economies, the informal sector in South Africa is relatively small and exhibits high barriers to entry, suggesting that workers displaced from formal to informal sector employment may experience a substantial loss in position, earnings and job stability (Kingdon and Knight, 2007).

We turn now to tourism, a sector that makes up a significant part of the South African economy, employing, in 2019, more individuals than the sectors of agriculture, utilities (electricity, gas and water), and construction (Statistics South Africa, 2021). Within the tourism sector, transportation is an important source of employment. For example, in 2007, road passenger transportation was the largest subsector of the tourism industry, representing 29 per cent of total tourism employment (Statistics South Africa, 2011). All forms of transportation (railway, road, air, rental, and travel agencies) represented 36 per cent of total tourism employment in 2007 (Statistics South Africa, 2011). Transportation has remained a consistent source of tourism employment in South Africa over time: in 2019, 31 per cent of tourism workers were employed in road transportation (Statistics South Africa, 2021).

Lastly we consider drought, which has significantly impacted the South Africa economy in recent years. Since 2015, South Africa has experienced severe drought, accompanied by stringent water restrictions (Baudoin *et al.*, 2017). Climate change is projected to increase temperatures in South Africa and reduce precipitation in the western and central regions (Schlosser *et al.*, 2021). Drought conditions are likely to have effects – both direct and indirect – on firms' employment decisions across the economy (Baudoin

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

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. As discussed above, drought has reduced tourist arrivals, tourist spending, and hotel occupancy rates (Mathivha *et al.*, 2017; Dube and Nhamo, 2020; Dube *et al.*, 2022).

Considered holistically, these features of labor markets, tourism, and drought in South Africa suggest that the South African labor market may be especially vulnerable to adverse weather shocks, and that South Africa's tourism sector may be especially vulnerable to drought.

3. Data

We use three datasets in our empirical analysis: employment data from the National Income Dynamics Study or NIDS of South Africa; weather data from the ERA5-Land hourly data set; and tourism data from South Africa's Department of Tourism.

3.1 Employment data

We use individual employment data from the NIDS of South Africa (Southern Africa Labour and Development Research Unit, 2018), a nationally representative dataset which provides household and individual data on employment, income, and consumption. Survey waves occur approximately every 2 to 3 years, starting in 2008, with an initial sample size of 28,000 individuals. We use all five waves of NIDS: 2008, 2010/2011, 2012, 2014/2015, and 2017. We restrict our sample to working age individuals, defined in South Africa to be ages 15 to 64. We exclude from our sample individuals who are institutionalized or permanently disabled and unable to work.

Within our sample, we assign each individual in each year one of four labor market outcomes: formally employed, informally employed, unemployed, or not economically active. Formal employment is defined as earning a regular wage or salary in either full-time or part-time work at the time of the survey. Informal employment is defined as self-employment or paid casual employment within the 30 days prior to the survey. Casual employment encompasses work that is irregular and short-term. Unemployment is defined as having the desire to work but not actually working in the past 30 days, while those who do not have the desire to work are defined as economically inactive. We also construct corresponding employment variables for the primary, secondary, and tertiary sectors. The primary sector covers agriculture and mining. The secondary sector includes manufacturing, utilities, and construction. The tertiary sector includes: wholesale and retail; transportation and communication; finance, real estate, and business services; community and social services; and, domestic workers.[4]

In addition to employment indicators, we construct labor income earnings for the month prior to the NIDS interview date, which we deflate to 2015 Rand.[5] Finally, we extract demographic controls on age, gender, and race from the NIDS survey.

Panels A and B of table 1 present summary statistics for our NIDS sample, for our employment variables and demographic variables, respectively. Thirty-five per cent of the working age population in our sample was employed at the time they were surveyed, with 17 per cent unemployed and the remaining 48 per cent not economically active.

[4]Community and social services includes services such as education and health care. Domestic workers includes workers such as housekeepers, gardeners, security guards, tutors, and caretakers.

[5]For the year 2015, the average exchange rate was 1 RAND = 0.0788 USD.

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

Table 1. Descriptive statistics

Panel A: Employment data	Observations	Mean	Std. Dev.	Min.	Max.
Employed	83,099	0.35	0.48	0.00	1.00
Employed in primary sector	83,099	0.05	0.22	0.00	1.00
Employed in secondary sector	83,099	0.07	0.25	0.00	1.00
Employed in tertiary sector	83,099	0.23	0.42	0.00	1.00
Formally employed	83,099	0.30	0.46	0.00	1.00
Informally employed	83,099	0.06	0.23	0.00	1.00
Unemployed	83,099	0.17	0.37	0.00	1.00
Not economically active	83,099	0.48	0.50	0.00	1.00
Monthly labor income (2015 Rand)	78,848	1957.21	6744.75	0.00	150000.00
Panel B: Demographic data	Observations	Mean	Std. Dev.	Min.	Max.
Age	83,099	33.79	13.89	15.00	64.00
Female	83,099	0.58	0.49	0.00	1.00
African	83,099	0.82	0.38	0.00	1.00
Asian or Indian	83,099	0.01	0.11	0.00	1.00
Coloured	83,099	0.14	0.34	0.00	1.00
White	83,099	0.03	0.17	0.00	1.00
Panel C: Weather data	Observations	Mean	Std. Dev.	Min.	Max.
Drought (fraction of the 12 previous months)	83,099	0.31	0.32	0.00	1.00
Total annual precipitation (meters)	83,099	0.40	0.14	0.04	0.80
Degree days, 31C threshold (100)	83,099	0.56	0.73	0.00	4.18
Annual average temperature (C)	83,099	17.43	1.93	12.83	22.22

Note: The table presents summary statistics for our analysis sample.

Looking at the 35 per cent who were employed, this can be broken down as 5 per cent of the sample employed in the primary sector, 7 per cent employed in the secondary sector, and 23 per cent employed in the tertiary sector.[6]

3.2 Weather data

We use weather data from the ERA5-Land hourly dataset (Hersbach *et al.*, 2018) , a global gridded dataset with 0.2-by-0.2 degree spatial resolution and hourly temporal resolution. To construct daily temperature and precipitation outcomes for each of South Africa's 52 districts, we overlay the district shape files with the ERA5 grid and take an area-weighted average of all the grid squares falling within a given district. We next aggregate up to 12-month values, always defined as the 12 months prior to a given NIDS interview date.

To capture the impacts of low rainfall, we first define a month to be in drought conditions if its total rainfall falls below the 20th percentile of that district-month's historical

[6]Primary sector employment is dramatically lower in South Africa than in the rest of sub-Saharan Africa (Brookings Institution, 2017).

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

rainfall distribution. We then create a 12-month drought measure that is the fraction of the 12 previous months that were in drought conditions. We use 1978 to 2007, the 30-year period prior to the start of NIDS, as our reference for the historical distribution, following the standard practice of the climatology literature (World Meteorological Organization, 2017). We focus on drought because the existing literature has found important nonlinear impacts in the precipitation–employment relationship (Adhvaryu *et al.*, 2013; Emerick, 2018). In addition to drought, we also construct a variable capturing total precipitation in the 12 months prior to the NIDS interview date.

To examine the impacts of high temperatures, we construct a degree days measure with a threshold of 31°C, defined as:

$$DD^{31}(T_{dmy}) = \sum (T_{dmy} - 31) \times 1(T_{dmy} > 31),$$

where T_{dmy} is the maximum temperature on day d, month m, and year y; and daily values are summed over the 12 months prior to the interview survey date. Earlier literature has demonstrated important nonlinearities of the impacts of temperature on employment (Graff Zivin and Neidell, 2014; Behrer *et al.*, 2021; Shayegh *et al.*, 2021; Somanathan *et al.*, 2021; Xie, 2021). We chose a degree day specification because it can capture nonlinearity, while being more concise than temperature bins (D'Agostino and Schlenker, 2016). Our chosen threshold of 31°C is broadly consistent with the thresholds found by the climate–employment literature (Graff Zivin and Neidell, 2014; Behrer *et al.*, 2021; Shayegh *et al.*, 2021; Somanathan *et al.*, 2021; Xie, 2021). In addition to degree days, we also construct average temperature, defined over the 12 months prior to the NIDS interview date.

Panel C of table 1 provides summary statistics for our weather variables. Online appendix figure A1 displays maps of temperature and precipitation for the South African districts.

3.3 Tourism data

To measure each province's level of tourism reliance, we use province-level data on tourism revenue shares in 2007 from the South African Tourism Strategic Tourism Unit (2008). We define tourist-reliant provinces to be those provinces whose ratio of tourist revenue share to population share exceeds the median. Using this definition, the tourism-reliant provinces are the Free State, Gauteng, Mpumalanga, Northern Cape, and Western Cape, and the less tourism-reliant provinces are Eastern Cape, KwaZulu-Natal, North West, and Northern Cape.[7]

4. Empirical strategy

To explore the impact of high temperatures and drought on employment, we estimate a linear probability model of the form:

$$Z_{ijpmt} = \beta_1 \text{Drought}_{jpmt} + \beta_2 DD^{31}_{jpmt} + X'_{it}\delta + \alpha_j + \alpha_m + \alpha_t + \lambda_p t + \epsilon_{ijpmt}. \quad (1)$$

In our general employment specification, Z_{ijpmt} is an indicator that equals one if individual i, in district j, province p, month m, and year t is employed and zero otherwise.

[7] We get the same categorization if we look at tourist bed-nights instead of revenues.

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

In our sectoral specifications, Z_{ijpmt} is an indicator variable that is one if individual i is employed in the primary, secondary, or tertiary sectors, respectively, and zero otherwise. Drought_{jpmt} measures for district j the fraction of the past 12 months that were in drought conditions, while DD^{31}_{jpmt} measures the total degree days in the past 12 months, relative to a 31°C threshold.

The term $X'_{it}\delta$ captures individual-level demographic controls, specifically indicators for race and gender, and controls for age and age squared. The term α_m is a month fixed effect that controls for any seasonality in employment. The terms α_j are district fixed effects, which control for time-invariant district-level characteristics, while α_t are year fixed effects, which control for time-varying shocks that occur nationwide. $\lambda_p t$ accounts for province-specific linear time trends. Finally, ϵ_{ijpmt} is the stochastic error term. We cluster standard errors at the district level to allow for serial and spatial correlation.

5. Results

Table 2 presents our main results on the effect of weather shocks on employment in South Africa. Panel A shows the impact of drought and high temperatures on all types of employment (formal and informal), while panels B and C look at the effects on formal and informal employment separately. We first discuss the impact of drought on employment. Our drought variable is measured as the fraction of months (in the 12 months prior to the NIDS survey interview) that were below the 20th percentile for that district-month's historical rainfall distribution. Looking at column (1) of panel A, we find that a higher prevalence of drought conditions decreases the probability of overall employment, with the effect significant at the 1 per cent level. In terms of magnitudes, the standard deviation of our fractional drought measure is 0.32, which corresponds to $0.32 * 12 = 3.84$ months. In other words, a one standard deviation increase in our drought variable corresponds to an additional 3.84 months in the previous year being under drought conditions. Our regression estimate from column (1) of panel A suggests that a one standard deviation increase in our drought variable will reduce overall employment by 0.49 percentage points, which, relative to the baseline employment rate of 35 per cent, corresponds to a 1.4 per cent reduction.

Turning now to the impact of high temperature on employment, we note that table 2 fails to detect any statistically significant impact of temperature on overall employment or on employment in any of the three sectors. This non-result also holds for formal and informal employment. This result is surprising since earlier work in other countries has found significant impacts of temperature on labor market outcomes (Graff Zivin and Neidell, 2014; Colmer, 2021; Xie, 2021; Liu *et al.*, 2022). One possibility for this discrepancy may be South Africa's relatively milder climate, compared to India's (studied by Colmer, 2021; Liu *et al.*, 2022) and Brazil (studied by Xie, 2021).[8]

Another potential explanation for our failure to find an impact of temperature on employment is the temporal resolution that we aggregate our data to (12-month windows), combined with the suite of fixed effects that we are using (district, month, and year fixed effects, plus province-specific time trends). It is possible that given the spatial and temporal range of our data, there is insufficient variation in temperature for us to capture a meaningful effect of temperature on employment. To explore this possibility,

[8]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).

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

Table 2. The effect of drought on the likelihood of employment

Panel A: All employment	(1) All	(2) Primary	(3) Secondary	(4) Tertiary
Drought	−0.0156 (0.0053)	−0.0026 (0.0041)	−0.0015 (0.0035)	−0.0126 (0.0058)
Degree days, 31C threshold	0.0156 (0.0120)	0.0058 (0.0087)	0.0066 (0.0062)	0.0049 (0.0103)
Observations	83,099	83,099	83,099	83,099
R^2	0.241	0.086	0.060	0.140
Dep. var. mean	0.3530	0.0534	0.0668	0.2344
Panel B: Formal employment	(1) All	(2) Primary	(3) Secondary	(4) Tertiary
Drought	−0.0046 (0.0067)	0.0003 (0.0047)	0.0003 (0.0033)	−0.0052 (0.0059)
Degree days, 31C threshold	0.0138 (0.0115)	0.0032 (0.0066)	0.0079 (0.0052)	0.0026 (0.0091)
Observations	83,099	83,099	83,099	83,099
R^2	0.201	0.085	0.050	0.121
Dep. var. mean	0.2991	0.0478	0.0518	0.1995
Panel C: Informal employment	(1) All	(2) Primary	(3) Secondary	(4) Tertiary
Drought	−0.0127 (0.0056)	−0.0030 (0.0016)	−0.0013 (0.0018)	−0.0084 (0.0045)
Degree days, 31C threshold	0.0055 (0.0072)	0.0019 (0.0034)	−0.0010 (0.0036)	0.0046 (0.0058)
Observations	83,099	83,099	83,099	83,099
R^2	0.052	0.010	0.021	0.031
Dep. var. mean	0.0579	0.0057	0.0151	0.0371

Notes: The dependent variable in column (1) is a binary indicator of employment; the dependent variable in columns (2), (3), and (4) is a binary indicator for employment in the primary, secondary, and tertiary sectors, respectively. In panel A, the indicators equal one if the individual has any type of employment; in panels B and C they equal one if the individual has formal or informal employment, respectively. The drought variable measures the fraction of 12 months prior to the interview that were in drought conditions; degree days also refer to the 12 months prior to the interview. All columns include district fixed effects, month fixed effects, year fixed effects, and province-specific time trends. All columns control for gender indicators, race indicators, age, and age squared. Standard errors, in parentheses, are clustered at the district level.

in online appendix table A1, we present the residual variation of our various weather variables for our sample, both looking at the raw data of each individual variable, and also looking at the residual variation that remains after we condition on our fixed effects. What we find is quite striking. Whereas the residual variation of our fractional drought measure falls only about 22 per cent in the presence of the fixed effects (from 0.3220 to 0.2501), the residual variation of our degree day measure falls by 77 per cent (from 0.1353 to 0.0518). Put differently, if we regress a given weather variable on our set of fixed effects, those fixed effects explain 39.7 per cent of the variation in our drought measure but a whopping 94.5 per cent of the variation in our degree day measure. From this exercise, we conclude that our study design will allow us to make inferences about the impact of drought on employment but not on the impact of high temperatures on employment. Thus, moving ahead, we focus on the impacts of drought, although we continue to include degree days as a control.

Turning back to drought, we now focus on columns (2), (3), and (4) of table 2 to explore the impact of drought on sectoral employment in the primary, secondary, and tertiary sectors. We do not detect an effect of drought on employment in the primary or secondary sectors in panel A, although the point estimates for these outcomes are negative. We do detect a negative and statistically significant effect of drought on employment in the tertiary sector. A one standard deviation increase in our drought variable will reduce tertiary sector employment by 0.40 percentage points, which is a 1.7 per cent reduction, relative to the baseline rate of 23 per cent. Our finding of a negative impact of a weather shock on tertiary sector employment is novel, since the primary and secondary sectors are often presumed to be more climate-exposed than the tertiary sector. The existing literature has largely focused on the impact of adverse weather shocks on employment in either the primary sector (Hlalele *et al.*, 2016; Schreiner *et al.*, 2018) or secondary sector (Somanathan *et al.*, 2021; Xie, 2021). In the case of South Africa, we hypothesize that service sector employment relies in part on tourism and recreation, and that reliance on those sectors may explain why we detect an effect of drought on the service sector, but not the primary and secondary sectors (Hoogendoorn and Fitchett, 2018). We will explore this in more detail in table 3.

But first, we turn to panels B and C of table 2 and discuss the separate impacts of drought on formal employment and informal employment. In panel B we do not detect a statistically significant effect of drought on formal employment for any sector. The point estimates for all-sectors and the tertiary sector are negative, but they are not significant and are about three times smaller than the corresponding estimates from panel A. In contrast, as shown in panel C, we find strong negative effects of drought on informal employment, both for all-sector employment (significant at the 5 per cent level) and for primary and tertiary employment (each significant at the 10 per cent level). The coefficients on drought in panel C are similar in magnitude to those of panel A, but – since baseline informal employment is relatively low – the proportional impacts are bigger. For example, a one standard deviation increase in our drought variable leads to a 0.41 percentage point decrease in all-sector informal employment which, relative to the 5.2 per cent baseline rate of informal employment in our sample, is a 7.8 per cent reduction in informal employment. The concentration of drought impacts in the informal sector – rather than the formal sector – makes intuitive sense, since informal workers (which encompasses casually employed workers) are inherently easier to hire and/or fire as needed, especially given South Africa's more rigid formal labor markets institutions (Godfrey *et al.*, 2007; Fedderke, 2012). Moreover, informal micro-enterprises are likely to be more vulnerable to external climate related shocks.

Taken as a whole, table 2 shows that drought has negative impacts on employment and that these effects appear to be concentrated in the tertiary sector and in the informal sector. Given that these findings on the tertiary sector are novel relative to the existing literature, we now explore what factors might be driving these tertiary sector impacts. Given that earlier work has shown South Africa's tourism industry to be vulnerable to drought (Mathivha *et al.*, 2017; Dube and Nhamo, 2020; Dube *et al.*, 2022), we begin by exploring the role of tourism reliance as a driver of our effects. In table 3, we repeat our main specification, but interact both of our weather shocks with a high-tourism indicator, which equals one for provinces where the ratio of tourism revenue to province

Table 3. The effect of drought on the likelihood of employment: heterogeneity by location's level of tourism dependence

Panel A: All employment	(1) All	(2) Primary	(3) Secondary	(4) Tertiary
Drought	−0.0010 (0.0069)	−0.0016 (0.0048)	0.0004 (0.0046)	−0.0010 (0.0065)
High tourism = 1 × Drought	−0.0365 (0.0127)	−0.0021 (0.0077)	−0.0047 (0.0077)	−0.0294 (0.0130)
Observations	83,099	83,099	83,099	83,099
R^2	0.241	0.086	0.060	0.140
Dep. var. mean	0.3530	0.0534	0.0668	0.2344
Panel B: Formal employment	(1) All	(2) Primary	(3) Secondary	(4) Tertiary
Drought	−0.0008 (0.0076)	−0.0013 (0.0049)	0.0006 (0.0042)	−0.0001 (0.0065)
High tourism = 1 × Drought	−0.0098 (0.0135)	0.0045 (0.0073)	−0.0009 (0.0067)	−0.0134 (0.0130)
Observations	83,099	83,099	83,099	83,099
R^2	0.201	0.085	0.050	0.121
Dep. var. mean	0.2991	0.0478	0.0518	0.1995
Panel C: Informal employment	(1) All	(2) Primary	(3) Secondary	(4) Tertiary
Drought	−0.0014 (0.0053)	−0.0003 (0.0021)	0.0006 (0.0024)	−0.0017 (0.0034)
High tourism = 1 × Drought	−0.0276 (0.0082)	−0.0065 (0.0024)	−0.0046 (0.0034)	−0.0165 (0.0067)
Observations	83,099	83,099	83,099	83,099
R^2	0.053	0.010	0.021	0.031
Dep. var. mean	0.0579	0.0057	0.0151	0.0371

Notes: High tourism is an indicator that equals one if an individual works in a province with a high reliance on tourism (Free State, Gauteng, Mpumalanga, Northern Cape, and Western Cape), which is defined as those provinces whose ratio of tourism revenue to province population was at or above the median in 2007. The provinces with a low reliance on tourism are Eastern Cape, KwaZulu-Natal, Limpopo, and North West. All columns control for degree days and degree days interacted with the high-tourism indicator. All columns include district fixed effects, month fixed effects, year fixed effects, and province-specific time trends. All columns control for gender indicators, race indicators, age, and age squared. Standard errors, in parentheses, are clustered at the district level.

population was at or above the median in 2007. Given this definition, the provinces with a high reliance on tourism are the Free State, Gauteng, Mpumalanga, Northern Cape, and Western Cape, while the provinces with a low reliance on tourism are Eastern Cape, KwaZulu-Natal, Limpopo, and North West. Interacting the weather shocks with the high-tourism indicator allows us to capture the potential heterogeneous effects of drought relative to tourism reliance.

The results presented in panel A of table 3 explore the heterogeneous effects of tourism reliance on overall employment. The coefficient on drought captures the impact of drought on employment for low-tourism areas, whereas the impact of drought on employment in high-tourism areas is captured by the sum of the drought coefficient and

https://doi.org/10.1017/S1355770X22000237 Published online by Cambridge University Press

the tourism-drought interaction term. All columns control for degree days and degree days interacted with the high-tourism indicator. Panel A shows that we fail to detect a statistically significant effect of drought on overall employment in the low-tourism areas. In high-tourism areas, we find that drought has a statistically significant negative effect on all-sector employment and tertiary sector employment. We find that in high-tourism areas, a one standard deviation increase in our drought variable leads to a 1.2 percentage point decrease in overall employment, which is a 3.4 per cent reduction relative to the 35 per cent baseline rate.

In panel B, we explore the heterogeneous effects of tourism reliance on formal sector employment. Here, consistent with the results of table 2, we fail to find any effect of drought on formal sector employment. Taken together, these results suggest that even in areas with high levels of tourism reliance, formal sector jobs seem to be relatively well-insulated from drought shocks. Finally, in panel C, we analyze informal employment. We fail to detect an impact of drought on informal employment in low-tourism areas. But, in locations with a high reliance on tourism, we find large, negative, and statistically significant effects of drought on informal employment for all-sector employment, primary sector employment, and tertiary sector employment. We find that a one standard deviation increase in our drought variable leads to a 0.9 percentage point decrease in all-sector informal employment, which is a 17.2 per cent reduction relative to the baseline rate of 5.8 per cent. Thus, we find larger effects on overall and informal employment in high-tourism areas than we found for the full sample in table 2. The coefficient sizes for drought impacts on the tertiary sector in high-tourism areas are also correspondingly larger in table 3 than they are in table 2.

The results in table 3 suggest that the impacts of drought on overall and tertiary sector employment in table 2 may be driven, in part, by the tourism sector. However, a potential concern that arises when interpreting the results of table 3 is that there may be systematic differences between high- and low- tourism reliance areas, and that these systematic differences – and not tourism reliance itself *per se* – could be driving the results of table 3. To explore this issue further, we construct a balance table. Column (1) of online appendix table A2 presents the mean and standard deviations for our weather, employment, and demographic variables for the high-tourism districts. Column (2) does the same for the low-tourism districts, and column (3) runs a t-test for the difference across the two groups.

From the weather variables in panel A, we see that over our sample period there is no statistically significant difference across high- versus low-tourism districts for the outcomes of drought, degree days, or average temperature. There is however, a statistically significant difference in levels of total precipitation: high-tourism districts have significantly less total precipitation in our sample period than low-tourism districts. This lower level of rainfall is concerning, because one could imagine that drought could be more harmful in areas that already suffer relatively lower rainfall. If this were the case, then heterogeneity in historical rainfall levels, rather than heterogeneity in tourism reliance, might be driving the results in table 3.

To explore this issue, online appendix table A3 repeats our tourism heterogeneity specification and adds controls for a low-historical-rainfall indicator that is interacted with our weather shocks. The low historical rainfall indicator equals one if a given district's historical rainfall is below the South African median, and is zero otherwise. The interaction between this indicator and our drought variable captures the fact that drought might have intensified impacts in areas with low historical rainfall. The results

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of table A3 are reassuring. We find that low historical rainfall levels may exacerbate the effect of drought, particularly on secondary sector employment. But, importantly our tourism heterogeneity results – for overall employment, informal employment, and tertiary sector employment – remain strongly robust to the inclusion of this additional control. Thus table A3 provides reassuring evidence that underlying differences in rainfall patterns do not drive our tourism heterogeneity results.

Turning now to panel B of online appendix table A2, we look at differences in our employment variables across the high- versus low-tourism districts. We find a large number of statistically significant differences. Relative to low-tourism districts, high-tourism districts have higher rates of overall employment, secondary sector employment, tertiary sector employment, and formal employment. High-tourism districts also have lower rates of economically inactive individuals and higher average labor income earnings. There are, however, no statistically significant differences in primary sector employment, informal employment, or unemployment. Taken holistically, these differences suggest that the high-tourism districts are overall more economically prosperous. Since all of these outcome variables are endogenous, we cannot attempt to control for them econometrically, as we did for historical rainfall levels. However, earlier research suggests that, within a country, adverse weather shocks are likely to have greater negative impacts on individuals in poorer areas, relative to those in more affluent areas (Hsiang *et al.*, 2019; Behrer *et al.*, 2021). In contrast, we find in table 3 that drought impacts are greater in the high-tourism areas. Thus, qualitatively, it seems unlikely that the higher rates of economic prosperity in high-tourism districts are driving the intensified drought response that we are finding. Rather, it may be the underlying structure of that economy, and its greater reliance on tourism.

To further understand the mechanisms driving our tourism heterogeneity results, we turn to an analysis of the subsectors of the tertiary sector, presented in table 4. Since certain subsectors of the tertiary sector are more or less likely to serve the tourism industry, we can test for differential effects across the tertiary subsectors and see whether we find greater effects in those subsectors most closely linked to tourism. The five subsectors of the tertiary sector, as given in the NIDS data, are wholesale and retail trade, transportation and communication, finance, business services and real estate, community and social services (such as education and health), and domestic workers. Online appendix B provides further details on the contents of these NIDS subsectors, which follow the classifications given in Statistics South Africa (2005). If a tourism channel is driving our results, then we might especially expect to detect impacts of drought on the wholesale and retail subsector (which includes hotels and restaurants) and the transportation subsector (which includes air, water, and land travel, travel agencies, and travel tours). However, looking at table 4, we fail to detect much of an effect on any subsectors. We do find that drought reduces overall and formal employment in the transportation sector, but these results are only significant at the 10 per cent level.

Table 5 tests for heterogeneous impacts on the tertiary subsectors, across the high- versus low-tourism reliant areas. Having disaggregated by the level of tourism reliance, we now find that, for high-tourism areas, drought has a large, negative, and statistically significant effect on overall, formal, and informal employment. Looking at overall employment, a one standard deviation increase in drought in high-tourism areas reduces transportation sector employment by 0.3 percentage points, a 20 per cent reduction relative to the 1.6 per cent baseline transportation employment rate. We also find negative

Table 4. The effect of drought on the likelihood of employment in subsectors of the tertiary sector

Panel A: All employment	(1) Wholesale & Retail	(2) Transpor-tation	(3) Finance & Real estate	(4) Community services	(5) Domestic workers
Drought	0.0011 (0.0045)	−0.0032 (0.0019)	−0.0046 (0.0028)	−0.0048 (0.0045)	−0.0016 (0.0026)
Degree days, 31C threshold	−0.0006 (0.0066)	−0.0003 (0.0031)	0.0007 (0.0030)	0.0090 (0.0067)	−0.0019 (0.0033)
Observations	83,099	83,099	83,099	83,099	83,099
R^2	0.035	0.025	0.036	0.058	0.035
Dep. var. mean	0.0668	0.0164	0.0255	0.0954	0.0320
Panel B: Formal employment	(1) Wholesale & Retail	(2) Transpor-tation	(3) Finance & Real estate	(4) Community services	(5) Domestic workers
Drought	0.0052 (0.0038)	−0.0027 (0.0015)	−0.0041 (0.0027)	−0.0032 (0.0043)	−0.0004 (0.0023)
Degree days, 31C threshold	−0.0039 (0.0045)	0.0002 (0.0022)	0.0004 (0.0026)	0.0104 (0.0063)	−0.0046 (0.0030)
Observations	83,099	83,099	83,099	83,099	83,099
R^2	0.030	0.021	0.033	0.055	0.032
Dep. var. mean	0.0503	0.0124	0.0242	0.0849	0.0277
Panel C: Informal employment	(1) Wholesale & Retail	(2) Transpor-tation	(3) Finance & Real estate	(4) Community services	(5) Domestic workers
Drought	−0.0049 (0.0036)	−0.0002 (0.0009)	−0.0004 (0.0005)	−0.0016 (0.0016)	−0.0012 (0.0008)
Degree days, 31C threshold	0.0039 (0.0042)	−0.0006 (0.0013)	0.0002 (0.0006)	−0.0015 (0.0028)	0.0025 (0.0015)
Observations	83,099	83,099	83,099	83,099	83,099
R^2	0.018	0.008	0.007	0.011	0.021
Dep. var. mean	0.0167	0.0040	0.0014	0.0107	0.0043

Notes: The dependent variables in columns (1) through (5) are binary indicators for employment in five subsectors of the tertiary sector, which are wholesale and retail trade, transportation, finance and real estate, community services (such as education and health), and domestic workers. Online appendix B provides further details on the industries included in each of these subsectors. All columns include district fixed effects, month fixed effects, year fixed effects, and province-specific time trends. All columns control for gender indicators, race indicators, age, and age squared. Standard errors, in parentheses, are clustered at the district level.

coefficients for formal transportation employment and informal transportation employment, all significant at the 1 per cent level. We emphasize that these results should not be interpreted as indicating that drought *only* impacts the transportation subsector, but rather that impacts here may be easiest to detect, due to the transportation subsector's high reliance on tourism, as discussed in section 2.2.

We now briefly analyze the impact of drought on labor income. In online appendix table A4, the dependent variable in panels A, B, and C is the inverse hyperbolic sine of an individual's labor income from the past 30 days, from all employment, formal employment, and informal employment, respectively. Individuals who are not employed are

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Table 5. The effect of drought on the likelihood of employment in tertiary subsector, heterogeneity by tourism-reliance

Panel A: All employment	(1) Wholesale & Retail	(2) Transpor-tation	(3) Finance & Real estate	(4) Community services	(5) Domestic workers
Drought	0.0005 (0.0043)	0.0016 (0.0021)	−0.0019 (0.0030)	0.0014 (0.0048)	−0.0031 (0.0035)
High tourism = 1 × Drought	0.0010 (0.0078)	−0.0120 (0.0028)	−0.0066 (0.0057)	−0.0156 (0.0079)	0.0038 (0.0054)
Observations	83,099	83,099	83,099	83,099	83,099
R^2	0.035	0.026	0.036	0.058	0.035
Dep. var. mean	0.0668	0.0164	0.0255	0.0954	0.0320
Panel B: Formal employment	(1) Wholesale & Retail	(2) Transpor-tation	(3) Finance & Real estate	(4) Community services	(5) Domestic workers
Drought	0.0013 (0.0041)	0.0003 (0.0018)	−0.0010 (0.0030)	0.0020 (0.0048)	−0.0027 (0.0030)
High tourism = 1 × Drought	0.0094 (0.0063)	−0.0076 (0.0026)	−0.0076 (0.0053)	−0.0133 (0.0079)	0.0057 (0.0044)
Observations	83,099	83,099	83,099	83,099	83,099
R^2	0.030	0.021	0.033	0.055	0.032
Dep. var. mean	0.0503	0.0124	0.0242	0.0849	0.0277
Panel C: Informal employment	(1) Wholesale & Retail	(2) Transpor-tation	(3) Finance & Real estate	(4) Community services	(5) Domestic workers
Drought	−0.0012 (0.0026)	0.0013 (0.0011)	−0.0009 (0.0006)	−0.0005 (0.0017)	−0.0005 (0.0012)
High tourism = 1 × Drought	−0.0093 (0.0056)	−0.0039 (0.0014)	0.0012 (0.0010)	−0.0027 (0.0030)	−0.0019 (0.0017)
Observations	83,099	83,099	83,099	83,099	83,099
R^2	0.018	0.008	0.007	0.011	0.021
Dep. var. mean	0.0167	0.0040	0.0014	0.0107	0.0043

Notes: The dependent variables in columns (1) through (5) are binary indicators for employment in five subsectors of the tertiary sector, which are wholesale and retail trade, transportation, finance and real estate, community services (such as education and health), and domestic work. Online appendix B provides further details on the industries included in each of these subsectors. All columns include district fixed effects, month fixed effects, year fixed effects, and province-specific time trends. All columns control for gender indicators, race indicators, age, and age squared. Standard errors, in parentheses, are clustered at the district level.

assigned a labor income value of zero.[9] Income values are deflated to the 2015 South African Rand. We use the inverse hyperbolic sine transformation because it approximates the natural logarithm transformation but with the added benefit of allowing the inclusion of zero-valued observations (Bellemare and Wichman, 2020). Focusing on panel A, we see that drought has a negative and statistically significant effect on overall income, for all sectors and for the tertiary sector. Looking at column (1) of panel A,

[9] The table has a slightly smaller sample size because some employed individuals are missing income data.

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we find that a one standard deviation increase in our drought variable decreases labor income by 4.7 per cent.[10] Turning to panel B, while the effect is only significant at the 10 per cent level, we find that drought reduces formal labor income from all sectors and from the tertiary sector. We do not detect a statistically significant effect on informal labor income.

In online appendix table A5 we test for heterogeneous effects of drought on labor income by tourism reliance. Consistent with our employment results, we fail to detect an effect of drought on labor income in low-tourism areas, but in high-tourism areas we find negative and statistically significant effects on all-sector and tertiary-sector labor income. These effects persist across overall employment, formal, and informal employment. Looking at column (1) of panel A, we find that a one standard deviation increase in our drought variable decreases labor income in high-tourism areas by 12.9 per cent.

6. Robustness

In this section we conduct several robustness tests.

Our first robustness test, shown in online appendix table A6, estimates the impact of drought on employment, while controlling for average temperatures instead of degree days. Reassuringly, the coefficients on drought in table A6 are very similar to our main results (table 2), both in magnitude and significance level. We do not detect any systematic effects of average temperature on employment outcomes. This is consistent with our failure to detect effects for degree days in our main specification and is likely driven by the limited residual variation in average temperature (table A1).

Our second robustness test, shown in online appendix table A7, explores whether total precipitation (in the 12 months prior to the NIDS survey) affects employment. We fail to detect a statistically significant impact of total precipitation on employment for most outcomes, although higher precipitation increases informal primary sector employment. Our failure to detect an effect of total precipitation – in contrast to the effects we detect for drought – is likely due to nonlinearities in the impact of rainfall on employment (Adhvaryu *et al.*, 2013; Emerick, 2018). The relatively limited residual variation in total precipitation, conditional on our fixed effects, may also contribute (table A1).

Our third robustness exercise, presented in online appendix table A8, tests whether the impact of drought on employment intensifies over time, given South Africa's recent severe drought (Baudoin *et al.*, 2017). We compare the impacts of drought on employment in the last two waves of NIDS (2014/15 and 2017) with impacts in the first three waves (2008, 2010/11, and 2012).[11] We do not detect evidence of intensified impacts.

Our fourth robustness test, presented in online appendix table A9, adds individual fixed effects to our baseline specification. While our district fixed effects control for time-invariant district-level characteristics, the inclusion of individual-level fixed effects allows us to control for unobservables at the individual-level. Our sample size falls about 15 per cent when we do this, due to singleton observations, and we lose statistical significance on our coefficients of interest.

[10] To calculate this semi-elasticity given our inverse hyperbolic sine specification, we use the formula that a one standard deviation increase in x will lead to a $100 * \beta * \sqrt{(1 + 1/\bar{y}^2)} * \sigma_x$ per cent change in y.

[11] The later waves of the survey are larger, so 48 per cent of the sample is assigned to the variable 'late,' with the remaining 52 per cent of the sample being assigned to 'early.'

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Finally, our fifth robustness test, online appendix table A10, estimates our main results using wild cluster bootstrap standard errors (Cameron and Miller, 2015; Roodman *et al.*, 2019). Since our number of clusters is relatively small (52), wild cluster bootstrap standard errors address potential concerns that conventional inference methods may not apply.[12] The results of online appendix table A10, which present bootstrap p-values and 95 per cent confidence intervals, are, reassuringly, consistent with our main results in table 2.

7. Conclusion

Climate change poses significant challenges to labor markets in low- and middle-income countries, and we find evidence that this holds true even for an upper-middle-income country like South Africa. We examine the impact of high temperatures and drought on employment outcomes, and find that drought reduces overall employment, with effects concentrated in the tertiary sector and in informal employment. We also find that the negative impacts of drought are concentrated in high-tourism areas and in the transportation subsector. The existing climate–labor literature has largely focused on the primary and secondary sectors; we contribute to this literature with evidence of significant impacts of adverse weather shocks on the tertiary sector.

Our findings are important because South Africa faces significant socioeconomic challenges: high unemployment, high rates of poverty, and sluggish economic growth. Our findings can help 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. This will be helpful for policy formation in South Africa, as well as other, similar, upper-middle-income countries.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X22000237.

Acknowledgments. We are grateful for feedback from Maggie Liu and Charles Staelin. We thank Susan Sayre and Minoru Higa for sharing code.

Competing Interests. The authors declare no competing interests.

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[12]There is no clearcut threshold for having 'too few' clusters, but the threshold may range from 20 to 50 clusters (Cameron and Miller, 2015).

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Cite this article: Brookes Gray H, Taraz V, Halliday SD (2023). The impact of weather shocks on employment outcomes: evidence from South Africa. *Environment and Development Economics* **28**, 285–305. https://doi.org/10.1017/S1355770X22000237