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Interdependence between climate change and migration: Does Agriculture, geography and development level matter in sub-Saharan Africa?

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Abstract

Concerns about the human effects of climate change have contributed to forecasts of how populations in drought-prone, and flood-prone areas would respond to these events. Empirical studies have predicted that human migration has been among the critical resilient strategy in responding to the impact of climate change. To obtain a more comprehensive understanding of the climate–migration relationship, the impacts of climate change on international migration flows from Sub-Saharan Africa (SSA) nations to South Africa are investigated empirically in this paper. The study employed a fixed effects model and panel data from 35 countries in SSA, spanning 1990 to 2017. The findings are as follows: (1) the analysis show that temperature has a positive and statistically significant effect on outmigration in agriculture-dependent nations. (2) the analysis shows that agricultural-value-added as a share in GDP has a negative and statistically significant effect on outmigration in agriculture-dependent nations. (3) the results also show that geographic location, and development level of a country, in addition to dependency on agriculture are key factors in the climate change–international migration nexus. Policy implications are discussed.

Key words: International migration; Sub-Saharan Africa; South Africa; Climate change; Agriculture.

JEL classification codes: F22; J61; Q50; Q54.

1. Introduction

It is becoming increasingly difficult to ignore the causes and impacts of climate change across the world and in all aspects of life. Climate change, in particular, is responsible for decreased agricultural productivity and increased food insecurity (Food and Agriculture Organization (FAO), 2019). The potential for large-scale movement of portions of the human population is one frequently cited response to the impacts of climate change (Myers, 2002; Stern, 2007; Warner et al., 2009; Marchiori et al., 2012). The World Bank observes that by 2050, 143 million people in three areas of the world (sub-Saharan Africa, South Asia, and Latin America) may be compelled to migrate either within their own countries or outside as climate change worsens—leading to decreased crop production, water scarcity, and sea-level rise (Rigaud et al., 2018). Migration is therefore seen as a critical resilience strategy against the impacts of climate change. While much of the common narrative suggests that migration results from a failure to adapt to climate change, it is in fact an adaptation strategy in and of itself. This is because certain regions are more susceptible to the negative impacts of climate change than others, and it seems natural that residents in such as regions such as SSA, will attempt to avoid the impacts of climate change by migrating. Most importantly, several countries in SSA lack the financial resources to abate climate change and thus, adaptation is usually seen as the only option for coping with the impacts of climate change. SSA is of particular interest given that most economies are dependent on agriculture. Agriculture in SSA is dependent on climate compared to most other developing regions in the world. Hence, variability in temperature and rainfall has dire consequences on food production and livelihoods (see Barrios et al., 2003). These impacts are especially pronounced in rural areas where agriculture is a source of livelihood for a significant number of the populace. Therefore, agriculture is considered to be one of the most significant channels that drive rural-urban migration (Barrios, Bertinelli & Strobl, 2006). Moreover, it is a plausible hypothesis that agriculture plays an important role in the climate and cross-border migrations worldwide (see Cai et al., 2016).

The plausible role that agriculture plays in the climate–migration nexus has been investigated in OECD countries (see Cai et al., 2016), but little attention has been given to cross border migration within SSA. Moreover, specific channels such as country-location and level of development are also highlighted as significant drivers of international migration. Though these channels have received attention, specifically in the cases where agriculture was assessed as an intermediating factor between climate change and migration (Cai et al. 2016), but within European perspectives. However, the literature shows that the majority of these migrants, in actuality, migrate inside their own countries and regions (Rigaud et al. 2018). More so, the quantitative literature on climate–

induced (international) migration is still in its infancy. So far, the analytical findings have been mixed. While several studies show a relationship between migration and climatic factors such as natural disasters, temperature, and precipitation (see Gray and Mueller, 2012; Feng et al., 2012; Bohra-Mishra et al., 2014), others show that climate change is insignificant in comparison to other drivers of migration such as employment, level of development etc. (see Mortreux and Barnett, 2009; Naudé, 2010). The obvious differences among the results of different studies are due in part to the fact that most of these studies are context-specific. They vary in terms of the geographic areas they represent and the time periods they cover. In particular, one study that stands out in the climate–migration literature in SSA is that of Barrios, Bertinelli & Strobl (2006). The study shows that climate change, as proxied by rainfall, has increased rural–urban migration in SSA but not elsewhere in the developing world.

To advance the literature, we focus on the cross-border migration and in order to obtain a more comprehensive understanding of the climate–migration relationship, our study considers agriculture-value-added as a share of GDP, agricultural dependency, geography and the level of development proxied by GDP as potential intermediating variables between climate change and migration in SSA, with South Africa as destination country¹. We do so because a large body of literature has already identified that crop yields are highly sensitive to climate change, especially variability in rainfall and temperature (see Lobell et al., 2008, 2011; Schlenker and Roberts, 2009). As stated earlier, agriculture is a significant economic field in many countries in SSA, and remains the primary source of income for a large proportion of the population. As a result, it is a reasonable assumption that agriculture has a significant impact on the climate–migration relationship. Further, Cai et al., (2016) shows that a country’s agricultural dependence is likely to be correlated with other characteristics such as the geographic location (country located in hot or low-latitude) and the level of development. To make sure that our analysis does not ignore these important channels, we consider country geographic location (using latitude) and the level of development (using GDP per capita) as additional channels in the climate–migration nexus. Moreover, agricultural value added as a share of GDP was considered in our study due to the fact that increasing added value is to increase state, and especially rural, incomes and to increase employment and investment opportunities which would eventually reduce the incentive to migrate.

On a continental scale, the number of migrants on the African continent rose from 15 million to 25 million between 2000 and 2017. This represents an estimated annual growth of 2.8 percent,

¹ The empirical studies show that Johannesburg in South Africa, serves as one of the main migration hubs on the African continent (see Purvis et al, 2019).

with women accounting for 47 percent of total outmigration. South Africa serves as one of the main migration hubs on the African continent (see Purvis et al, 2019). Migration has always been a natural process which produces other significant transformations in the environment as well as in everyday life, in economic systems, cultures, religions etc. As the effects of climate change become more severe, climate-induced migration will become more common. Sub-Saharan Africa (SSA) is extremely sensitive to the impacts of climate change because agriculture production is dependent on rainfall. Therefore, out-migration, whether permanent or temporary, can help a person or family reduce the impacts of climate change on their livelihood. Nevertheless, the repercussions of international migration may also include increased housing stress on the receiving country, political and social friction, increased costs to provide social amenities, overcrowding, disease transmission, and the marginalization of migrants into low-status and low-paying employment (see Solomon, 1994). An effective climate adaptation policy requires an understanding of how temperature and rainfall variability affect migration patterns. Cities, governments, and regions in SSA need to be more aware of the issue and incorporate it into their planning at all levels. Among all climate-induced migrants, those crossing the political borders would be a matter of particular concern as both receiving and sending countries are affected. Identification of the drivers underlying the climate–(international) migration relationship would be useful to national governments and international agencies devising policies to manage migration flows.

Using a fixed effects model and panel data from 35 countries in SSA, spanning 1990 to 2017, we have added to the current literature in the following ways. First, we show that temperature have a positive and statistically significant effect on outmigration in agriculture-dependent nations in SSA to South Africa. Second, we provide evidence to support existing literature that agricultural-value-added as a share of GDP has negative and statistically significant effect on outmigration in agriculture-dependent nations in SSA to South Africa. Lastly, we also show that geographic location, and development level of a country, in addition to dependency on agriculture are key mediating factors in the climate change–international migration relationship in SSA.

The rest of our paper will be organized as follows. We provide a review of existing literature in Section 2. In Section 3, we outline the analytical framework, and in Section 4, we show data and estimation strategy. In Section 5, we provide and discuss the findings of the various models that were estimated, and In Section 6, we discuss and conclude on the policy implications of the findings.

2. Review of existing literature

The factors driving human migration have a wide literature that spans numerous disciplines. One of the most major migration drivers is the desire to maximize one's income (Roy, 1951; Borjas, 1989; Clark et al., 2007; Mayda, 2010). Simply put, a potential migrant is expected to weigh the wage disparity between origin and many destinations, as well as the cost of migrating, before deciding on a location that maximizes income. However, climate and environmental variables, such as sea level rise, environmental degradation, weather-related crop failures, and extreme weather occurrences, have received increasing attention in the migration literature in recent decades (Hugo, 1996; Myers, 2002; Warner et al., 2009; Piguet et al. 2011; Foresight, 2011; Gray and Mueller, 2012).

The connection between climate change and migration is assumed to be obvious as people will be forced to migrate if drought occurs and they record low crop yields (see El-Hinnawi, 1985; Myers, 1993). In light of this, several studies have shown that climate change has a major impact on human migration.

Using a Mexican state-level panel data of migration flows, Feng et al. (2010) discovered a major semi-elasticity of migration from Mexico to the United States in relation to climate-induced changes in crop yields. Depending on the warming scenarios used and adaptation levels assumed by farmers, with other factors held constant, by approximately the year 2080, climate change is estimated to induce 1.4 to 6.7 million adult Mexicans (or 2% to 10% of the current population aged 15–65 years) to emigrate as a result of declines in agricultural productivity alone.

Mallick, et al., (2020) examined the link between socio-ecological systems and livelihood circumstances, as well as how a sustainable livelihood affects non-migration decisions among persons living in vulnerable situations. A mixed-methods approach was used in five communities in southwest coastal Bangladesh. The findings demonstrated that livelihood possibilities varied depending on socioeconomic position, and that (non-)migration ambitions are mostly determined by livelihood adaption options, which influence an individual's long-term livelihood status in the face of future disaster risk. Other studies such as Joarder & Miller, (2013) investigated whether environmental migrants in Bangladesh are moving permanently or temporarily. They based their research on data collected in 2010 and 2011, and focused on four themes: migrant characteristics, environmental change-related variables, conflict and adaption techniques, and social networks. The results of binary logit models demonstrate that the majority of factors have statistically significant effects on the choice to migrate temporarily versus permanently. Females are more likely to temporarily relocate than male. They also found that prior occupational experience has a

substantial impact on the likelihood of wanting to relocate temporarily: migrants who previously worked in agriculture or fishing are more likely to migrate permanently. In addition, households that reported losing assets as a result of environmental threats were shown to have a greater likelihood of becoming permanent migrants. Loss of livestock and crop failure, on the other hand, are linked to a higher risk of temporary migration. The empirical findings suggest also which groups may be targeted in settlement strategy in destination locations, as well as which groups can be aided in returning home once any immediate threat has passed. Additionally, Gray and Mueller (2012) show that crop failures caused by rainfall shortages have a significant impact on mobility in Bangladesh, while flooding has a minor impact. Mueller et al. (2014) added that flooding has a minor effect on migration, but heat stress raises long-term migration in Pakistan. While Bohra-Mishra et al. (2014) discovered that a rise in temperature and, to a lesser degree, changes in rainfall are likely to have a greater impact on permanent outmigration of households than natural disasters following province-to-province movement of more than 7000 households in Indonesia over a decade and a half. Falco et al., (2019) used panel data of 108 countries from 1960 to 2010 to examine the link between weather variability, changes in agricultural output, and international migration. They found that negative climate-related shocks to agricultural output considerably boost emigration from developing nations, with a particularly high impact in poor countries but a lesser impact in middle-income countries.

Further, the literature also shows evidence of climate shocks and internal migration. For instance, Thiede, et al., (2016) based their study on more than 21 million observations of individuals aged 15 to 40 collected from 25 censuses in eight South American nations. They analysed heterogeneity across sex, age, and socioeconomic categories, as well as between nations and historical climatic circumstances, in order to assess the effects of climate variability on migration. They also disaggregated migration by destination status (rural versus urban). In comparison to monthly rainfall shocks and progressive climatic changes over multi-year periods, they showed that exposure to monthly temperature shocks has the most persistent effects on migration. The findings revealed in addition that there is heterogeneity among demographic groupings and nations. Climate-related migration is mostly oriented into urban regions. In addition, Bohra-Mishra, et al., (2017) examined the effect of climate variations and extremes referred by the temperature, precipitation and events of typhoons on aggregate inter-provincial migration within the Philippines. The findings revealed that the rising temperature tends at some increases the typhoon activities that lead to outmigration while precipitation has no persistent and meaningful influence. The results reported also that temperature and typhoons have substantial negative impacts on rice yields, a proxy for agricultural productivity, and cause greater outmigration from

provinces that are more agriculturally dependent and have a higher proportion of rural population. They also found that rising temperatures and typhoons had a greater impact on the migratory decisions of men, younger people, and those with higher levels of education.

In Africa studies like (Marchiori et al. 2012; Morrissey, 2013; Grace, et al., 2018; Klaiber, 2014; Mueller, et al., 2020; Atuoye, et al.; 2021; Ripkey, et al., 2021) have provided empirical findings on climate-migration relationship. For instance, Mueller, et al., (2020) used a regression analysis to examine transitory migratory responses to local temperature and precipitation anomalies in East Africa. The findings revealed that climatic impacts were most evident in urban areas, with a standard deviation rise in temperature and a decrease in rainfall resulting in 10 and 12 percent decreases in out-migration, respectively, when compared to mean values. Marchiori et al. (2012) also show that weather fluctuations have increased internal and inter-national migration across both amenity and economic networks using country-level panel data from Sub-Saharan Africa. Grace, et al., (2018) examined the individual and community level responses to climate variability as a driver of out-migration. The findings implied that, in general, out-migration behavior does not change as a result of failures or in the rainy season. The effect of climate on migration varied significant by migrant characteristics. For instance, black and low-income earners in South Africa migrants are strongly influenced by climatic variables compared to white high-income migrants (Mastrorillo, et al., 2016). In comparison to the above studies, we will use a special international migration dataset that spans a 20-year timeframe and contains 35 Sub-Saharan African countries in South Africa. We will examine the differences between different country pairs using this rich dataset, which is augmented by accurate climate data controlling for the country fixed effects and time trends. Our study also investigates the important role of agriculture dependence, agriculture-value added as a share of GDP and the significance of geographical location to explain the climate change-outmigration relationship.

3. Analytical framework

We use a panel data to assess the influence of climatic changes and on international migration. This allows us to leverage random variations in the incidence of weather patterns experienced and its impact on international migration across time. Though several studies have used rainfall to proxy for climate change (e.g., Barrios, Bertinelli, & Strobl, 2010; Barrios, Bertinelli, & Strobl, 2006), climate change in Sub-Saharan Africa is also highly associated to temperature changes. Temperature variations can determine whether a location is semi-arid, like northern Kenya, or desert, like Namibia. Dell, Jones, and Olken (2009) demonstrate that the negative impact of climate change on economic performance is mostly driven by yearly temperature changes. As a result, our

goal in this study is to focus on temperature variations to explain climate change impacts on international migration in SSA to South Africa.

4. Data and estimation strategy

We compiled a new collection of data for 35 Sub-Saharan African nations, spanning the years 1990 to 2017. This cross-country panel data set is made up of migration variables, climate variables, and economic variables. Table A1 in the Appendix has a list of the countries. The countries were selected solely on the availability of data.

Table 1. Data description & source

Variables	Description	Source
Agricultural Output	Agricultural Gross Production Value (constant 2014-2016 thousand US\$).	FAO Statistics
GDP Per Capita	The purchasing power parity converted GDP Per Capita at 2017 constant prices.	WDI
Migration	Total migrant stock at mid-year by origin and by major area, region, country or area of destination, 1990-2017.	United Nations
Temperature	Monthly mean temperature measured in degrees Celsius.	World Bank
Latitude	World country latitude values.	World Bank Creative Commons 4.0 license
Agriculture value added	Agriculture, forestry, and fishing, value added as percentage of GDP.	World Bank

The outmigration dataset covers bilateral international migration flows and stocks of foreigners from SSA countries to South Africa. The purchasing power parity converted GDP Per Capita at 2017 constant prices as a proxy for the domestic wage. Given that agriculture provides 15% of total GDP on average in SSA, and employs more than half of the overall labor force (IMF, 2012), and directly employs around 175 million people (Alliance for a Green Revolution in Africa, 2014), and since most of the SSA are agricultural dependent countries we used the share of agriculture value added in GDP (% of GDP) as a dependent variable to explain the migration and to indicate that a country is highly agricultural dependency. Table 1 provides data description and source of the data used in the study.

To answer the research objective, we adopt and modify Cai et al. (2016) model specification to estimate a country-pair fixed-effects migration model that considers temperature as independent variables, and its interaction with share of agriculture value added in GDP. Our specification is as follows:

$$\mathcal{M}_{ijt} = \alpha_0 + \alpha_1 Temp_{it} + \alpha_2 AGRV_{it} + \lambda Temp_{it} * A_i + \phi x_{it-1} + \alpha_3 year + \gamma_{ij} + \varepsilon_{ijt} \quad (1)$$

Where \mathcal{M}_{ijt} denotes the natural logarithm of migration rate of country i to country j at year t . $Temp_{it}$ represents the annual average of monthly total temperature in the origin country i in Celsius at year t . AGR_{it} represents share of agriculture value added in GDP specific to origin country i and γ_{ij} measured in percentage. This variable was introduced to investigate the role of agricultural value added as a determinant of migration. $\lambda Temp_{it} * A_i$ indicates the interaction of temperature with agricultural dependence (A_i). A_i is a dummy variable that equals 1 if the origin country i is defined as highly agriculture-dependent, 0 otherwise, x_{it-1} are vectors of important migration determinant – income (approximated by GDP per capita). γ_{ij} denotes country-pair fixed effects, which capture time-invariant unobserved characteristics between two specific countries, such as distance, historical and cultural ties, linguistic distance, and many more. Using country-pair fixed effects. Year is included to capture linear time trends which control for time variant factors such as urbanization, employment possibilities, welfare schemes, migrant networks, and immigration policy schemes. ε_{ijt} shows the error term. α, λ, ϕ are parameters to be estimated.

Moreover, given the fact that extreme heat is correlated both with lower crop yields and higher outmigration flows. And agricultural countries are usually also low-latitude hot countries and tend to be poor, we interact temperature with latitude and GDP, respectively, to rule out the possible “hot” effect and “poor” effect. we extend the specification in Eq. (1) to include temp, latitude and GDP per capita interaction. Hence, the specification in Eq. (1) becomes as follows:

$$\mathcal{M}_{ijt} = \alpha_0 + \alpha_1 Temp_{it} + \alpha_2 AGR_{it} + \lambda_1 (Temp_{it} * A_i) + \lambda_2 (Temp_{it} * Lat_i) + \lambda_3 (Temp_{it} * GDPA_{it}) + \phi x_{it-1} + \alpha_3 year + \gamma_{ij} + \varepsilon_{ijt} \quad (2)$$

where the variable $(Temp_{it} * Lat_i)$ and $(Temp_{it} * GDPA_{it})$ means that temperature is interacted with latitude and GDP per capita (GDPA) respectively. Description of the main variables used in the study is provided in Table 2.

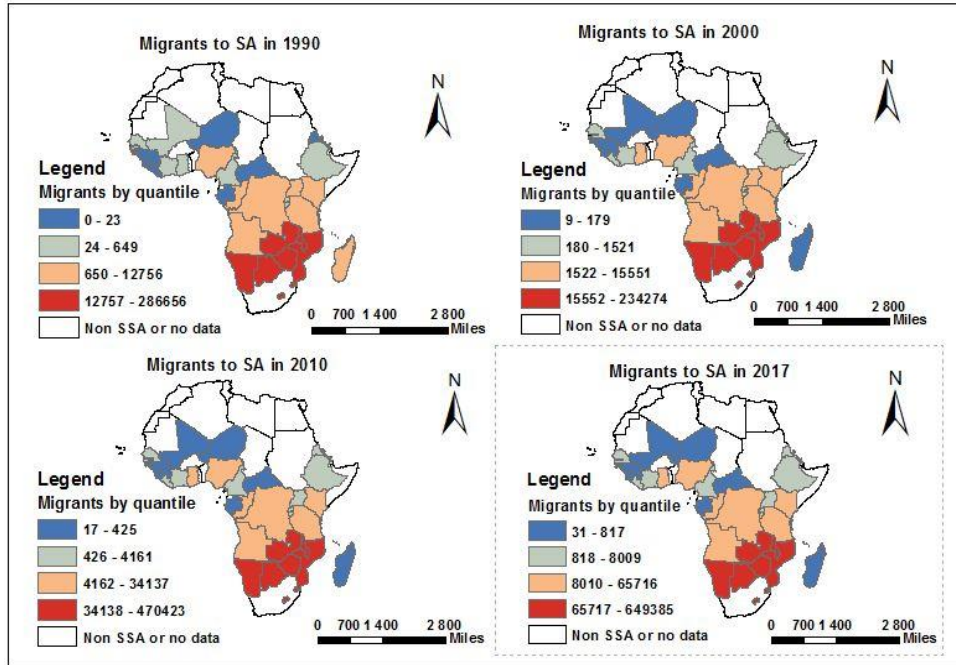
Table 2. Descriptive statistics

Variable	Obs	Mean	SD	Min	Max
Migration	245	35768.6	89233.29	0	649385
Agricultural output	245	3510000	7680000	372	6.40e+07
GDP Per Capita of original countries	245	1592.6	2422.468	55.2281	15906.1
GDP per Capita of destination country	245	4928.95	1526.421	3032.439	7328.615
Temperature	245	24.245	3.185	11.86	29.38
Agric value added	245	25.104	16.762	1.828	96.158

The total number of observations is 245 during the period of 1990–2017. On average, about 35 769 people from SSA with some countries ranging between 0 to 649 385 annual people migrating

to south Africa during the study period. A more country specific migration description is provided in the Figure 1 below.

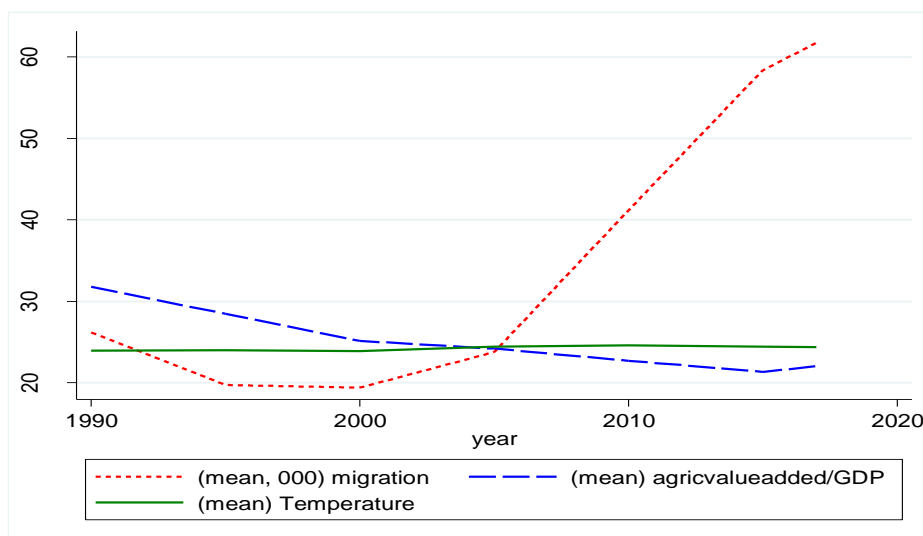
Figure 1: Migrants from SSA countries to South Africa between 1990-2017



Source: Authors' self-painting using United Nations Outmigration online database

The descriptive statistic in figure shows that the people from countries nearby to South Africa occupy nearly 90 percent share of the total migrant from SSA to South Africa. However, the number of migrants from each quantile has been growing up overtime. The growing trend of migrants to south Africa from SSA countries is depicted in Figure 2 below.

Figure 2: Average trends of key variables



Source: Authors computation

Figure 2 shows that on average migration (in thousands) from SSA to SA was decreasing prior to 1994 SA independence, after independence the trend has been ever increasing. The percentage share of agriculture value added in GDP has been decreasing on average while the average temperature has been fairly increasing in the SSA region.

5. Results and discussion

In this section, the study's key findings are provided and discussed. We first estimate a reduced-form model that links origin country temperature variations to its international outmigration, while controlling for an important migration determinant – income (approximated by GDP per capita) of both the destination and origin countries– as well as unobserved time-invariant country-pair factors and country-specific time trends as indicated in Eq. (1). Our key findings are shown in Table 3. The estimated coefficients can be directly interpreted as elasticities because the output and input variables are in logarithmic form. We regress the natural logarithm of migration rate on current temperature in the origin countries with the control variables in column (1). In column (2), we add agriculture value added as a share in GDP. The interaction term between temperature and agricultural dependency are added in column (3) of Table 3 which is our preferred specification as indicated in Eq. (1). All four models include a set of country-pair fixed effects particular to the origin countries.

Table 3. Climate and international migration: the main results

VARIABLES	Column (1)	Column (2)	Column (3)
Temperature	1.216*** (0.195)	0.449*** (0.0884)	0.460*** (0.0993)
Agriculture-value-added/GDP		-0.0118* (0.00618)	-0.0262*** (0.00651)
Log of GDPA of destination country		0.800*** (0.144)	0.799*** (0.149)
Log of GDPA of origin countries		-0.140 (0.195)	-0.105 (0.181)
Temp* Agriculture dependency			0.0248*** (0.00738)
Year		0.117*** (0.0135)	0.116*** (0.0136)
Constant	-21.68*** (4.722)	-207.9*** (25.65)	-205.8*** (25.45)
Observations	244	209	209
R-squared	0.179	0.628	0.648
Number of countries	35	35	35

Robust standard errors clustered by origin countries are reported in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Agriculture dependency is measured as a dummy variable whereby highly agricultural countries with agricultural value added as % of GDP $\geq 35\%$ are assigned with 1, and the remaining countries are assigned with 0.

A positive and substantial coefficient estimate for the linear effect of temperature indicates that, the variable drive outmigration from origin countries to South Africa. Our findings are in line with existing literature which has shown that environmental factors are increasingly being acknowledged as potential drivers of cross-border and intra-national human migration (see Laczko and Aghazarm, 2009). Indeed, poor environmental conditions ranging from natural disasters and extreme weather events to more gradual changes in climate may prompt people to migrate as an adaptation strategy (see McLeman and Smit, 2006). GDP per capita of origin countries also has a negative effect while the GDP per capita of the destination country has positive and significant linear effect on out migration. This is consistent with studies such as Cai et al., (2016) who also found similar results. More so, the interaction term shows that temperature impacts significantly across the agricultural channel in model (3), and that agricultural countries are more likely to see major outmigration. The findings from Table 3 further show that weather impacts on migration are nonlinear, which is in accordance with the nonlinear yield–temperature connection that has been described in the literature (see Schlenker and Roberts, 2009; and Cai et al. 2016). Extreme heat during growth seasons, in particular, is harmful to crops and is likely to cause outmigration. According to the results in column (3) of Table 3, a 1°C increase in temperature results in about 0.0248% increase in outmigration from agricultural dependent countries (statistically significant at the 1% level) to South Africa. This is consistent with the findings of Marchiori et al. (2012) and Cai et al. (2016), who discovered that climate variations in agricultural dependent nations is a major driver of outmigration in Africa.

Table 4 shows a variety of robustness tests for the coefficient of the interaction term between temperature and agricultural dependency. We incorporate the interaction term between temperature and agricultural dependency and run a robustness test to see if the temperature effect differs between the top 25% of agriculture-dependent countries and the rest. For both the origin and destination countries, we also include the natural logarithm of lagged GDP per capita. All four models include linear time trends that are distinctive to each country. We adhere strictly to the literature (see Cai et al 2016) and employ a continuous measure of agricultural dependence, which is the percentage of agricultural value-added in GDP. Column (1), (2), (3) and (4) provide the alternative definitions of agriculture dependency at 25%, 30% and 35% respectively. Furthermore, agriculture dependency is measured as a continuous variable. Whereby countries with agricultural value added as percentage of GDP $\geq 25\%$, 30% and 40% respectively are assigned with 1, and the remaining countries are assigned with 0 based on data available at the World Bank². Overall, the

² World Bank national accounts data, 2021. Agriculture, forestry, and fishing, value added (% of GDP).

findings support the notion that agriculturally reliant countries are more prone to undergo outmigration as temperatures rise.

Table 4. Robustness check for the main results

VARIABLES	Column (1)	Column (2)	Column (3)	Column (4)
Temperature	0.255** (0.123)	0.369*** (0.106)	0.381*** (0.0975)	0.366*** (0.0992)
Temp* Agriculture dependency	0.00485 (0.00451)			
Temp* Agriculture dependency $\geq 25\%$		0.00178 (0.00916)		
Temp* Agriculture dependency $\geq 30\%$			0.0120 (0.00823)	
Temp* Agriculture dependency $\geq 40\%$				0.00534 (0.0102)
Agriculture-value-added/GDP	0.110 (0.113)	-0.0110 (0.00675)	-0.0163** (0.00613)	-0.0135 (0.00931)
Log of GDPA of destination country	0.789*** (0.145)	0.796*** (0.147)	0.805*** (0.147)	0.802*** (0.147)
Log of GDPA of original countries	-0.175 (0.205)	-0.177 (0.202)	-0.154 (0.195)	-0.179 (0.203)
Year	0.123*** (0.0124)	0.121*** (0.0131)	0.120*** (0.0130)	0.121*** (0.0133)
Constant	-225.2*** (22.78)	-218.1*** (25.16)	-215.4*** (24.67)	-218.0*** (25.35)
Observations	209	209	209	209
R-squared	0.644	0.639	0.645	0.640
Number of countries	35	35	35	35

Robust standard errors clustered by origin countries are reported in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Discussions on the findings in Table 3 and 4 have shown the detrimental effects of temperature on outmigration from SSA countries to South Africa. Further, we also show that this nexus is plausible through the agriculture channel. Nonetheless, although it is highly implausible, it is feasible that a country's amount of agricultural dependence is only a proxy for other variable(s); that might be influencing the relationship between temperature and migration. To further rule out such possibilities, we perform two things in as indicated in Eq. (2). First, a country's agricultural dependence is likely to be correlated with other characteristics such as the geographic location (country located in hot or low-latitude). Dell et al. (2012) observe that agricultural dependent nations are often low-latitude hot countries. To make sure that our analysis does not ignore this important channel, we consider country geographic location (proxied by latitude). Second, we show that the level of development proxied by GDP is a potential intermediating factor between climate change and migration in SSA. In doing so, we follow the literature (see Cai et al. 2016) and consider the possibility of "hot" and "poor" effects by introducing direct temperature–latitude and GDP–temperature interaction terms in the model as indicated in Eq. (2). In column (4), we include interactions of latitude and temperature, and GDP per capita with temperature. The results show

that the interaction of temperature with both location and the level of development has a positive and significant effect on outmigration. Overall, the results reveal that not only agriculture, but also geographic location and level of development in destination countries, are key mediators in the temperature–migration nexus in SSA. As GDP is a significant determinant of international migration, this gives further proof of the relevance of the agriculture channel's function. Because agriculture dependent countries are most likely to be poor, a rise in temperature which affect agriculture production induce migration to South Africa, given that it is one the highest developed countries in SSA.

Table 5. Adding latitude–temperature and GDP–temperature interactions

VARIABLES	Column (1)	Column (2)	Column (3)	Column (4)
Temperature	0.458*** (0.153)	0.434*** (0.158)	1.088*** (0.173)	1.057*** (0.182)
Agriculture-value-added/GDP		-0.017* (0.008)		-0.020** (0.007)
Temp*Latitude	0.016*** (0.004)	0.014*** (0.005)		
Temp*GDP			0.064*** (0.019)	0.065*** (0.019)
Log of GDPA of destination country	0.537*** (0.140)	0.495*** (0.144)	0.670*** (0.135)	0.610*** (0.136)
Log of GDPA of origin countries	-0.433*** (0.154)	-0.410*** (0.150)	-1.98*** (0.455)	-1.989*** (0.473)
Temp* Agriculture dependency		0.093 (0.085)		0.131*** (0.075)
Year	0.095*** (0.010)	0.093*** (0.010)	0.095*** (0.010)	0.093*** (0.010)
Constant	-174.534*** (18.842)	-171.00*** (19.319)	-159.897*** (20.579)	-157.863*** (21.312)
Observations	244	244	244	244
R-squared	0.678	0.685	0.680	0.690
Number of countries	35	35	35	35

Robust standard errors clustered by origin countries are reported in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

When we include the interaction of latitude with temperature without the agriculture interaction term in column (1), we find a positive and significant effect on outmigration. Likewise, when we include both latitude–temperature and agriculture dependency–temperature interactions in the regression as seen in column (2), the coefficient of the latitude–temperature term slightly reduces in size and stays highly significant but the agriculture dependency–temperature term though positive is non-significant. From column (3) and (4), the GDP–temperature interaction terms are included. When we exclude the agriculture dependency–temperature term from column (3), we find that the GDP–temperature interaction term is positive and highly significant. To account for

possible nonlinearity, we combine the GDP–temperature term with the agriculture dependency–temperature term in column (4). In both scenarios, the agriculture–temperature and GDP–temperature term stays positive are highly significant. Our findings build on the existing literature (see Cai et al. 2016), that not only the agriculture channel is a mediating factor in the climate change migration relationship, but also, geographic location and the level of development plays critical and significant roles in the climate change–migration link.

6. Conclusion & policy implications

The impacts of climate change on international migration flows from SSA nations to South Africa are investigated empirically in this study. The analysis uses yearly panel data from 35 countries in SSA, spanning the years 1990 to 2017. The findings show that temperature has a positive and statistically significant influence on outmigration in agriculture-dependent nations in SSA. The results also support the nonlinear temperature–yield relationship that has been observed in the literature. This implies that extreme heat levels decrease agricultural output and encourages international migration in SSA. Further, we show that, key mediators in the climate change–migration nexus includes geographic location, and development level of a country in addition to the agricultural dependency channel. In particular, we find that agriculture dependency, development level in destination country, and geographic location are major determinants in the intermediary linkages between climate change and international migration from SSA nations to South Africa. Moreover, our study found that agriculture-value-added as a share in GDP has negative and significant impact on migration from SSA nations to South Africa, suggesting that the higher a country increase its agriculture value added the less people will migrate from the country. Our findings have important policy implications. Given that climate change is found to influence international migration, it is recommended that governments should provide alternative adaptation strategy as a response to climate change which among others should include but not limited to increased spending on research and development (R&D), and also the promotion of high agriculture-value-added as a share in GDP. Given the long-held belief that increases in the use of traditional inputs do not account for a large portion of productivity growth in agricultural production (see Timmer, 2005; Fan, Zhang, & Rao, 2004), investments in R&D are often seen as critical to generating productivity growth through new knowledge and innovation. Thus, spending on R&D will serve as a means of adaption by farmers to climate change through the development of drought resistant crops and seedlings. At the same time, increase in agriculture-value-added will provide more income, employment, and decent livelihood to farmers and indirectly to the people who will be engaged in the value chain process. This may lessen migration incentives given that farmers can increase agricultural output with the expectation of higher returns. Furthermore,

building an enabling environment for entrepreneurs to thrive is required for the value addition of agriculture produce. An appealing investment atmosphere encourages tremendous investment interest and effort. In this vein, agriculture policymakers must implement policies and programs that encourage investment in agriculture produce value addition in order to support economic growth. Access to finance and capital, electricity, technology infrastructure, standards, and certification must be made available through rigorous agribusiness development programs. Corporate efforts that strive to encourage agriculture value addition will prosper, and thus have the necessary economic and social impacts when these issues are addressed. A major caveat to this study is that it uses macro level data. Therefore, it is recommended that future studies pay more attention to sub-national levels to bring into detail the impact of climate change on international migration.

Credit authorship contribution statement

Frank Bannor conceived the key ideas for this research paper. He collected and analysed the data. He also worked on the introduction, methodology, and discussion of the results. Isaiah Hubert Magambo worked on the methodology, data analysis, and discussion of the results. Jugal Mahabir worked on data compilation and analysis and wrote the conclusion of the paper. Jean-Luc Mubenga worked on the introduction and literature review of this research paper. Software: Frank Bannor and Isaiah Hubert Magambo. All authors have read and approved the final version of this manuscript.

Declaration of competing interest

The authors declare no conflict of interest. The University of Johannesburg and the School of Economics had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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Appendix

Table A1. List of countries

No.	Name of Country
1	Angola
2	Botswana
3	Burundi
4	Cameroon
5	Central Africa Republic
6	Comoros
7	Congo Democratic Republic
8	Congo
9	Cote d'Ivoire
10	Eritrea
11	Eswatini
12	Ethiopia
13	Gabon
14	Ghana
15	Guinea
16	Guinea Bissau
17	Kenya
18	Lesotho
19	Liberia
20	Madagascar
21	Malawi
22	Mali
23	Mauritius
24	Mozambique
25	Namibia
26	Niger
27	Nigeria
28	Rwanda
29	Senegal
30	Seychelles
31	Sierra Leone
32	Tanzania
33	Uganda
34	Zambia
35	Zimbabwe