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ORIGINAL ARTICLE

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 nations to South Africa are investigated empirically in this paper. The study employed static and dynamic models and panel data from 35 countries in sub-Saharan Africa, spanning 1990 to 2017. The findings are as follows: (1) The analysis shows that historical 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 gross domestic product 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.

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 (Marchiori et al., 2012; Solomon, 1994). The World Bank observes that, by 2050, 143 million people in three areas of the world (sub-Saharan Africa [SSA], 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 rising sea levels.

Therefore, migration is seen as a critical resilience strategy against the impacts of climate change. Although 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 relative to others, and it seems natural that residents in such 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 as a result, adaptation is perceived 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 more dependent on the climate compared with most developing regions in the world, and variability in temperature and rainfall can have dire consequences on food production and livelihoods (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 one of the most significant factors that drive rural–urban migration (Barrios et al., 2006). Moreover, it is a plausible hypothesis that agriculture plays an important role in the climate and cross-border migrations worldwide (Cai et al., 2016).

The plausible role that agriculture plays in the climate–migration nexus has been investigated in Organisation for Economic Cooperation and Development (OECD) countries (Cai et al., 2016), but little attention has been given to cross-border migration within SSA. Furthermore, specific channels, such as country location and level of development, are also highlighted as significant drivers of international migration. These channels have received attention predominantly within European perspectives, specifically in the cases where agriculture was assessed as an intermediating factor between climate change and migration (Cai et al., 2016). However, the literature shows that the majority of these migrants, in actuality, migrate inside their own countries and regions. More so, the quantitative literature on climate-induced (international) migration is still in its infancy. So far, the analytical findings have been mixed. Although several studies show a relationship between migration and climatic factors such as natural disasters, temperature, and precipitation (Bohra-Mishra et al., 2014; Gray & Mueller, 2012), others show that climate change is insignificant in comparison with other drivers of migration such as employment and level of development (Mortreux & Barnett, 2009; Naudé, 2010). The obvious differences among the results of these 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 et al. (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.

Our paper intends to advance the current literature in three ways. First, we focus on cross-border migration in SSA in order to obtain a more comprehensive understanding of the climate–migration relationship in the region. Second, our study uniquely places South Africa as the destination country for migration from other SSA countries. In doing so, the paper provides a holistic assessment of migration to South Africa by directly assessing whether climate change factors are driving migration to the country, among the other more apparent push and pull factors. This is important for two reasons: (1) Official estimates put the country's immigrant population at around 4.2 million (Africa Migration Report, 2019), the highest destination country in SSA, and (2) such migration, particularly from SSA, is a growing sociopolitical issue resulting in increasing social tensions and a growing xenophobic sentiment in the country.[1] Understanding the climate dimension of migration to South Africa can have important consequences for policy and can shed light on the potential indirect impacts of climate change on sociopolitical issues faced by contemporary society. Lastly, from an empirical perspective, our study considers agriculture value

[1]Empirical studies show that Johannesburg in South Africa serves as one of the main migration hubs on the African continent. Since 2008, there have been 961 incidences of xenophobic-related violence resulting in 123,402 displacements, 4662 shops vandalised, and 397 deaths (Xenowatch, 2023).

added as a share of gross domestic product (GDP), agricultural dependency, geography (proxied by latitude), and the level of development (proxied by GDP) as potential intermediating variables between climate change and migration.

A large body of literature has already identified that crop yields are highly sensitive to climate change, especially variability in rainfall and temperature (Lobell et al., 2011; Schlenker & Roberts, 2009). As stated earlier, agriculture is a significant economic sector 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, agriculture value added as a share of GDP is considered in our study due to the fact that increasing added value is to increase state, and more especially, rural incomes, employment, and investment opportunities which would eventually reduce the incentive to migrate.

Estimating the extent climate change has as a potential push factor for migration can have important consequences for the origin and the destination countries, the latter being South Africa in this analysis. South Africa was chosen as the country of destination for migration in this analysis due to the unique impact migration is having on its sociopolitical and economic landscape. As mentioned, South Africa is one of the key destinations for immigration in Africa and, in particular, the SSA and Southern African Development Corporation region. In fact, the country has the most immigrants on the African continent, with official estimates putting the country's immigrant population at around 4.2 million (Africa Migration Report, 2019). This is largely attributed to its middle-income position, strong democratic institutions, and comparatively industrialised economy. Figure 1 shows that, although there are other countries with substantial immigrant populations, South Africa holds the majority share of net migrants by far compared with the rest of immigrants' host countries in the SSA region.

As a consequence of being one of the most favourable countries for immigration in the region, South Africa is currently grappling with a growing xenophobic sentiment that has resulted in violent reprisals against foreigners, which is a concern for policymakers and politicians in the current political discourse. Indeed, this issue has been a social concern to the country from 2008 following a considerable increase in the number of immigrants in the country in the preceding decade. Figure 2 shows the stock

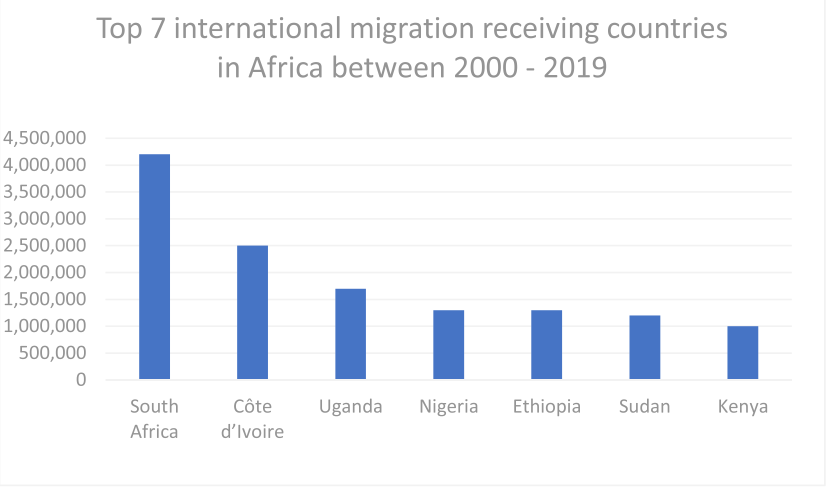

FIGURE 1 Top 7 migration receiving countries in Africa. *Source*: Authors compilation.

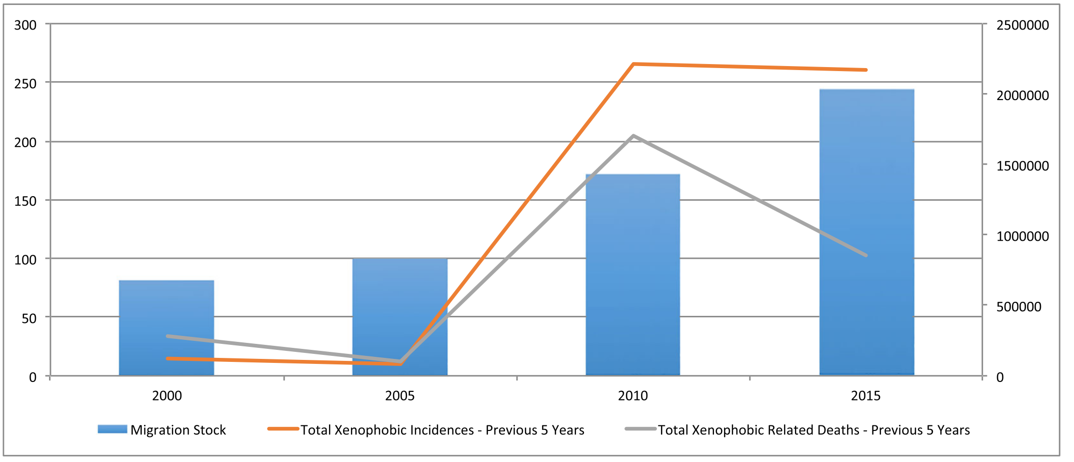

FIGURE 2 Stock migrants and xenophobic incidents. *Source*: Authors compilation.

of immigrants in the years 2000, 2005, 2010, and 2015 along with the cumulative number of xenophobic-related incidences and deaths in the five years preceding each of these years. As illustrated, there has been a substantial growth in the number of immigrants in the country from 2000 until 2015, with a growth of 679,486 immigrants in the country in 2000 to over 2 million immigrants in 2015. One can also notice a stark increase in the number of xenophobic-related incidences and deaths corresponding to the increase in the number of immigrants in the country, a possible indication of the increased social tensions driven by migration.

The growing impact of climate change on world economies and global societies is well documented, with many of the obvious impacts like extreme weather patterns and events like flooding and droughts having a clear effect on human settlements, infrastructure, and living conditions. Placing South Africa as the destination country in this analysis provides a good example to assess a potential indirect impact of climate change on a contemporary socio-economic and political issue, such as xenophobia and other social tensions, via climate-induced migration. As a result, contemporary policymakers face the prospect of not only addressing the direct impacts of climate change but also the potential indirect impact climate change is having on the social fabric and social cohesion via intermediate channels, such as migration.

Furthermore, as the effects of climate change become more severe, climate-induced migration will become more common, placing and increased burden on the receiving country. This may include increased housing stress on the receiving country, political and social friction, increased costs to provide social amenities, overcrowding, disease transmission, and the marginalisation of migrants into low-status and low-paying jobs (Solomon, 1994). To mitigate this problem, an effective climate adaptation policy is partly required. An adaptation policy requires an understanding of how climate change affects migration patterns. 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 static and dynamic models 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 has a positive and statistically significant effect on outmigration in agricultural-dependent nations in SSA to South Africa. In this study, we do so by examining both the effects of mean monthly temperature and historical temperature changes within SSA nations on outmigration to South Africa. We use this approach because it is well established in contemporary literature that hot countries are poor, with national income declining by 8.5% for every degree Celsius increase in temperature (Dell et al., 2009). Second, we provide evidence to support existing literature that agriculture value added as a share of GDP has negative and statistically significant effects on outmigration in agricultural-dependent nations in SSA to South Africa. Third, we also show that geographic location and the development level of a country, in addition to dependency on agriculture, are key mediating factors in the climate change–international migration relationship in SSA. Lastly, we confirm that climate change factors contribute to migration to South Africa, thus emphasising the indirect effect climate change can have on current sociopolitical issues.

The rest of the paper is organised as follows. We provide a review of existing literature in Section 2. In Section 3, we show data and estimation strategy. In Section 4, we provide and discuss the findings of the various models that were estimated, and in Section 5, 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 maximise one's income (Borjas, 1989; Clark et al., 2007; Roy, 1951). Drawing a theoretical foundation from income maximisation, 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 maximises income. In addition to the income maximisation conceptualisation, studies have used the utility maximisation framework that allowed the incorporation of non-income determinants of migration. Some of these determinants include structural transformations, cultural and linguistic distance, political pressures, conflicts and wars, networks of family and friends, educational and social benefits, immigration policies, subjective well-beings, and amenities (Cai et al., 2016; Clark et al., 2007). 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 (Foresight, 2011; Gray & Mueller, 2012; Piguet et al., 2011; Solomon, 1994).

The relationship 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 (El-Hinnawi, 1985; Feng et al., 2010; Myers, 1993). However, climate-induced migration can either be permanent or temporary and can either be internal (rural to urban areas within a country) or international. Different studies have explored different determinants on the link between climate change and migration. Gray and Mueller (2012) show that crop failures caused by rainfall shortages have a significant impact on mobility in Bangladesh, and 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. Further empirical studies have established the determinants on the link between climate change and migration by types such as the study by Joarder and Miller (2013), which found that migrants who previously worked in agriculture or fishing are more likely to migrate permanently. In addition, households that reported losing assets because of environmental threats have a greater likelihood of becoming permanent migrants. Bohra-Mishra et al. (2014) discovered that in Indonesia, 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.

Using migration flows from all African countries between 1980 and 2015 into 16 OECD countries, Wesselbaum (2021) re-examines the question of whether climate is a driver or inhibitor of migration. According to the study, climate can influence migration either positively or negatively, depending on the severity of the temperature shock. The author observes a U-shaped relationship for temperature at the destination country and an inverted U-shaped relationship at the origin country to demonstrate the nonlinear impacts of temperature on migration. The study also reveals that the agricultural pathway does have a quantitative impact: Nations with higher agricultural dependence see higher migrant flows. Based on the CLIMIG database, Piquet (2021) compiles a comprehensive and analytical list of published scientific references on migration and the environment. In the study titled "Linking climate change, environmental degradation, and migration: An update after 10 years," the author offers a methodological typology of an extraordinarily high number of published case studies.

Falco et al. (2019) and Feng et al. (2010) found similar mechanisms that affected outmigration. Feng et al. (2010) estimated that, by 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 because of declines in agricultural productivity alone. Cai et al. (2016) looked into the link between climate variability and international migration from Africa to OECD countries. Only in the most agricultural-dependent countries does the study reveal a positive and statistically significant relationship between temperature and international outmigration.

There are also studies on Africa (Atuoye et al., 2021; Grace et al., 2018; Klaiber, 2014; Marchiori et al., 2012; Morrissey, 2013; Mueller et al., 2020; Ripkey et al., 2021) that provide empirical findings on the 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% decreases in outmigration, respectively, when compared with mean values. Marchiori et al. (2012) also show that weather fluctuations have increased internal and international migration across both amenity and economic networks using country-level panel data from SSA. Grace et al. (2018) examined the individual- and community-level responses to climate variability as a driver of outmigration. The findings implied that, in general, outmigration behaviour does not change because of failures or in the rainy season. The effect of climate on migration varied significantly by migrant characteristics. For instance, Black and low-income earners in South Africa are strongly influenced by climatic variables compared with White high-income migrants. This likely reflects the fact that subsistence farming is predominant in Black communities in South Africa.

In general, present studies on the relationship between climate change and migration focus either on migration within countries outside the African continent, migration from Africa to OECD countries, or migration within countries on the African continent. As a result, it falls short of providing a comprehensive picture of the potential long-term impact of weather changes on migration from African countries to a potential destination on the continent. Our paper does exactly this by considering the important role of agricultural dependence, agriculture value added as a share of GDP, and the significance of geographical location and level of development to explain the climate change–outmigration relationship. It differs from previous work by controlling for country fixed effects (FE) and time trends, endogeneity dynamism, and persistence effects of the time series.

3 | DATA AND ESTIMATION STRATEGY

We compiled a new collection of data for 35 SSA nations, spanning the years 1990 to 2017, on international migration to South Africa. In relation to the total migration population, Southern Africa hosted the largest migrant population (6.7%), followed by Middle Africa (2.2%), Western Africa (1.9%), Eastern Africa (1.8%), and Northern Africa (1.2%) (Africa Migration Report, 2019). Out of this statistic, the Africa Migration Report (2019) observes that South Africa hosted the largest number of international migrants, 4.2 million, on the African continent. Our cross-country panel data set consists of migration variables, climate variables, and economic variables. Table A1 has a list of the countries. The countries were selected solely on the availability of data.

The outmigration data set 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 the total GDP on average in SSA, employs more than half of the overall labour force, and directly employs around 175 million people (Alliance for a Green Revolution in Africa [AGRA], 2014). In addition, most nations in 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 agriculturally dependent. Table 1 provides data description and source of the data used in the study.

TABLE 1 Data description and 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 midyear 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	Climate Portal
Agriculture value added	Agriculture, forestry, and fishing, value added as percentage of GDP	Google Public Data Explorer World Bank
Political stability	A measurement of perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism in units of a standard normal distribution, ranging from −2.5 to 2.5	WDI

Abbreviation: GDP, gross domestic product.

To answer the research objective, we adopt, and modify, Cai et al. (2016) model specification to estimate a country-pair FEs 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 $\mathcal{M}_{\mathrm{ijt}}$ denotes the natural logarithm of migration rate of country i to country j at year t. $Temp_{\mathrm{it}}$ represents the annual average of monthly total temperature in the origin country i in Celsius at year t. $AGRV_{\mathrm{it}}$ represents share of agriculture value added in GDP specific to origin country i. This variable was introduced to investigate the role of agriculture 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, and x_{it-1} are vectors of important migration determinant—income (approximated by GDP per capita). γ_{ij} denotes country-pair FEs, which capture time-invariant unobserved characteristics between two specific countries, such as distance, historical and cultural ties, linguistic distance, and many more. Year is included to capture linear time trends that control for time-variant factors such as urbanisation, employment possibilities, welfare schemes, migrant networks, and immigration policy schemes. $\varepsilon_{\mathrm{ijt}}$ shows the error term. $\alpha, \lambda, \text{and}\, \phi$ are parameters to be estimated.

Moreover, given the fact that extreme heat is correlated both with lower crop yields and higher outmigration flows and that 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 Equation (1) to include temperature, latitude, and GDP per capita interaction. Hence, the specification in Equation (1) becomes as follows:

$$\begin{aligned}\mathcal{M}_{ijt} = {} & \alpha_0 + \alpha_1 Temp_{it} + \alpha_2 AGRV_{it} + \lambda_1 \left(Temp_{it} * A_i\right) + \lambda_2 \left(Temp_{it} * Lat_i\right) + \lambda_3 \left(Temp_{it} * GDPA_{it}\right) \\ & + \phi x_{it-1} + \alpha_3 year + \gamma_{ij} + \varepsilon_{ijt}, \end{aligned} \quad (2)$$

where the variables $(Temp_{it} * Lat_i)$ and $\left(Temp_{it} * GDPA_{it}\right)$ mean that temperature is interacted with latitude and GDP per capita, respectively.

However, our static models in Equations (1) and (2), on the other hand, have two intrinsic endogeneity problems. First, one of the independent variables could be endogenous theoretically. Second, as established in classic dynamic modelling by Blundell and Bond (2000), independent variables in the model could be correlated with the time lag of the dependent variable. Within the FE framework, a maximum-likelihood estimator or a Generalised Method of Moment (GMM) (Kelejian & Prucha, 1998) can be used to provide consistent results. In this study, we use the GMM framework as it robustly handles the endogeneity problems enumerated above and provides more efficient estimates (Abid, 2016). We add one lag of the dependent variable as an additional explanatory variable to Equation (1) to account for the dynamism and persistence effects of the time series (Liu & Bi, 2019), and thus, we obtain a dynamic model with the following functional form:

$$\begin{aligned} \mathcal{M}_{ijt} = \alpha_0 + \alpha_1 M_{ijt-1} + \alpha_2 Temp_{it} + \alpha_3 AGRV_{it} + \lambda_1 \left(Temp_{it} * A_i \right) + \lambda_2 \left(Temp_{it} * Lat_i \right) \\ + \lambda_3 \left(Temp_{it} * GDPA_{it} \right) + \phi x_{it-1} + \alpha_4 year + \gamma_{ij} + \varepsilon_{ijt}, \end{aligned} \tag{3}$$

where M_{ijt-1} denotes the first period lag of the dependent variable and α_1 is the coefficient to be estimated.

One of the objectives of this study is to assess the potential impacts of climate change on a contemporary sociopolitical issue in the form of social tensions and xenophobia related to increased migration. It was argued above that South African society is currently facing such an issue and thus provides an opportune example to assess such an indirect impact of climate change. As a result, the analysis uses South Africa as a destination country. However, it is important to acknowledge that this approach does have an empirical drawback. Having one destination country does not effectively and simultaneously account for the pull factors of other potential destination countries in the SSA region. It also does not effectively account for other bilateral factors that can drive migration in SSA, such as shared borders, colonial ties, and common languages. However, given that one of the objectives of this study is to ascertain the extent of climate induced migration to South Africa directly, we find this a necessary adaption for the study.

Description of the main variables used in the study is provided in Table 2.

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 and 649,385 people annually, migrated to South Africa during the study period. A more country-specific migration description is provided in Figure 3.

The descriptive statistic in Figure 3 shows that the people from countries nearby to South Africa occupy nearly a 90% share of the total migrants from SSA to South Africa, and the nearby countries might be susceptible to share similar climatic vulnerability and, hence, migration be motivated by other factors besides the climate. Figure A1 shows that South Africa has experienced a steady increase in temperature overtime as compared with the rest of the nearby countries. The studies by Cai et al. (2016) and Melillo et al. (2014) show that temperature variations are more important factor to explaining agricultural output. Increasing temperature variability in nearby countries can be associated to poor agriculture output and thus induce migration. The study by Melillo et al. (2014) provides the justification for

TABLE 2 Descriptive statistics.

Variable	Obs	Mean	*SD*	Min	Max
Migration	245	35,768.6	89,233.29	0	649,385
Agricultural output	245	3,510,000	7,680,000	372	6.40e+07
GDP per capita of origin countries	245	1592.6	2422.468	55.2281	15,906.1
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

Abbreviation: GDP, gross domestic product.

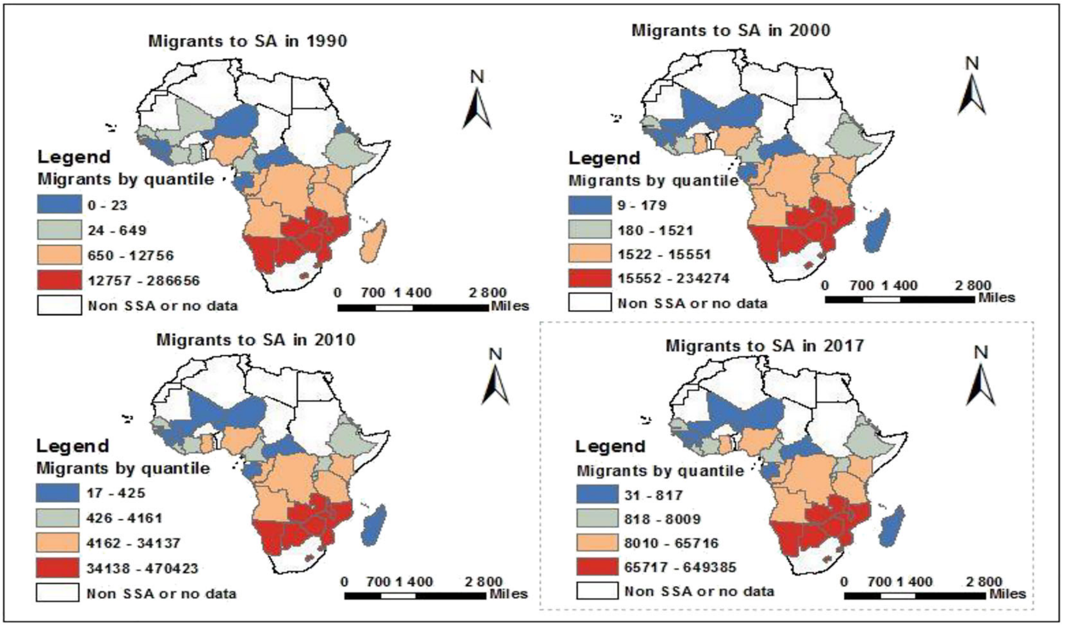

FIGURE 3 Migrants from sub-Saharan Africa (SSA) countries to South Africa (SA) between 1990 and 2017. *Source*: Authors' self-painting using United Nations outmigration online database.

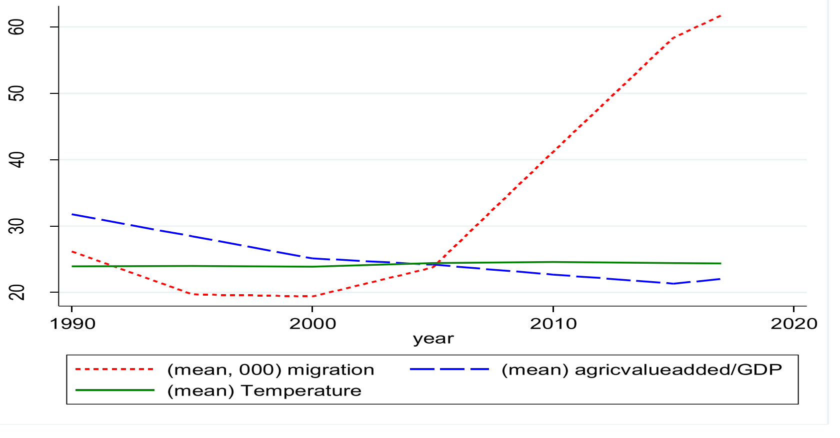

FIGURE 4 Average trends of key variables. *Source*: Authors computation.

temperature variations to be a major factor for lower agricultural output; thus, for the agricultural-dependent countries, this could be a driving factor for people to migrate. Therefore, our findings support the fact that increasing migration to South Africa from the nearby countries is to some extent climate induced.

However, the number of migrants from each quantile has been growing upwards over time. The growing trend of migrants to South Africa from SSA countries is depicted in Figure 4.

Figure 4 shows that average migration (in thousands) from SSA to South Africa was decreasing prior to the first democratic elections in the country in 1994, with substantial increases from the year 2000 onwards. The percentage share of agriculture value added in GDP has been decreasing on average, whereas the average temperature has been fairly increasing in the SSA region.

4 | 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 Equation (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 agriculture dependency is added in column (3) of Table 3, which is our preferred specification as indicated in Equation (1). All four models include a set of country-pair FEs particular to the origin countries.

A positive and substantial coefficient estimate for the linear effect of temperature indicates that the variable drives outmigration from origin countries to South Africa. According to the last row of Table 3, a 1°C rise in temperature increases outmigration from SSA nations to South Africa by 0.46 percentage points. One of the most well-documented long-term effects of increased average surface temperature is a decrease in agricultural production. The optimal production of agricultural products has been adjusted to

TABLE 3 Climate and international migration: The main results.

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

Note: Robust standard errors clustered by origin countries are reported in parentheses. Agriculture dependency is measured as a dummy variable whereby highly agricultural countries with agricultural value added as % of GDP ≥ 35% are assigned with 1, and the remaining countries are assigned with 0.

Abbreviations: GDP, gross domestic product; GDPA, gross domestic product per capita.

*$p < 0.1$. **$p < 0.05$.

***$p < 0.01$.

local temperature, and numerous studies (Burke & Emerick, 2016; Cattaneo & Peri, 2016) have demonstrated that agricultural GDP peaks at roughly 14°C and decreases at higher temperatures. Agriculture is the backbone of most African economies, providing the bulk of livelihoods on the continent. As a result, Africa is a "hot spot" for exposure and vulnerability to the effects of climatic variability particularly when African temperatures have warmed at a rate slightly faster than the world mean surface temperature of 13.9°C (Blunden & Boyer, 2022; World Meteorological Organization [WMO], 2019). More so, we have included "Year," which captures the time trend as a control variable to capture structural transformations that might have occurred within both the migration receiving country and the origin countries. The time trend variables are found to be significant and thus increase migration to South Africa.

Our findings are in line with contemporary studies which have shown that environmental factors (herein, temperature) are increasingly being acknowledged as potential drivers of cross-border and intranational human migration. Indeed, poor environmental conditions ranging from natural disasters and extreme weather events to more gradual changes in the climate may prompt people to migrate as an adaptation strategy. GDP per capita of origin countries also has a negative effect, whereas the GDP per capita of the destination country has positive and significant linear effect on outmigration. 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 climate impacts on migration are nonlinear which is in accordance with the nonlinear yield–temperature connection that has been described in the literature (Cai et al., 2016; Schlenker & Roberts, 2009). 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 are a major driver of outmigration in Africa. The agriculture value added as a share of total GDP variable has a negative impact on outmigration flows. This finding suggests that a relatively strong agricultural sector tends to support local labour absorption and economic opportunities and discourages migration. However, through the interactive variables, it appears that outmigration is more apparent when agricultural-dependent countries are impacted by climate change variables, such as high temperatures. The finding confirms the potential susceptibility of the agricultural sector to climate-related shocks. This finding, complemented with the findings of the interactive variables, does suggest that the results are driven largely by climate change relative to possible structural transformation in the economy of these countries.

Discussions on the findings in Table 3 have shown the significant effects of temperature on outmigration from SSA countries to South Africa. Nonetheless, 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 additional extensions to our specification, as indicated in Equation (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. (2009) 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 (measured by latitude). Second, we show that the level of development, measured by GDP, is a potential intermediating factor between climate change and migration in SSA. In doing so, we follow the literature (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 Equation (2). In column (4) of Table 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 agricultural-dependent countries are most likely to be poor, a rise in temperature would affect agriculture production and induce migration to South Africa, given that it is one of the highest developed countries in SSA.

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 nonsignificant. From columns (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 terms stay positive and are highly significant.

4.1 | Results of the dynamic panel models

Though FE effects estimation accounts for factor heterogeneity within our panel data set, the estimates can be skewed because the dynamism and persistence effects of time series are ignored. The equivalence in Equation (3) took this into account by using one lag period of the migration variable as a regressor, thus addressing possible endogeneity into the regression equation driven by heterogeneity, simultaneity, and dynamic factors. In order to obtain unbiased estimates from Equation (3), the GMM approach was used, and the results are shown in Tables 5 and 6. For all of the baseline regressions, the estimated

TABLE 4 Adding latitude–temperature and GDP–temperature interactions.

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

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

Abbreviations: GDP, gross domestic product; GDPA, gross domestic product per capita.

$^{*}p < 0.1$. $^{**}p < 0.05$.

$^{***}p < 0.01$.

coefficient of $Migration_{-1}$ was found to be positive and statistically significant, as shown in Table 5 (from regressions 1 to 3). This finding demonstrates that the two have a positive relationship. The positive effect's outcome is consistent with theory, which states that positive lagged values are more likely to have positive effects on present values due to persistence effects (Bannor et al., 2021; Liu & Bi, 2019). From Table 5, at the 10% level, the temperature estimate is positive and statistically significant. The magnitude of the predicted coefficient of temperature is bigger than in the FE regressions. Overall, the results of the temperature variable imply that increases in average temperatures may actually increase emigration. The literature has revealed a correlation between temperature and per capita income. Income/productivity changes are positive for average yearly temperatures between 10°C and 20°C but decline for temperatures above a threshold around 20/25°C (Cattaneo & Peri, 2016). This suggests that temperature increases are more detrimental, particularly in agriculture production. Our finding supports the theory that climate-driven emigration is linked to worsening of local opportunities, with migrants moving to areas where they have a greater opportunity to obtain work given their current constraints.

Given that SSA countries are generally hotter and more agricultural, in Table 6, we interact temperature with both geographic location and development level under dynamic models. The findings provide evidence to support our FE estimates that temperature has a significant impact on outmigration. In column (4), a 1°C increase in temperature increases outmigration from SSA nations to the destination country by 2.5 percentage points. Given that Africa's yearly temperature has risen at a pace of 0.13°C per decade on average since 1910 but has more than doubled to 0.29°C since 1981, developing proper policy responses to environmental-induced migration is critical. Using the interaction of temperature and agriculture dependency, we also find that temperature affects outmigration in agricultural-dependent countries. Our results imply that agricultural output contractions induced by high temperatures appear to be a driving factor of outmigration by 0.27 percentage points.

The significant effects of temperature shocks on outmigration suggest that the temperature–migration link needs to be investigated further. Therefore, we investigate the possible channels through

TABLE 5 Climate and international migration: Results of dynamic panel model.

Variables	Column (1)	Column (2)	Column (3)
$Migration_{-1}$	0.815*** (0.052)	0.762*** (0.024)	0.869*** (0.024)
Temperature	7.857*	1.157	2.476*
	(4.221)	(0.892)	(1.452)
Agriculture value added/GDP		−0.526***	−0.180***
		(0.137)	(0.017)
Log of GDPA of destination country		0.703***	0.625***
		(0.121)	(0.125)
Log of GDPA of origin countries		−0.329***	0.078
		(0.096)	(0.059)
Temp * agriculture dependency			0.006***
			(0.0006)
Constant	−21.709*	3.424*	2.482
	(12.483)	(2.011)	(3.800)
Observations	209	209	209
Wald χ^2	350.38	2654.87	2422.40
Number of countries	35	35	35

Note: Standard errors in parentheses.

Abbreviations: GDP, gross domestic product; GDPA, gross domestic product per capita.

$^{*}p < 0.1$. $^{**}p < 0.05$.

$^{***}p < 0.01$.

TABLE 6 Latitude–temperature and GDP–temperature interactions: Dynamic panel model results.

Variables	Column (1)	Column (2)	Column (3)	Column (4)
Migration$_{-1}$	0.760*** (0.036)	0.819*** (0.045)	0.819** (0.035)	0.809*** (0.063)
Temperature	1.785***	1.563**	1.761***	2.529***
	(0.387)	(0.532)	(0.478)	(0.852)
Agriculture value added/GDP		−0.0006		−0.037*
		(0.012)		(0.022)
Temp * latitude	0.008** (0.004)	0.010*** (0.003)		
Temp * GDP			0.007** (0.003)	0.014*** (0.002)
Log of GDPA of destination country	0.029	0.294***	0.227	0.463***
	(0.100)	(0.100)	(0.140)	(0.100)
Log of GDPA of origin countries	−0.009	−0.200*	−0.233***	−0.673***
	(0.067)	(0.108)	(0.072)	(0.087)
Temp * agriculture dependency		0.124 (0.105)		0.277*** (0.094)
Constant	−2.708**	−2.616	−1.559	−5.222**
	(1.311)	(1.924)	(1.713)	(2.550)
Observations	174	174	174	174
Wald χ^2	1613.77	33,102.87	992.99	1478.01
Number of countries	35	35	35	35

Note: Standard errors in parentheses.
Abbreviations: GDP, gross domestic product; GDPA, gross domestic product per capita.
$^{*}p < 0.1$. $^{**}p < 0.05$.
$^{***}p < 0.01$.

which temperature could affect outmigration by interacting temperature with level of development and geographic location. We find that geographic location (herein, how hot or cold a country is located) is a determining factor in outmigration to South Africa. The interaction of geographic location and temperature drives outmigration by 0.01 percentage points. This is not surprising as most SSA countries are located in the tropics, where temperatures are high and water is scarce, leaving farmers to rely on rainfall for farming. The interaction between temperature and development has a positive effect on outmigration. The interaction of temperature and development level increases outmigration by 0.014 percentage points. Given the middle-income status and, comparatively, industrialised economy, migration to South Africa could be driven largely by the pursuit of economic opportunities.

4.2 | Robustness check

To check for the robustness of our results, we perform two things. First, the literature shows that changing weather patterns and an increase in extreme events have an impact on migration, particularly in regions where agriculture is dependent on rainfall (Porter et al., 2014). Therefore, rather than mean monthly temperature, we use the long-run variability of temperature to further investigate the international migration–temperature relationship. We follow the literature (Amare et al., 2018; Bannor et al., 2021) and capture temperature variability as follows:

$$\text{Temperature variability}\,(\text{tv}_{\text{it}}) = \log\left(\frac{\overline{y}_{it} - y_{it-1}}{y^{SD}}\right), \tag{4}$$

TABLE 7 Temperature variability–political stability inclusion: Dynamic panel model results.

Variables	Column (1)	Column (2)	Column (3)	Column (4)
$Migration_{-1}$	0.862*** (0.024)	0.831*** (0.041)	0.821*** (0.045)	0.825*** (0.045)
Temperature variability	0.925*	1.168***	3.332***	2.180*
	(0.540)	(0.320)	(0.907)	(1.144)
Agriculture value added/GDP			−0.496***	−0.425***
			(0.090)	(0.103)
Political stability				−0.305*** (0.073)
Log of GDPA of destination country		0.171 (0.112)	0.092 (0.131)	0.337*** (0.115)
Log of GDPA of origin countries		−0.285***	−0.430***	−0.224**
		(0.057)	(0.110)	(0.088)
Temp var * agriculture dependency		0.004***	0.134***	0.115***
		(0.001)	(0.023)	(0.027)
Constant	−2.139	−6.712***	10.373**	5.306
	(2.113)	(1.671)	(3.420)	(4.367)
Observations	173	173	173	173
Wald χ^2	1220.61	872.5	1556.79	595.25
Number of countries	35	35	35	35

Note: Standard errors in parentheses.
Abbreviations: GDP, gross domestic product; GDPA, gross domestic product per capita.
$^{*}p < 0.1$. $^{**}p < 0.05$.
$^{***}p < 0.01$.

where $\bar{y}_{it}$ represents the average historical temperature estimated for the sample period in country i at a time (t), y_{it-1} indicates temperature in previous year, and y^{SD} indicates the standard deviation from the mean temperature from 2011 to 2017. Lastly, it is documented in the empirical literature that political instability is a determinant of international migration. We control for political stability which measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism in units of a standard normal distribution, ranging from approximately −2.5 to 2.5 in dynamic model.

Results from Table 7 show that our results are robust irrespective of the measurement of the climate variable. Temperature variability significantly influence outmigration between 0.9 percentage points and 2.1 percentage points from columns (1) to (4). Furthermore, a crucial explanatory element for outmigration is political stability. Political stability reduces outmigration by 0.3 percentage points. Our findings show that political instability is a push factor that policymakers concerned with international migration must address. The findings confirm that adding value to agriculture will significantly reduce international migration from SSA countries to South Africa. Agriculture value addition reduces outmigration by 0.49 percentage points. Similarly, the more countries are reliant on agriculture, the more likelihood temperature variability will drive people to migrate.

5 | CONCLUSION AND POLICY IMPLICATIONS

Climate change is currently one of, if not the, most paramount challenges facing modern day society. The impact of climate change is having profound impacts on the natural environment with a very apparent spill over to the contemporary economic, social, and political environments. The latter is clear with increasing concerns over agricultural productivity, long-term water supply, and human health issues related to the changing environment. South Africa is not immune to such impacts, and there is increasing evidence that various aspects of the country's political, economic, and social landscape are being detrimentally impacted by the impacts of climate change. One of these socio-economic issues is that of migration. South Africa is currently a society struggling with the effects of increased migration on the moral and social fabric of the country, with increasing social tensions resulting in non-violent and violent incidences driven by a xenophobic sentiment. Although the conventional drivers of migration are well known and empirically tested, the impact of climate change on migration, and the formers' increasing impact on socio-economic issues, in SSA and South Africa has not been tested explicitly, particularly with South Africa as the destination country for migration.

Given the above, the impacts of climate change on international migration flows from SSA nations to South Africa are investigated empirically in this study. The analysis used 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 agricultural-dependent nations in SSA. The results also support the nonlinear temperature–yield relationship that has been observed in the literature. This implies the extreme temperature levels impact on agricultural output and encourages international migration in SSA. Further, we show that the key mediators in the climate change–migration nexus include 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 increases its agriculture value added, the less people will migrate from the country. This finding, along with the findings on the interaction terms of temperature and agricultural dependency, suggests that extreme weather variability seems to be driving outmigration more so than possible structural changes in the economy.

Our findings have important policy implications. Given that climate change is found to influence international migration, it is recommended that governments should provide an alternative adaptation strategy as a response to climate change, which, among others, should include increased spending on research and development (R&D) on climate mitigation technologies and strategies, particularly in the agricultural sector. 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 (Fan et al., 2004; Timmer, 2005), 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 would 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 programmes 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 programmes. 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 macrolevel data. Therefore, it is recommended that future studies pay more attention to subnational levels to bring into detail the impact of climate change on international migration. We also propose extensions to the analysis on temperature by looking at deviations from the steady-state value of temperature to directly assess the impact of increasing temperature driven by climate change on migration. More so, barring data constraints future studies should adopt the multiple destination approach to investigate this phenomenon on other destination countries in Africa.

CONFLICT OF INTEREST STATEMENT

The author(s) reports no potential conflicts of interest.

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APPENDIX A

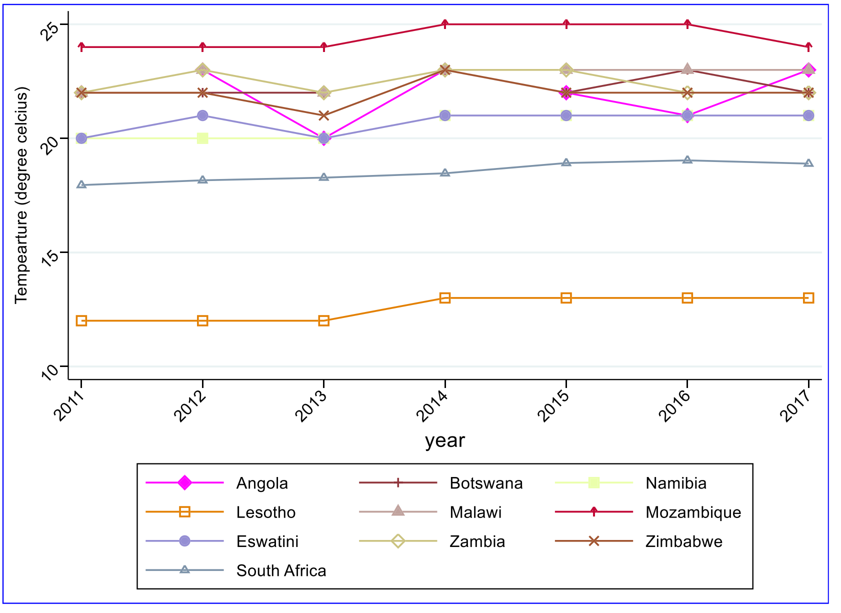

FIGURE A1 Temperature variations among Southern African Development Corporation countries.

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