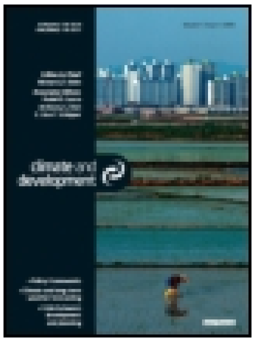

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RESEARCH ARTICLE

Climate change and development in South Africa: the impact of rising temperatures on economic productivity and labour availability

Soheil Shayegh [a,b], Vassiliki Manoussi[c] and Shouro Dasgupta [d,e]

[a]Department of Economics, Bocconi University, Milano, Italy; [b]RFF-CMCC European Institute on Economics and the Environment (EIEE), Centro Euro-Mediterraneo sui Cambiamenti Climatici, Milan, Italy; [c]Athens University of Economics and Business (AUEB), Athens, Greece; [d]Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), Venice, Italy; [e]Department of Environmental Sciences, Informatics and Statistics, Università Ca' Foscari Venezia, Venice, Italy

ABSTRACT
Climate change has a major impact on productivity of different economic sectors as well as different labour groups. Here we study the crucial linkage between gradual climate change and availability of low-skilled labour in rural areas of South Africa. Using a nationally representative panel of micro-survey data, we derive marginal impacts of rising temperatures on labour availability. Our econometric findings suggest that optimal conditions maximizing weekly labour supply are heterogeneous across sectors. We develop an analytical model of overlapping generations to study the long-term impacts of future climate and socioeconomic changes on labour supply and welfare. Overall, high exposure of low-skilled labour to climate change and rising temperatures reduces the supply of low-skilled labour which in turn, reduces the wage gap between high-skilled and low-skilled labour. However, the overall impact of climate change on economy remains negative and the welfare in terms of output per adult drops by 20% compared to the baseline case with no climate change.

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Climate change; rural development; labour supply; climate change impacts

1. Introduction

Climate change impacts goes well beyond the variations in natural systems and spreads over to all socioeconomic dimensions of human systems (Pachauri et al., 2014; Smith et al., 2015). These include warming temperatures and changes in precipitation that have direct impacts on agricultural productivity (Schlenker & Roberts, 2009) and increases in the frequency or intensity of extreme weather events (Rosenzweig et al., 2001) and rising sea levels that threatens the livelihood of communities in coastal areas (Shayegh et al., 2016). Empirical evidence suggests that variations in climate affect economic growth across countries over time (Pretis et al., 2018) and growth in agricultural production in particular, is significantly and non-linearly affected by temperature and precipitation variability (Carleton & Hsiang, 2016). Moreover, higher temperatures substantially reduce economic growth in poor countries compared to rich countries (Dell et al., 2008). Overall, the relationship between economic productivity and temperature is shown to be non-linear for all countries (Burke et al., 2015). Nevertheless, people have adjusted to climatic shocks through a various of adaptation measures ranging from insurance and reinsurance, to coastal planning, changing lifestyle, to demographic change (Casey et al., 2017) and migration (Shayegh, 2017). In labour markets, increasing temperatures reduce the availability of workers in industries with high exposure to climate such as farming and other outdoor activities (Antonelli et al., 2020; Bale et al., 2002). In that sense, climate change imposes negative health risks that mainly impact low-income countries with low adaptation capacity and threatens the livelihood of the most vulnerable groups in these countries (Haines et al., 2006). An estimation of the impacts of temperature on time allocation shows that increase in temperature reduces both hours worked in industries with high exposure to climate and time allocated to outdoor leisure (Zivin & Neidell, 2014). Some studies have looked at the impact of reducing emissions on improving the health and labour productivity by developing an analytical general-equilibrium model (Williams, 2003). However, the broader impact of increasing emissions and temperatures on labour supply and economic development remains unclear. While some studies have found that only short-run changes in temperature can lead to statistically significant decreases in human capital highlighting the significant role of adaptation in limiting the long-run impacts of climate shocks (Graff Zivin et al., 2018), other studies have shown a long-term reduction in human capital accumulation and skill acquisition due to climate change impacts on economic productivity (Casey et al., 2017). In this paper, we aim to reconcile these findings and develop a general framework that accounts for both the short-term impacts of climate change on labour availability, and its long-term consequences on human capital accumulation and skill acquisition. We use a multi-year, cross-regional and cross-sectoral labour survey conducted in South Africa between 2008 and 2015 to obtain key information about the relationship between weekly maximum temperatures and working hours among high-skilled and low-skilled labour. We combine these findings with estimations of damages on sectoral productivity under future climate change scenarios

CONTACT Soheil Shayegh soheil.shayegh@eiee.org
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(Desmet & Rossi-Hansberg, 2015). By exploring these two types of climate change damages (i.e. damages on sectoral productivity and labour availability), we are able to compare their importance in a broader context of future development pathways and highlight the adaptation mechanisms in terms of changes in the ratio of high-skilled to low-skilled labour.

South Africa presents a good example of a country with a relative potential gains from climate change. As the agricultural sector in South Africa is suffering from reduction in precipitation and rising temperature due to climate change (Calzadilla et al., 2014), the relative productivity of non-agricultural sector to agricultural sector is also expected to fall sharply by the end of the century. We analyze our model under a moderate Shared Socioeconomic Pathway (i.e. SSP2) scenario and four Representative Concentration Pathway (RCP) scenarios. These scenarios cover a wide range of possible carbon concentration outcomes based on climate policies ranging from a stringent policy (RCP2.6) to a very relaxed policy (RCP8.5). We compare the results with our baseline case where the climate conditions are held constant over time. Country-specific temperature forecasts can be obtained for each RCP scenario. This allows us to quantify the impact of climate change on the labour market in both agricultural and non-agricultural sectors under different climate change conditions. While this model is quantitative, our primary goal is to provide evidence for the qualitative conclusions.

2. Econometric evidence

2.1. Background data

We use econometric evidence from a longitudinal survey data in South Africa to calibrate the labour availability function in our economic model. We focus on the impact of weekly maximum temperature on the availability of the workforce in different sectors. It has been shown that as maximum temperature increases above 30°C, workers in the U.S. industries with high climate exposure reduce time allocated to labour (Zivin & Neidell, 2014) and the total output reduces subsequently (Somanathan et al., 2018). However, there is a lack of micro-based evidence on the impact of temperature on labour supply. Only a very recent study has used micro-survey data from Uganda by controlling for calorie intake to show that warming has a non-linear impact on agricultural labour supply, with the number of hours worked are maximized at temperatures around 21.3°C (Antonelli et al., 2020). Similar to this study, we utilize a Poisson regression to model the impact of weekly maximum temperature on the number of hours worked in the primary occupation by types of occupation (low-skilled, high-skilled and services).

The data comes from the four waves (from 2008 to 2015) of the National Income Dynamics Study (NIDS) conducted by the Southern Africa labour and Development Research Unit (SALDRU) based at the University of Cape Town[1]. This is the first nationally representative panel study of households in South Africa and uses a stratified, two-stage cluster sample design to sample households in the nine provinces of the country. NIDS primarily examines the livelihoods of individuals and households over time and provides information coping with shocks and includes detailed information on poverty and well-being; fertility and mortality; migration; labour market participation and economic activity; human capital, health, and education; and vulnerability and social capital (see Appendix section A1 for more details on NIDS).

Table 1. Working hours and temperature statistics at provincial level.

Province	Primary working hours	Max temp (weekly avg.)	Max temp
Western Cape	39.59	23.95	39.88
Eastern Cape	32.66	25.97	39.93
Northern Cape	40.2	29.94	38.85
Free State	42.45	27.76	36.58
KwaZulu-Natal	40.33	27.43	39.69
North West	47.28	26.58	36.89
Gauteng	41.27	25.29	35.62
Mpumalanga	44.49	27.15	40.26
Limpopo	44.79	28.83	42.78

2.2. Descriptive statistics

Table 1 provides basic descriptive statistics for the nine provinces in South Africa; the data suggests that the North West province has the highest average weekly working hours (47.3) while the Eastern Cape has the lowest average 32.7 h. The survey also provides information on the occupational code for each respondent, we re-categorize the ten occupational codes for the primary occupation into; low-skilled (agricultural, hunting, forestry, and Fishing; mining and quarrying; and construction), high-skilled (manufacturing and utilities), and services (private household service; NGO, foreign government; wholesale and retail; transport, storage, and communication; finance and insurance; and community service). The data suggest that the average weekly working hours for these three macro-categories are 45.8, 43, and 39.8 h, respectively.

Figure 1 shows the weekly mean and maximum temperatures across the different provinces in South Africa, the plots suggest that there is significant heterogeneity in climatic variables across the country.

2.3. Econometric framework

Following the recent empirical studies in this field (Zivin & Neidell, 2012, 2014), we use the econometric framework as follows:

$$y_{it} = f(temp_{ipt}) + \delta X_{it} + \phi Z_{hm} + \alpha_p + \gamma_t + \epsilon_{it} \qquad (1)$$

Our dependent variable (y_{it}) is the number of hours worked (labour supply) by an individual worker i in a given week t in province p where the respondent lives. f(temp) represents the non-linear impact of maximum weekly provincial temperature on labour supply. The number of working hours may increase due to temperature increases at relatively cold temperatures, however, beyond a threshold – incremental increases in temperature may have a negative impact (Antonelli et al., 2020; Galloway & Maughan, 1997; Zivin & Neidell, 2014). This is controlled for by including both the linear and second-degree polynomial terms of maximum weekly temperature.

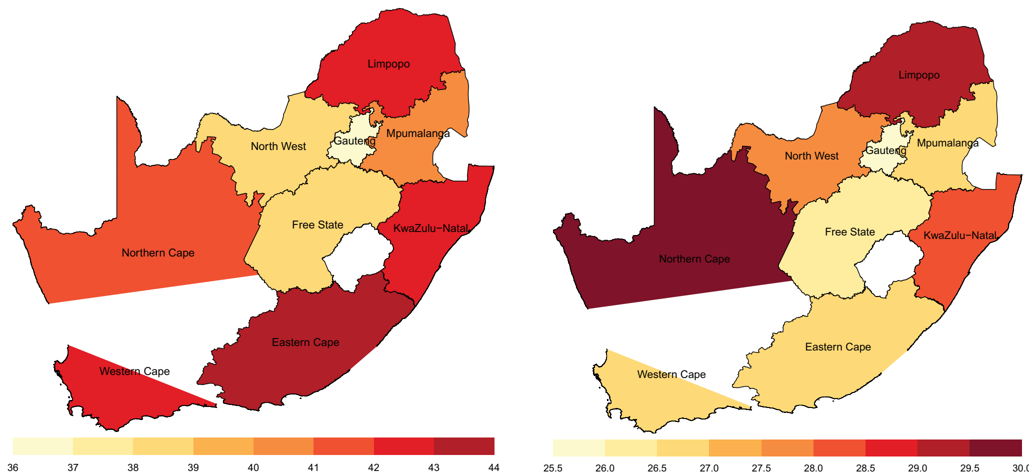

Figure 1. Maximum temperature (left-panel) and mean temperature (right-panel) by province in South Africa in 2014.

The term δX_{it} represent individual-level covariates including age (and its second-degree polynomial), race, gender, educational qualification and a dummy variable for health expenditure in the last 30 days[2]. The term ϕZ_{hm} represents the log of monthly household income (and its second-degree polynomial) in month m. We include household income to control for and investigate the labour–leisure relationship; as income increases, labour availability should increase, however, beyond a threshold of household income, individual labour availability is likely to decline. Our base specification also includes year-season[3] and province level (α_p) fixed-effects capturing all time-invariant attributes affecting labour supply. These fixed-effects allow us to identify the effects of weekly temperature with the plausibly exogenous variation in temperature over time within provinces and within seasons, thus, the temperature related parameters are estimated from weekly variations within a province. We are also able to identify short-run behavioral responses to temperature changes through these provincial fixed-effects and a temperature-province interaction-term is included to allow the maximum temperature slope to vary by province. The term γ_t represents weekly fixed-effects, while ϵ_{it} is a random error-term. We estimate Equation (1) separately for low-skilled and high-skilled workers.

2.4. Empirical results

We find that labour allocation is responsive to temperature changes, this differs from the findings by (Zivin & Neidell, 2014). Our results show that the response functions are hump-shaped in line micro-based findings by Antonelli et al. (2020) and macro-based ones from Burke et al. (2015). Panel (a) in Figure 2 shows the marginal plot for the relationship between maximum temperature and working hours among the low-skilled workers in South Africa. Results from our baseline specification suggest that an increase in maximum temperature initially has a positive impact on labour supply, however, beyond the threshold of 26.2°C, there is a negative impact on the number of hours worked per week. Panel (b) in Figure 2 shows that the non-linearity continues to hold in the case of high-skilled workers. However, the threshold beyond which labour supply declines is significantly higher at 28.2°C and the response function is flatter – implying that the availability of high-skilled labour is less sensitive to temperature changes compared to low-skilled labour. This is expected, as the exposure to climatic stressors are likely to be lower for high-skilled workers compared to the low-skilled workers. Unlike (Zivin & Neidell, 2014), our results are not sensitive to controlling for higher-order polynomials; coefficients for polynomials beyond the second-degree are not statistically significant.

Our empirical analysis highlights an important avenue through which climate change may affect the labour availability. Agricultural and other labour-intensive activities that are usually performed outdoor are more exposed to the change in the environment and therefore, the availability of low-skilled labour suffers more with the changes in maximum temperature. As maximum temperature increases, the availability of labour increases up to a threshold and then declines which can intensify the advert impacts of temperature on productivity. In our extended statistical analysis, we find a non-linear impact of monthly household income on labour supply in South Africa (see Figure A2 in Appendix). Our results also suggest that low-skilled females work 18% fewer hours per week compared to low-skilled male workers and as expected, the health expenditure dummy variable is negative and statistically significant.

Results from a pooled model by interacting maximum temperature with skill type, our results (Figure 3) suggests that the coefficients of maximum temperature are statistically different between the low and high-skilled groups.

Finally, for the robustness check, we replace the year-season fixed-effects with year-month fixed-effects but the optimal temperature does not change considerably (26°C for low-skilled and 28.2°C for high-skilled workers). In a further sensitivity analysis, we add total weekly precipitation to the model; however, the optimal temperatures do not change (see Table A1 and Table A2 in Appendix).

We also control for bins of maximum weekly temperature instead of continuous maximum temperature. In each case,

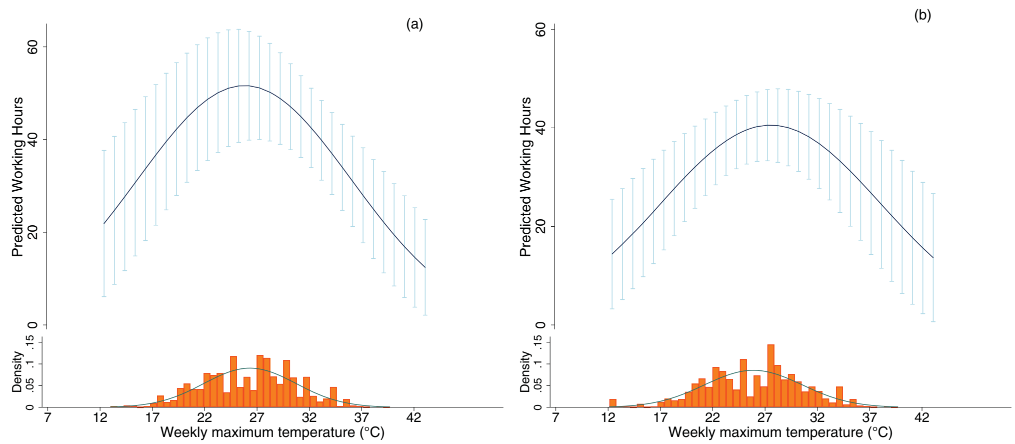

Figure 2. Non-linear relationship between weekly maximum temperature and number of hours in primary occupational activity (continuous line) with 95% confidence interval (vertical spikes). Panel (a) shows the impact for low-skilled labour ($N = 21{,}168$) while panel (b) shows the impact for high-skilled labour ($N = 20{,}693$). Specification controls for age, gender, race, education, health status, monthly household income, year-season, province, and week fixed-effects, and temperature-province interaction term.

we use the bin with sectoral optimal temperatures as the reference bin. The bins are computed as the weekly sum of the number of times maximum daily temperature fell within a given range.[4]. For both the sectors (Figure A1 in Appendix), we find that the number of hours worked falls in the higher ranges of maximum temperature. In the case of low-skilled workers, the number of hours worked per week decreases significantly by as much 2 h at maximum temperatures above 37°C. These findings are similar to that of (Zivin & Neidell, 2014); however, the calibration of the overlapping generation (OLG) model to estimate the impact of future climate change requires the temperature variable to be continuous. Thus, Equation (1) is our base specification in this paper.

3. Model description

We use an OLG framework (Diamond, 1965; Galor, 2011) with two types of labour and a two-sector economy. This model is generally able to capture most of the transformation characteristics of economy and labour. We do not include service sector here in order to get the closed-form solutions for the model but it will be possible to add a third sector to the model in the future. We assume that one economic sector is agriculture (denoted by a) that uses only low-skilled labour (Caselli & Coleman, 2001; Gollin et al., 2014). The other sector is non-agriculture (denoted by b) that uses only high-skilled labour. This clear labour division helps simplify the results and make them tractable. We assume low substitutability between the two types of goods in order for labour to reallocate towards more damaged sector and region where the demand is higher. We use the population projections under SSP2 scenario to calibrate our model. We use temperature projections in each RCP scenario to calculate climate damages.

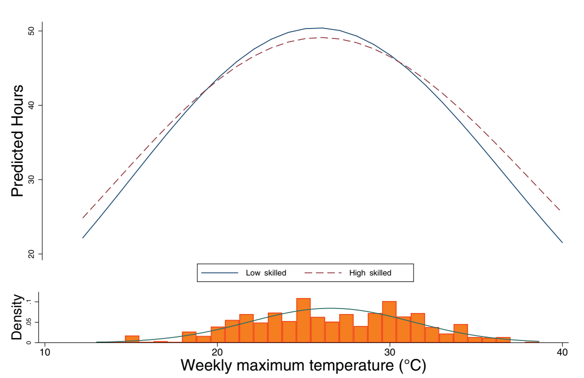

Figure 3. Non-linear relationship between weekly maximum temperature and number of hours in primary occupational activity. Specification controls for age, gender, race, education, health status, monthly household income, year-season, province, and week fixed-effects and temperature-province interaction term.

Individuals live for 2 periods and can be either high-skilled (s) or low-skilled (u) depending on the fertility choice of their parents. Here fertility choice is modelled in a fashion going back to (Becker & Barro, 1988). In the first period of their lives, they are children that only consume parental time (Galor, 2011). In our model, a child of type j consumes τ^j units of time. In the second period of their life, they will be assigned to each of the two sectors based on their skill level. As they become adults in the next period, they work, consume goods and have children for the next period of their life. The objective of each individual is to maximize lifetime utility of consumption and her children's future well-being by making consumption and fertility decisions. The child-rearing costs are different for children with different skill levels.

This model has been used to study the impacts of climate change on fertility (Casey et al., 2017) and migration (Shayegh, 2017). However, none of the previous applications have included explicit damages on labour availability. Our model expands the previous research by including damages on labour availability and the interaction between these damages and damages on sectoral productivity in order to fully capture the extend in which climate change impacts socioeconomic development pathways.

3.1. Utility maximization

We assume the utility of each parent will depend on their own consumption and also the future wages of their children. They decide about their skill level of their children (high-skilled (s and low-skilled u) in order to assign them to two economic sectors: agriculture (a) and non-agriculture (b).

$$U(c_t, n^u, n^s) = (1-\gamma)ln(c_t) + \gamma ln(d^u_{t+1} n^u_t w^u_{t+1} + d^s_{t+1} n^s_t w^s_{t+1}) \quad (2)$$

where γ is the total time spent on raising children, w^u is the wage of a low-skilled labour and w^s is the wage of a high-skilled labour. The number of children of each skill type is shown by n^u and n^s for low-skilled and high-skilled children, respectively. The availability of labour of type i is shown by d^i. A child of type i consumes τ^i units of time. The child-rearing costs are different for children with different skill levels. Thus, the budget constraint corresponding to (2) for every adult in each region is given by:

$$c_t = (1 - \tau^u n^u - \tau^s n^s) w_t. \quad (3)$$

The maximization of (2) subject to (3) yields:

$$c_t = (1-\gamma) w_t \tau^u n^u + \tau^s n^s = \gamma. \quad (4)$$

Also, for parents to have both types of children, it must be the case that:

$$\tau^r = \frac{\tau^s}{\tau^u} = \frac{d^s}{d^u}\frac{w^s}{w^u} \quad (5)$$

3.2. Consumption

Furthermore, households maximize their consumption bundle that is a constant elasticity of substitution (CES) function of consumption of two goods:

$$c^k = \left\{ \alpha (c^i_a)^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)(c^i_b)^{\frac{\epsilon-1}{\epsilon}} \right\}^{\frac{\epsilon}{\epsilon-1}}, \quad (6)$$

where ε is the elasticity of substitution, c_a is consumption of the agricultural good, and c_b is consumption of the non-agricultural good.[5] As ε approaches zero, consumers get less satisfaction from substituting non-agricultural goods for agricultural goods. In the limit, there is no substitution and the goods are consumed in fixed proportions. The consumer optimization problem conditioned on the budget constraint can be formulated using the Lagrangian multiplier λ:

$$Max\{c^i - \lambda(p_a \delta c^i_a + p_b c^i_b - (1-\gamma) w^i)\}, \quad (7)$$

where p_b and p_a are the prices of non-agricultural and agricultural goods, respectively. The solution to this optimization problem provides a relationship between these prices:

$$p_r = \frac{p_b}{p_a} = \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{c^i_b}{c^i_a}\right)^{\frac{-1}{\epsilon}}, \quad (8)$$

3.3. Labour supply

Total supply of labour L is given in each period from the population projections under SSP2 scenario. This scenario depicts a middle of the road pathway for socioeconomic development in the twenty-first century. Under this scenario, the skill ratio is moderately increasing, while population will peak around the middle of the century and then will reduce towards the end of the century. Global average temperature is increasing following the current trend in emissions. From our analysis, we use the projected population data from (Lutz, 2017) and temperature data were downloaded from the 'KNMI Climate Explorer', which is an online repository of climate data (Trouet & Van Oldenborgh, 2013).

Each household has to decide how many children should be allocated to each skill level. These children will comprise the labour force in the agricultural and non-agricultural sectors in the next period. The gross number of labour with skill level j will be:

$$\hat{L}^j_{t+1} = N_t \; n^j_t, \quad (9)$$

where N_t is adult population at time t. The net number of labour with skill level j will be calculated by taking into account the impacts of climate change on labour availability:

$$L^j_{t+1} = \hat{L}^j_{t+1} d^j_{t+1} \quad (10)$$

where d^i represents the availability of labour type i.

3.4. Climate change damages

The availability factor d^i depends on the maximum temperature ($T_{\max}$):

$$d^i(T_{\max}) = \gamma_0 + \gamma_1 T_{\max} + \gamma_2 T^2_{\max} \quad \text{for } i = u \text{ or } s \quad (11)$$

The coefficients γ_0, γ_1, and γ_2 are the coefficients of the non-linear relationship between labour availability and maximum temperature and income. In our model, $T_{\max}$ is the annual average of maximum temperature and T_{mean} is the annual average of mean temperature. Based on the projection of mean and maximum temperature under SSP2 scenario, we estimate a linear relationship between the global mean and maximum temperatures[6].

Direct impact of temperature on sectoral productivity of sector j is captured by $D_j(T_{mean})$ that depends on the mean temperature (T_{mean})[7] as described in (Desmet & Rossi-Hansberg, 2015) by a quadratic response function:

$$D_j(T_{mean}) = \delta_0 + \delta_1 T_{mean} + \delta_2 T^2_{mean} \quad \text{for } j = a \quad \text{or } b \quad (12)$$

The coefficients δ_0, δ_1, and δ_2 describe the non-linear relationship between sectoral damages and mean temperature, respectively. Given the values of parameters δ_0, δ_1 and δ_2 for each sector, we can show that the response function thus has an optimal temperature between 21.1 (agriculture) and 17.4 (non-agriculture) degrees Celsius, and with a maximum productivity loss of 90%. The shape of this function is depicted in Figure 4.

3.5. Production

We assume that agricultural sector uses only low-skilled labour and non-agricultural sector uses only high-skilled labour. This division of labour helps simplify our model to capture the

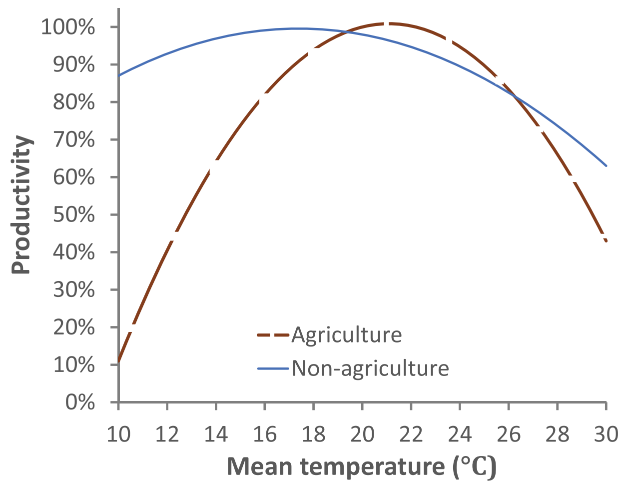

Figure 4. Agricultural and non-agricultural productivity response function to change in mean temperature based on Desmet and Rossi-Hansberg (2015).

impact of climate change on labour supply.

$$Y_a = D_a\ A_a L^u, \tag{13}$$

$$Y_b = D_b\ A_b L^s \tag{14}$$

where A_j is the total factor of productivity (TFP) in sector j and D_j is the damage in sector j as a function of the mean average temperature. TFP growth is described by

$$A_j = (1+\theta_j)A_{j,t-1} \quad \text{for } j = a \quad \text{or } b \tag{15}$$

where θ_j is the growth rate of total factor of productivity in sector j.

Wages can be calculated by taking the derivative of Equations (13) and (14):

$$w_a^u = p_a D_a A_a \tag{16}$$

$$w_b^u = p_b D_b A_b \tag{17}$$

This will immediately give us

$$\frac{w_b^s}{w_b^u} = \left(\frac{p_b}{p_a}\right)\left(\frac{D_b}{D_a}\right)\left(\frac{A_b}{A_a}\right) \tag{18}$$

We can rearrange this equation to get

$$p_r = \frac{p_b}{p_a} = \tau^r \left(d^r\right)^{-1}\left(D^r\right)^{-1}\left(A^r\right)^{-1} \tag{19}$$

where $D^r = \frac{D_b}{D_a}$ and $A^r = \frac{A_b}{A_a}$ are relative productivity and relative technological change in non-agricultural sector compared to agricultural sector, and $d^r = \frac{d^s}{d^u}$ is the relative availability of high-skilled to low-skilled labour.

The consumption of good type j by adults of each skill level is calculated by the following: equations:

$$c_j^u = \frac{Y_j}{L^s\tau^r/d^r + L^u}, \quad c_j^s = c_j^u\tau^r/d^r. \tag{20}$$

3.6. Equilibrium

Combining Equations (8) and (19), we will have

$$ln\left(\frac{\hat{L}^s}{\hat{L}^u}\right) = \epsilon ln\left(\frac{1-\alpha}{\alpha}\right) - \epsilon ln(\tau^r) - (1-\epsilon)\left[ln(d^r) + ln(D^r) + ln(A^r)\right]. \tag{21}$$

At each time period, the population of adults is given from the SSP2 projection data:

$$\hat{L}_{t+1}^s + \hat{L}_{t+1}^u = \hat{L}_{t+1} \tag{22}$$

Using Equations (21) and (22), we can calculated the number of children with each skill level given the future climate and population growth trajectories. This equation allows us to investigate the role of climate change in altering human capital accumulation in long term. If an increase in temperature negatively affects agricultural sector more than non-agricultural sector, then the ratio D^r is increasing is temperature. At the same time if low-skilled labour is more affected by the rise in temperatures than high-skilled labour, the availability ratio d^r is increasing in temperature. If $\epsilon < 1$ (i.e. the substitution between goods is sufficiently low), then both factors will contribute to a decrease in the relative wages of high-skilled individuals. This raises the relative return to working in agriculture, causing parents to have relatively more low-skilled children.

4. Results

Figure 5 demonstrates the temperature profile of South Africa under four RCP scenarios. RCP2.6 scenario is associated with a stringent climate policy with low concentrations that aims to reduce emissions and keep the temperature rise below the 2°C target. RCP4.5 and RCP6.0 project higher concentration

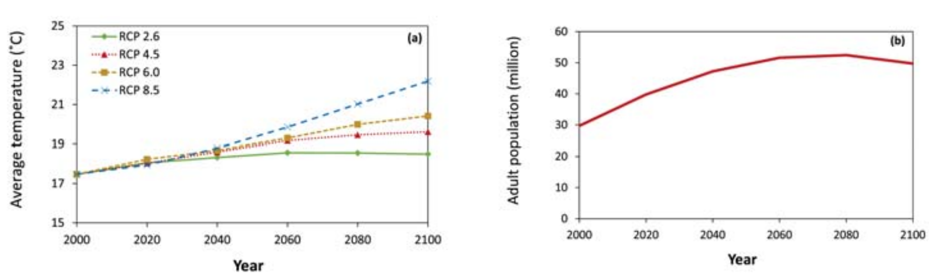

Figure 5. The climate and socioeconomic projections for South Africa under SSP2 and four RCP scenarios. (a) Average temperature under four RCP scenarios, and (b) the population of adult labour from the Wittgenstein Centre projections (Lutz et al., 2014).

scenarios with modest to high-temperature rise. Finally, RCP8.5 scenario depicts a world with very high emissions (Van Vuuren et al., 2011). Under RCP2.6 scenario, average temperature in South Africa will rise about one degree above its current level by the mid-century and stays constant afterwards (Panel (a) in Figure 5). In contrast, under RCP8.5, average temperature keeps increasing and reaches 22.2°C by the end of the century. Figure 5 also represent the human capital evolution of South Africa under SSP2 (Lutz, 2017; O'Neill et al., 2017). The population of adults increases from about 30 million in year 2000 to 50 million by the end of the century (Panel (b) in Figure 5).

Figure 6 examines the effect of climate change on economic and demographic outcomes of the model under the four RCP scenarios. We define the baseline as a case without changes in the temperature and therefore, without any damages to sectoral productivity (Equation (12)) or labour availability (Equation (11)). We analyze this case and compare the results to the baseline case.

The first column in Figure 6 shows the relative productivity of non-agricultural sector to agricultural sector. In the baseline case with no temperature change, this ratio remains constant over time at its initial level of 1.09 under all RCP scenarios (panel (a0) in Figure 6). Similarly, the relative availability of high-skilled to low-skilled labour is constant at around one in the baseline case (Panel (b0) in Figure 6). The ratio of high-skilled to low-skilled labour increases from 1.5 in year 2000 to 33.0 in year 2100 (Panel (c0) in Figure 6).

The second row examines the case with sectoral productivity damages only. As average temperature in South Africa rises under each RCP, the relative productivity of non-agricultural sector to agricultural sector decreases. For example, under RCP8.5 this ratio drops by about 13.6% by the end of the century (Panel (a1) in Figure 6). At the same time, the relative availability of high-skilled to low-skilled labour remains constant in this case (Panel (b1) in Figure 6). Decline in relative productivity of non-agricultural sector to agricultural sector increases the demand for high-skilled labour in non-agricultural sector and induces parents to acquire higher education for their children. As a result, the relative number of high-skilled labour increases between 1.3% and 3.7% under different RCP scenarios (Panel (c1) in Figure 6).

The third row explores the case with labour availability damages only. The relative productivity of non-agricultural sector to agricultural sector remains constant in this case (Panel (a2) in Figure 6). As average temperature increases under each RCP, low-skilled labour in agricultural sector is getting affected more and the relative availability of high-skilled to low-skilled labour increases. For example, under RCP8.5 it increases by about 11.8% by the end of the century (Panel (b2) in Figure 6). Decline in relative availability of low-skilled labour increases the demand for this type of labour in agricultural sector and induces parents to acquire lower education for their children. As a result, the relative number of high-skilled labour decreases between 0.5% and 2.8% under different RCP scenarios (panel (c2) in Figure 6).

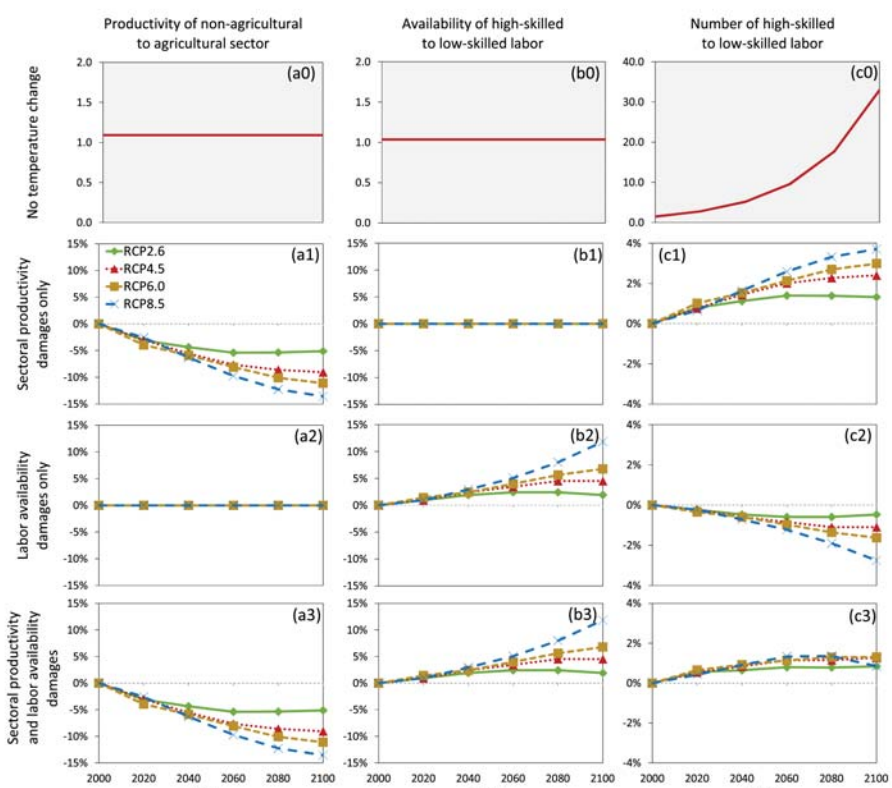

Figure 6. Impact of labour availability on the socioeconomic indicators in South Africa under SSP2 and four RCP scenarios. The first row shows the results for the baseline case with no change in temperatures. The following three rows indicate the relative deviation from the baseline case in terms of percentage changes.

Finally, the last row shows the combined effect of damages on both sectoral productivity and labour availability. As temperature increases, the relative productivity of non-agricultural sector to agricultural sector decreases (Panel (a3) in Figure 6) and the relative availability of high-skilled to low-skilled labour increases (panel (b3) in Figure 6). These two changes, as shown in the last two cases, have opposite effects on skill ratio. The reduction in relative productivity of non-agricultural sector to agricultural sector increase the return to acquiring skills, inducing parents to invest more resources in the education of their children. In contrast, an increase in relative availability of high-skilled to low-skilled labour, increases the need for low-skilled labour. Therefore, the net impacts of these two opposite factors result in slight increase of about 1% in relative number of high-skilled to low-skilled labour (Panel (c3) in Figure 6).

Although the two types of damages we investigate here show opposite impacts on the skill ratio, the overall impact of climate change on welfare and output remains negative. Panel (a0) in Figure 7 shows the ratio of high-skilled to low-skilled wages in the baseline case without temperature change. The wage ratio stays at 1.3 throughout the century. On the other hand the output per adult increases from about 5000 (constant 2010 USD) to about 120,000 (constant 2010 USD) by the end of the century (Panel (b0) in Figure 7).

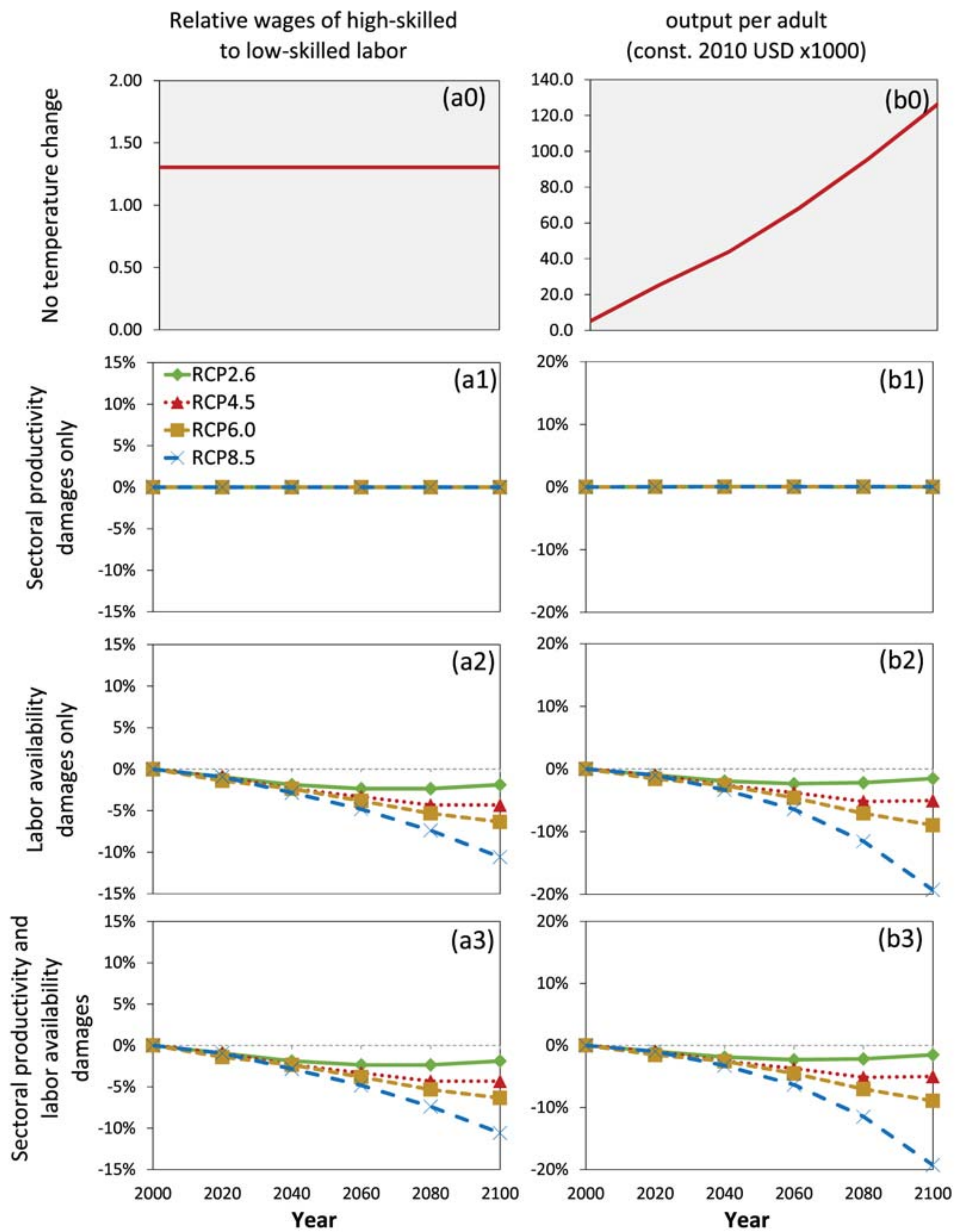

Figure 7. Impact of climate change on welfare in South Africa under SSP2 and four RCP scenarios. The first row shows the results for the baseline case with no change in temperatures. The following three rows indicate the relative deviation from the baseline case in terms of percentage changes.

The second row examines the case with sectoral productivity damages only. As average temperature in South Africa rises under each RCP, the relative productivity of non-agricultural sector to agricultural sector decreases, and more high-skilled labour is allocated to non-agricultural sector. As a result The overall wage ratio (Panel (a1) in Figure 7) and output per adult (Panel (b1) in Figure 7) remain constant.

The third row explores the case with labour availability damages only. As average temperature increases under each RCP, the relative availability of low-skilled to high-skilled labour decreases inducing the relative wages of high-skilled to low-skilled labour to drop by about 10% under RCP8.5 (Panel (a2) in Figure 7). The overall impact on output per adult, however, will be about 20% decline by the end of the century (Panel (b2) in Figure 7).

Finally, the last row shows the combined effect of damages on both sectoral productivity and labour availability. The combination of the two damages is driven by labour availability. In this case, similar to the previous case, while relative wages of high-skilled labour compared to low-skilled labour decreases (Panel (a3) in Figure 7), output per adult experiences a larger decline (Panel (b3) in Figure 6).

5. Discussion

The results of our analysis highlight three important underlying mechanisms that shape the future dynamics of gradual climate change impact on labour availability. First, using rich nationally representative micro-survey data, we find that optimal conditions maximizing weekly labour supply are heterogeneous across sector: low-skilled labour in agricultural sector has its peak of productivity at lower temperatures than high-skilled labour. That is, the optimal maximum temperature maximizing weekly labour supply is 26.2°C and 28.2°C for low-skilled and high-skilled workers, respectively.

Second, by modelling different sectors and different types of labour, our analysis shows that heterogeneity in impacts of climate change on sectoral productivity and labour availability may result in different combinations of pull and push factors for different types of labour. In the case of South Africa, a decrease in relative productivity of non-agricultural to agricultural sector creates a market demand for high-skilled labour to compensate the loss in non-agricultural sector productivity (pull factor). On the other hand, a decrease in the relative availability of low-skilled to high-skilled labour, requires more supply of low-skilled labour to cover the loss in their availability (push factor). In the Appendix, we have presented a case of Uganda where damages on sectoral productivity and labour availability act in the same detection resulting in greater decline in human capital development and social welfare. Furthermore, the negative impacts of climate change can be exacerbated by reduction in food consumption and calorie intake among particularly among vulnerable low-skilled labour (Antonelli et al., 2020)

Third, the net effect of climate change on human capital development can be calculated by taking into account both pull and push factors. Increasing demand for low-skilled labour, coupled with reduction in economic output due to climate change, reduces the wage gap between high-skilled and low-skilled labour but reduces overall output per adult. We estimate that under a severe climate scenario (e.g. RCP8.5), output per adult drops by about 20% by the end of the century compared to the baseline case without climate change. In other words, climate change creates a waste in labour productivity by consuming parental time on raising children who will not be able to work due to the impacts of climate change.

6. Conclusion

In this paper, we have taken a novel approach in coupling empirical data from national surveys with a theoretical framework to study the impact of climate change on labour markets. The non-linear effects of (mean) temperature on sectoral productivity (Burke et al., 2015; Carleton & Hsiang, 2016) and labour availability (Antonelli et al., 2020; Zivin & Neidell, 2012) have been demonstrated in separate studies before. We reconcile these two threads of research to generate a unified framework for studying the impacts of climate change on economic development. We use longitudinal survey data for South Africa to demonstrate the impact of temperature change on relative availability of high-skilled to low-skilled labour. The results of our projection model show that climate change impacts on labour market are potentially greater than what has been studied before (Zivin & Neidell, 2014), depending on the geographic location and socioeconomic pathways of the country. In rural areas of South Africa, climate change will reduce the availability of low-skilled labour which in turn, will have a negative impact on economic output.

It is important to note that we only consider the impact of climate change through gradual rising of average and maximum temperatures. Other climate factors such as precipitation, sea-level rise, or climate shocks such as floods or droughts are not considered in this study. Therefore, it is safe to assume that we have provided a conservative estimate of the climate change damages on productivity and welfare. A more thorough analysis of climate change impacts on labour availability may include other important avenues such as the impacts on nutrition (Antonelli et al., 2020), migration (Shayegh, 2017) and income distribution (Baarsch et al., 2020).

Our analysis is one of the first in quantifying the heterogeneous impacts of climate change on the labour market. The results call for better calibration of climate change damages by taking into account the heterogeneity of such damages to different sectors of the economy and different types of labour. Our findings also highlight the need for adaptation policy making in labour markets (Day et al., 2018). We hope that our results pave the way for better understanding of the relationship between climate change and labour supply.

Notes

1. http://www.nids.uct.ac.za/
2. We also include marital status and number of children; however, these variables are not statistically significant and do not have any impact on the optimal temperature levels.

3. In South Africa, seasons are classified as follows; Autumn: March – May, Winter: June – August, Spring: September – November, and Summer: December – February.
4. The maximum temperature bins used are: 0°C–5°C, 5°C–10°C, 10°C–13°C, 13°C–16°C, 16°C–19°C, 19°C–22°C, 22°C–25°C, 25°C–28°C, 28°C–31°C, 31°C–34°C, 34°C–37°C, and > 37°C.
5. The time subscripts in this equation and the ones follow are suppressed for convenience.
6. Other studies support such assumptions. For example, Easterling et al. (1997) show that over the past 100 years, the global maximum temperature has risen by about 0.88°C, while the mean temperature has gone up by only 0.5°C.
7. We use the multi-model mean temperature from RCP ensemble of ACCESS1-0, ACCESS1-3, bcc-csm1-1, BNU-ESM, CanESM2, CCSM4, CESM1-BGC, CESM1-CAM5, CMCC-CM, CMCC-CMS, CNRM-CM5, CSIRO-Mk3-6-0, EC-EARTH, FGOALS-g2, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M and GISS-E2. Data have been downloaded from https://climexp.knmi.nl/start.cgi

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Data availability statement

The data that support the findings of this study are available from the Southern Africa Labour and Development Research – http://www.nids.uct.ac.za/.

Notes on contributors

Soheil Shayegh is a researcher at RFF-CMCC European Institute on Economics and the Environment (EIEE) in Milan, Italy. His research is focused on economic modeling of the interaction between human and natural systems, analyzing climate change policies, and investigating the management and governance of global challenges.

Vassiliki Manoussi is a researcher at Athens University of Economics and Business (AUEB) in Greece working on economic modeling of climate change impacts and sustainable development.

Shouro Dasgupta is currently a Researcher at Fondazione CMCC and a Lecturer at Università Ca’ Foscari Venezia. His research investigates the impacts of climate change on labour, inequality, health, food security, energy supply, and migration/displacement using micro and spatial econometrics.

ORCID

Soheil Shayegh http://orcid.org/0000-0002-8960-8244
Shouro Dasgupta http://orcid.org/0000-0003-4080-8066

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