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# Does rainfall variability matter for food security in developing countries ?

Somlanare Romuald Kinda[1*] and Felix Badolo[2]

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*Corresponding author: Somlanare Romuald Kinda, Universite de Ouaga II, Burkina Faso
E-mail: skinda@univ-ouaga2.bf

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Additional information is available at the end of the article

**Abstract:** This paper contributes to the existing literature on rainfall variability and food security. It analyses the effect of rainfall variability on food security for 71 developing countries from 1960 to 2016. Results suggest that rainfall variability reduces food security in developing countries. Indeed, it reduces food availability per capita and increases the percentage of total undernourished population. Moreover, the negative effects of rainfall variability are exacerbated in the presence of civil conflicts and are high for the countries that are vulnerable to food price shocks.

**Subjects: Economics and Development; Environment & the Developing World; Econometrics; Development Economics**

**Keywords: food prices shocks vulnerability; food security; rainfall variability; civil conflicts**

## 1. Introduction

According to several reports (World Bank, 2018), the number of people living in extreme poverty has reduced from 2 billion (36% of the world's people) to 736 million (10% of the world's people) between 1990 and 2015. These results validate several previous studies (Chen & Ravallion, 2010; Milanovic, 2012) that report a continued decline in global poverty during the last three decades.

### ABOUT THE AUTHORS

Somlanare Romuald Kinda Graduated from the CERDI at the University Clermont Auvergne (France) from where he has received a PhD in Development economics, a Master in Development economics and a Master in Economic Development and Projects Analysis, Dr KINDA is currently an Assistant Professor in Economics at the University OUAGA 2 in Burkina Faso. He is the co-supervisor of the Master Agricultural Economics and Food Security (EASA). He has published several articles on economic development, environmental quality, green economy and climate change. He has more than twelve years of experience in international development as a development economist at several international institutions (UNECA, UNUWIDER, UNIDO, AfDB).

Felix Badolo Graduated from the CERDI at the University Clermont Auvergne (France) from where he has received a PhD in Development economics, Dr BADOLO is currently an Agricultural Economist at the International Crops Research Institute for the Semi-Arid Tropic (ICRISAT) in Bamako in Mali.

### PUBLIC INTEREST STATEMENT

This paper contributes to the empirical literature on climate change and food security. It analyses the effect of rainfall variability on food security for 71 developing countries from 1960 to 2016.

Using econometric tools and complementary indicators of food security (food availability and proportion of undernourished people), empirical findings suggest that rainfall variability reduces food security in developing countries. Indeed, it reduces food availability per capita and increases the percentage of total undernourished population. Moreover, the negative effects of rainfall variability are exacerbated in the presence of civil conflicts and are high for the countries that are vulnerable to food price shocks.

However, progress is currently not fast enough and is different across regions. From 1991 to 2015, the extreme poverty rate in East Asia and Pacific fell from 62% to 3% and from 57% to 41% in Sub-Saharan Africa. Despite national and international efforts to reduce poverty the number of undernourished people in the world has increased from around 804 million to 821 million between 2016 and 2017 (FAO, 2018), and a significant proportion of households depend on agriculture. They are more exposed to the risks of food shortages and hunger that could be caused or increased by climatic change (St.Clair & Lynch, 2010).

In the recent years, the debate on climatic variability has led to a renewed interest in the effects of climatic variability on agriculture. Many authors have analysed the relationship between climatic variability and the indicators of food security. We can distinguish two strands in the literature. First, several authors develop theoretical arguments or prospective studies which evidence that climatic variability has a negative impact on agricultural production and decreases food availability. A report by FAO (2018) emphasizes that hunger is significantly worse in countries with agricultural systems that are highly sensitive to rainfall and temperature variability and severe drought, and where the livelihood of a high proportion of the population depends on agriculture. Asante and Amuakwa-Mensah (2015) suggest that there is a projected high temperature and low rainfall in the years 2020, 2050 and 2080, and desertification is estimated to be proceeding at a rate of 20,000 hectares per annum in Ghana, with a negative impact on the agricultural sector. Ringler, Zhu, et al. (2010) and, St. Clair and Lynch (2010) conclude that climatic variability is a factor of childhood malnutrition in Sub-Saharan Africa. Based on Intergovernmental Panel on Climate Change (IPCC)´ climatic projection models, some authors (Schlenker & Lobell, 2010; Zinyengere, Crespo, & Hachigonta, 2013) estimated agricultural yield losses due to climate change range from 18% for Southern Africa to 22% aggregated across Sub-Saharan Africa, with yield losses for South Africa and Zimbabwe in excess of 30%. While the majority of studies are based on theoretical or prospective analyses, the second strand of literature concerns empirical analyses. Using panel data for Asian countries from 1998 to 2007, Lee, Nadolnyak, and Hartarska (2012) shows that high temperature and more precipitations in summer increase agricultural production. Tesso, Emana, and Ketema (2012) reveal that in Ethiopia, food production faces severe challenges due to climate change, noting that the annual production losses to climate variability significantly increase from year to year. Sawe, Mung'ong'o, and Kimaro (2018) reveal that climate change and variability impact crop farming system in different ways such as damaging of crops and persistent low yields, that could lead to household food insecurity. There are some reasons that could explain the difficulties of studying the effect of climatic variability on food security at the macroeconomic level. First, the absence of suitable climatic data for many developing countries over a long period may justify the fact that there are few empirical papers. Second, food security is a complex concept that includes several dimensions.

The objective of this paper is to analyse the causal relationship between rainfall variability and food security. It differs from the existing literature on rainfall variability and food security in two ways. First, while most of the literature is mainly theoretical, we perform an empirical and macroeconomic analysis for 71 developing countries from 1960 to 2016. Second, we identify mechanisms by which rainfall variability may influence food security.

The plan of the paper is as follows. Section 2 contains a discussion of the literature review on the relationship between climatic variability and food security. Section 3 discusses the econometric method used to evaluate the effect of rainfall variability on the indicators of food security. Section 4 presents the empirical results. The last section is devoted to concluding remarks and implications.

## 2. Relationship between climatic variability and food security

In this section, we present, the first three approaches highlighting the explanatory factors of food security. Second, we show how climatic shocks affect food security through these approaches.

### *2.1. What could explain food security?*

#### *2.1.1. The production-based approach*

The production-based approach is derived from the assumption that food insecurity is the result of a decline in food availability. This approach is based on the relationship between population growth and the ability of humans to confront the scarcity of food and natural resources, which has dominated the literature on food security (Malthus, 1798). The Malthusian theory suggests that in order to maintain equilibrium between population and food, the rate of growth of food availability should not be lower than the rate of growth of the population (Burchi & Muro, 2012). Contrary to neo-Malthusians, several authors believe that technology and human ingenuity have always adequately confronted existing scarcities and will continue to do so in the future. Zhou and Wan (2017) emphasize that rapid economic growth in Asia has equipped many countries with stronger capabilities to cope with external shocks that affect their food security.

#### *2.1.2. The market-based approach*

The market-based approach is based on the idea that famine is not due to food supply but due to food access. The concept of entitlements developed by Sen (1983) partly joined this approach. The author suggests that people have an entitlement to food.[1] Entitlements depend mainly on personal endowments[2] and exchange conditions.[3] In developing countries, an important part of a household's resources comes from labour activities. Moreover, exchange conditions allow people to use their resources to access the set of commodities through trade and production and the determination of relative prices of products or goods.

In the market-based approach of food security, we also find studies on the relationship between economic performance and food insecurity. A poor economic performance can be a major cause of poverty. The effects of poverty on hunger and undernutrition are pervasive. Poor households and individuals have inadequate resources for care and are unable to achieve food security and to utilize resources for health on a sustainable basis. In contrast, a sustained economic growth has a positive direct impact on food security. Breisinger, Ecker, Perrihan, and Yu (2012) suggest that economic growth driven by exports improves the balance of payments and generates foreign exchange for food imports. Mihalache-O'keef and Li (2011) found that foreign direct investment improves food security by raising employment and wages, technology and knowledge spillovers. Noordwijk et al. (2014) suggest that economic growth improves human development, increases the public's purchasing power and reduces poverty, thereby increasing access to food and reducing hunger.

#### *2.1.3. Institutional failures*

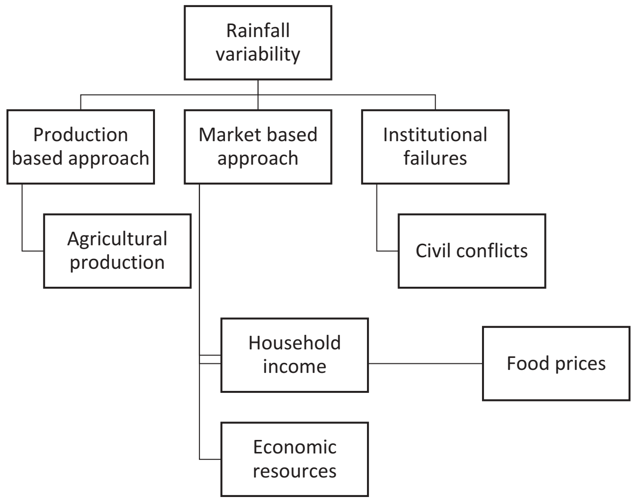
Several authors have highlighted the importance of institutions as an explanation of food insecurity. Democratic institutions can foster accountability for fighting hunger by promoting electoral competition, thereby encouraging public action to reduce hunger and promote development. Using a panel of 106 low and middle-income countries from 1990 to 2012, Rossignoli and Balestri (2018) find that democratisation process contributes to improve food security. However, Harris (2014) highlights the fact that variables measuring the procedural and institutional elements of democracy are not connected to levels of hunger in Africa. According to Sen (2000), the failure to deliver food can be due to the implementation of inappropriate policies or government's failure to intervene and the existence of civil conflicts. Moreover, he suggests that democracy and political rights can help to prevent famines and other economic disasters. Indeed, authoritarian rulers tend to lack incentives to take timely preventive measures. Finally, Barnett (2003) show that combatants frequently use hunger as a weapon by cutting off food supplies and productive capacities, starving opposing populations into submission, and hijacking food aid intended for civilians.

### *2.2. How do climatic variability matter for food security?*

There are several channels through which climatic variability is likely to affect food security in developing countries. To elucidate these channels, we reflect on Figure 1, the effect of climatic variability on each approach.

**Figure 1. How Rainfall variability matters for food insecurity—diagrammatic presentation.**

Source: Authors




### *2.2.1. Climatic variability and agricultural production*

Most developing countries are particularly vulnerable to climatic change (especially climatic shocks) because their economies are closely linked to climatic sensitive sectors such as agriculture (Mitra, Chopde, Kumar, & Wajih, 2008). Millions of people in developing countries depend on agricultural production. This vulnerability is particularly high in Africa where agricultural production is the primary source of livelihoods for 66% of the total active population (ILO, 2007). The World Development Report (World Bank, 2002) has established that 39% of people on fragile (arid and semi-arid) lands live in Africa. They are consequently threatened by climate change and climatic shocks. Battisti and Naylor (2009) emphasize that higher growing season temperatures can significantly impact agricultural productivity, farm incomes and food security. Ochieng, Kirimi, and Mathenge (2016) find that climate variability and change affect agricultural production, but effects may differ across crops in Kenya. The temperature has a negative effect on crop and maize revenues, while rainfall has a negative effect on tea production.

### *2.2.2. Climatic variability, households' income and economic resources*

Climatic variability has direct and indirect effects on agricultural incomes and thus can harm food security. By reducing households' agricultural incomes, climatic variability also leads to a decrease in demand for goods and services in the affected communities. This threatens the livelihoods of people who indirectly depend on agriculture, such as traders. Nhemachena, Hassan, and Chakwizira (2009) show that rainfall variability and higher average temperatures negatively affect households' income that comes from agricultural crops and livestock in Africa. Shumetie et al. (2017) examine the effect of climate variability on smallholder's crop income, and they conclude that variability in rainfall during the cropping season has a significant and negative effect on farmers' crop income.

Climatic variability can impact food security at the macroeconomic level through its effect on economic growth. Dell, Jones, and Olken (2008) show that climatic variability has large and negative effects on economic growth in the poor countries. Because developing countries have a disproportionate share of their Gross Domestic Product (GDP) in climatic sensitive sectors, their economic resources are vulnerable to climatic variability. It may reduce the level of output and the economy's ability for growth (productivity growth) through a reduction in agricultural production and exports (Jones & Olken, 2010) and investments in research and development. By affecting economic growth, climatic shocks can reduce the resources available to the governments (low tax revenues, for example). This can be a factor that contributes to food insecurity because climatic shocks affect the ability of countries to purchase food on international markets, to invest in technology, services and infrastructure that support food and agricultural production and, to finance public services and investments in health and education.

*2.2.3. Climatic variability and food prices*

Climatic variability impacts food security through its great negative effect on food prices. Because food is a basic necessity good and the demand for food is highly price inelastic, a decrease of food surplus may lead to an important increase in food prices, thus reducing food accessibility. Using a theoretical model, Ringler, Zhu, et al. (2010) find that climatic variability increases childhood malnutrition in Sub-Saharan Africa through higher food prices. Moreover, Aker (2010) considers that climatic variability may have an effect on traders' entry and exit in response to the profitability of food trading. Indeed, climatic variability leading to an increase (decrease) in profits may incite the traders to enter (or exit) the local market. As markets are not well integrated and the dispersion of food (agriculture goods, cattle) prices is high in the least developed countries (Aker 2010; Araujo, Bonjean, Combes, & Motel, 2005), climatic shocks may amplify them and harm food security.

*2.2.4. Climatic variability and civil conflicts*

Climatic variability can be a factor of food insecurity by increasing the risk of civil conflicts. Several authors suppose that climatic variability will likely lead to greater scarcity and variability of renewable resources in the long term (Buhaug, 2008), as well as increase conflict over limited resources. Koubi, Bernauer, Kalbhenn, and Spilker (2012) support that climate variability affects non-democratic countries that are more likely to experience civil conflict when economic conditions deteriorate. Moreover, the literature on the determinants of civil war shows that economic opportunity is more important that political factors. According to Bohlken and Sergenti (2010), abrupt shortages of rainfall may lead to violent conflict through their negative impact on macro-economic performance. This dynamic is primarily relevant for countries that highly depend on agriculture (for instance Sub-Saharan Africa and large parts of Central and South Asia (Wischnath & Buhaug, 2014). Burke, Miguel, Satyanath, Dykema, and Lobell (2009) find that climatic shocks (inter-annual variability in rainfall, higher temperatures) are associated with more conflicts. The exacerbation of the scarcity of resources and the risk of civil war caused by climatic shocks may reduce food security.

## 3. Empirical analysis

### 3.1. Empirical model

The objective of this paper is to analyse the effect of rainfall variability and food security over the period 1960 to 2016 for 71 developing countries. For this purpose, based on previous studies on food security (Santangelo, 2018; Jenkins and Scanlan, 2001; Wimberley and Bello, 1992), Equation 1 is specified:

$$Y_{i,t} = \alpha_i + \beta CV_{i,t} + \omega X_{i,t} + \gamma_t + \varepsilon_{i,t} \quad (1)$$

With $CV_{i,t}$ the variable of rainfall variability (log) in a country i at the period t. $\varepsilon_{i,t}$ is the error term, $\gamma_t$ represents time-fixed effect and $\alpha_i$ country fixed effects. The data cover the period 1960–2008 and the study is based on yearly panel data. $Y_{i,t}$ is the food security indicator (food availability per capita). Food availability is used similarly to previous authors (Santangelo, 2018).

Control variables ($X$) come production-based approach (population growth), market-based approach (income per capita) and institutional failures (democratic institutions). In robustness checks, we include arable land, cereal production land and squared term of rainfall level.

We identify potential heterogeneities in the relationship between rainfall variability and food security. Two heterogeneities are analysed. We test if the effects of rainfall variability can be different depending on whether the country was under conflict (Equation 2), in the context of food price shock vulnerability (Equation 3).

$$Y_{i,t} = \alpha_i + \beta CV_{i,t} + \beta_1 CV_{i,t} * Conflict_{i,t} + \theta Conflict_{i,t} + \omega X_{i,t} + \gamma_t + \varepsilon_{i,t} \quad (2)$$

$$Y_{i,t} = \alpha_i + \beta CV_{i,t} + \beta_2 CV_{i,t} * PSVul_{i,t} + \theta_1 PSVul_{i,t} + \omega X_{i,t} + \gamma_t + \varepsilon_{i,t} \quad (3)$$

$Conflict_{i,t}$ is the conflict variable and $PSVul_{i,t}$ is the vulnerability of countries to food price shocks

Three estimators can be used: ordinary least square (OLS), fixed effects (FE) or random effects (RE). The OLS estimator is, however, biased because it does not take into account unobserved heterogeneity of countries, which simultaneously affects rainfall variability and food security. Therefore, fixed effect (FE) and/or random effect (RE) estimators can be used. The Hausman test shows that the fixed effect model is more appropriate than the random effect model.

### 3.2. Variables description and data sources

#### 3.2.1. Food security

According to (FAO, 1996), food security can be defined as "a situation that exists when all people at all times have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". According to several authors (Tweeten, 1997), food security has three essential dimensions. The first dimension is food availability, which refers to the supply of foodstuffs in a country from production or imports. The second dimension is food access, which refers to the ability to acquire food for consumption through purchase, production or public assistance. The third dimension is food utilization, which concerns the physical use of food derived from human distribution. Food may be available to individuals who have access, but health problems may result from the imbalanced diet of food that is consumed. Because it is hard to find a single or a global indicator[4] that takes all dimensions of food security into account, we consider two indicators. First, we use food availability. It measures the availability of food in a country through any means (national food production, food imports, etc.). We consider the main cereals (maize, rice, sorghum, millet and wheat), soybeans and sugar for the calculation of food availability. They represent an important proportion in the population's food in most of developing countries. Food availability obtained is a simple average of food supplies of selected commodities expressed in kg/person/year. To take into account access to food by people, we use the proportion of undernourished people for robustness checks.

#### 3.2.2. Rainfall variability

Rainfall variability is measured as the standard deviation of the growth rate of rainfall, which is frequently used in the economic literature. Rainfall variability is defined as the five-year rolling standard deviation of the growth rate of rainfall series.

#### 3.2.3. Sources

The data on population growth, income per capita and proportion of undernourished people are from World Development Indicators. Those on democratic institutions, civil conflicts, rainfall and food availability are, respectively, from Polity IV (2017), CERDI and Food and Agriculture Organization (2011). The index of food price shocks vulnerability is built using the procedure developed by (De Janvry & Sadoulet, 2008) and (Combes, Ebeke, Etoundi, & Yogo, 2014). Appendix 1 recapitulates the definition and source of variables whereas descriptive statistics are summarized in Appendix 2.

## 4. Results

This section first, shows the effect of rainfall variability on food security. Next the analysis turns to the econometric results in countries under conflict and for countries that are vulnerable to food price shocks.

### 4.1. Basic results

Column 1 of Table 1 shows the results of the effects of rainfall variability on food security. Results suggest that rainfall variability has a negative and significant effect on food availability. These results can be explained by several arguments. First, changing rainfall patterns is a source of high uncertainty with regards to food production. This increases fluctuations in agricultural production and reduces households' incomes. For countries that depend on the weather conditions (rain-fed agriculture), it reduces food production and availability. Second, by reducing agriculture production in developing countries, rainfall variability reduces agricultural incomes and hence negatively affects economic growth (Dell et al. (2008).

**Table 1. Effect of rainfall variability on food availability per capita**

| Dependent variable | Food availability per capita | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Rainfall variability | −0.0157*** | −0.0160*** | −0.0173*** | −0.0144*** |
| | (−3.369) | (−3.611) | (−3.904) | (−3.115) |
| Rainfall level | 0.00719 | 5.37e-05 | 0.000198*** | 0.00190*** |
| | (1.583) | (0.739) | (2.717) | (6.502) |
| Income per capita | 0.0374*** | 0.0381*** | 0.0466*** | 0.0421*** |
| | (5.907) | (6.268) | (7.672) | (6.652) |
| Population growth | −0.000871 | 0.000113 | −0.000409 | −0.00128 |
| | (−0.350) | (0.0460) | (−0.172) | (−0.519) |
| Democratic institutions | 0.00403*** | 0.00287*** | 0.00198*** | 0.00393*** |
| | (8.772) | (6.477) | (4.374) | (8.594) |
| Cereal production land | | 0.116*** | | |
| | | (19.07) | | |
| Arable land | | | 0.188*** | |
| | | | (19.15) | |
| Rainfall squared | | | | −0.00719 |
| | | | | (−1.583) |
| Intercept | 4.682*** | 3.088*** | 4.444*** | 21.13*** |
| | (42.75) | (23.05) | (42.21) | (8.874) |
| Observations | 2,284 | 2,284 | 2,284 | 2,284 |
| R-squared | 0.60 | 0.64 | 0.65 | 0.62 |
| Countries | 71 | 71 | 71 | 71 |

Note: t-statistics are presented in parentheses under the estimated coefficients. ***, ** and * indicate the significance of the estimated coefficient at 1%, 5% and 10%, respectively. The study period is 1960–2016.

The next step consists of adding other control variables to check the robustness of results to changes in the baseline model (see columns 2–4): cereal production land, arable land and squared term of rainfall level. Whatever controls are included, the coefficient for rainfall variability remains negative and significant. Moreover, results show that a policy allowing better use of cereal production and arable lands (columns 2–3) increase food availability in developing countries. The rainfall squared has no effect on it (column 4).

### *4.2. Heterogeneities on the impact of rainfall variability*

This section is devoted to the identification of potential heterogeneities in the relationship between rainfall variability and food security. First, we test to determine if the impact of rainfall variability can be different depending on whether the country was under conflict. Second, we analyse the impact of rainfall variability on food security in the context of food price shock vulnerability.

#### *4.2.1. The importance of civil conflicts*

We suppose that the impact of rainfall variability on food security is high for countries that are in conflict. For this, we add the variables of civil conflicts and its interactive term (rainfall variability*civil conflicts). Column (2) of Table 2 presents the results of the nonlinear effect of rainfall variability and civil conflicts. Results suggest that the impact of rainfall variability on food availability per capita is more severe in the countries under conflict. A characteristic of civil conflicts is its negative effect on market access, political and social networks. First, civil conflicts destroy infrastructure, social services, assets and livelihoods, social cohesion, institutions and norms, and they displace populations and create fear and distrust. In addition, civil conflicts disrupt the farming systems (irrigation schemes) and production (crop production, livestock production and off-farm activities) operated by households. Second, market disruption

**Table 2. Heterogeneities on the effect of rainfall variability: the importance of civil conflicts and vulnerability to food price shocks**

| Dependent variable | Food availability per capita | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| Rainfall variability | −0.0157*** | −0.0205** | −0.0348*** |
| | (−3.369) | (−2.586) | (−4.071) |
| Rainfall variability * Civil | | −0.0120*** | |
| conflicts | | (−2.669) | |
| Civil conflicts | | −0.0420*** | |
| | | (−3.779) | |
| Rainfall variability*Food Price | | | −0.113*** |
| Shocks vulnerability | | | (−3.031) |
| Food Price Shocks Vulnerability | | | −0.00174*** |
| | | | (−5.722) |
| Rainfall | 0.0220 | 0.0359 | 0.0224 |
| | (0.447) | (0.933) | (0.651) |
| Income per capita | 0.0374*** | 0.0399*** | 0.0262*** |
| | (5.907) | (6.299) | (2.774) |
| Population growth | −0.000871 | 0.000396 | −0.00526 |
| | (−0.350) | (0.159) | (−1.224) |
| Democratic institutions | 0.00403*** | 0.00388*** | 0.00482*** |
| | (8.772) | (8.405) | (7.647) |
| Intercept | 4.682*** | 4.670*** | 4.711*** |
| | (42.75) | (29.76) | (42.99) |
| Observations | 2,284 | 2,284 | 2,284 |
| Countries | 71 | 71 | 71 |
| R-squared | 0.64 | 0.65 | 0.61 |

Note: t-statistics are presented in parentheses under the estimated coefficients. ***, ** and * indicate significance of the estimated coefficient at 1%, 5% and 10%, respectively. The study period is 1960–2016.

increases difficulties with regards to households going to market to sell and buy goods, and this leads to a loss of earnings. Final, civil conflicts have negative effects on economic growth by reducing investments and economic infrastructures. These effects can be factors of the poverty trap (Kremer & Miguel, 2007), increasing vulnerability and food insecurity. Therefore, rainfall variability is likely to increase this vulnerability and dampen livelihoods of households affected by civil conflicts. In other words, the destruction of assets caused by civil conflicts, as well as unstable economic, social and political environments, will significantly impact the ability of countries to confront rainfall variability. Interesting results are also found regarding the additive terms of civil conflicts. Civil conflicts have a negative impact on food availability. Indeed, civil conflicts can negatively affect harvests and reduce active population in the agricultural sector because the armed leaders can recruit farmers by offering them high incomes. This leads to a decrease in food availability through the collapse of agricultural production.

### *4.2.2. The importance of food price shocks vulnerability*

Second, this subsection analyses the impact of rainfall variability on food availability, depending upon the level of vulnerability of countries to food price shocks. According to (Combes et al., 2014)., these countries are characterised by: (i) a higher food dependency, (ii) a higher food import burden, (iii) a higher net food import as a percentage of GDP, and (iv) a lower income per capita. Column (3) of Table 2 presents the results of the nonlinear effect of rainfall variability and the level of vulnerability of countries to food price shocks. Result reveals that the negative impact of rainfall variability on food availability increases with the level of vulnerability of countries to food price shocks. Countries that are more vulnerable to food price shocks may be less able to maintain food availability. Indeed, vulnerable countries have very little policy space and limited fiscal and administrative capacity to organize safety nets to import food and protect their population from rainfall shocks (De Janvry & Sadoulet, 2008). In these countries, policy instruments available to facilitate food accessibility by increasing agricultural production or food imports are limited or ineffective. Climatic variability increases the food import burden of countries. In addition, by reducing agricultural production, households' incomes, rainfall variability increases food dependency and food burden of households (because income from agriculture represents a large proportion of the total household's income in many developing countries). Hence, the negative effect of rainfall variability on food availability can increase with the vulnerability of countries to food price shocks.

### *4.3. Robustness checks*

Three robustness checks are implemented. First, the effect of rainfall variability on food availability is examined with an alternative measure of rainfall variability. Rainfall variability is measured by the average deviation in absolute value of the distribution of rainfall relative to its mean or to its long-term trend (1960–2016). Results (Table 3) reveal that rainfall variability has a negative impact on food availability per capita.

Second, it may be also of interest to discover if food availability in developing countries is characterized by inertia phenomena. In other words, we want to know if the lagged level of food availability is a potential determinant of the current level of food availability. We check this by

**Table 3. Effect of alternative measure on food availability per capita**

| Dependent variable | Food availability per capita | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| Rainfall variability | −0.0145** | −0.0485*** | −0.0614** |
| | (−2.187) | (−3.510) | (−2.196) |
| Rainfall variability*Food Price | | −0.294*** | |
| Shocks vulnerability | | (−3.655) | |
| Food Price Shocks Vulnerability | | −0.177** | |
| | | (−2.285) | |
| Rainfall variability * Civil | | | −0.122*** |
| conflicts | | | (−3.397) |
| Civil conflicts | | | −0.0576** |
| | | | (−2.100) |
| Rainfall | 0.000192** | 0.000181* | 0.000189** |
| | (2.019) | (1.901) | (1.978) |
| Income per capita | 0.0470*** | 0.0581*** | 0.0584*** |
| | (3.767) | (7.186) | (7.228) |
| Population growth | −0.0135*** | −0.0256*** | −0.00753*** |
| | (−4.987) | (−6.928) | (−2.767) |
| Democratic institutions | 0.00372*** | 0.00378*** | 0.00377*** |
| | (7.171) | (7.308) | (7.281) |
| Intercept | 4.887*** | 5.134*** | 4.237*** |
| | (63.61) | (47.53) | (30.12) |
| Observations | 2,284 | 2,284 | 2,284 |
| Countries | 71 | 71 | 71 |
| R-squared | 0.62 | 0.59 | 0.60 |

Note: t-statistics are presented in parentheses under the estimated coefficients. ***, ** and * indicate the significance of the estimated coefficient at 1%, 5% and 10%, respectively. The study period is 1960–2016.

**Table 4. Effect of rainfall variability on food availability: inertia of food availability**

| Dependent variable | Food Availability per capita | | |
|---|---|---|---|
| | Fixed effect (1) | GMM-system One step (2) | GMM-system Two step (3) |
| Lagged food availability per capita | | 0.0126 | 0.0151 |
| | | (0.653) | (0.840) |
| Rainfall variability | −0.0157*** | −0.0116*** | −0.0124** |
| | (−3.369) | (−4.783) | (−2.438) |
| Rainfall | 0.00719 | 0.00728*** | 0.00999** |
| | (1.583) | (2.674) | (2.181) |
| Income per capita | 0.0374*** | 0.0133** | −0.0347*** |
| | (5.907) | (2.204) | (−4.084) |
| Population growth | −0.000871 | −0.00266 | −0.00261 |
| | (−0.350) | (−0.398) | (−0.391) |
| Democratic institutions | 0.00403*** | 0.00362* | 0.00210** |
| | (8.772) | (1.772) | (2.577) |
| Intercept | 4.682*** | 4.475*** | 4.485*** |
| | (42.75) | (64.93) | (65.09) |
| Observations | 2,284 | 2,497 | 2,497 |
| R-squared | 0.60 | | |
| Countries | 71 | 71 | 71 |
| AR(1) | | 0.006 | 0.003 |
| AR(2) | | 0.16 | 0.19 |
| Hansen test | | 0.37 | 0.41 |
| Instruments | | 58 | 58 |

Note: t-statistics are presented in parentheses under the estimated coefficients. ***, ** and * indicate significance of the estimated coefficient at 1%, 5% and 10%, respectively. The study period is 1960–2016.

including the lagged level of food availability in the baseline equation. The dynamic nature of the specified model requires system—Generalized Method of Moments (GMM) estimation from Arellano and Bond (1991), Arellano and Bover (1995) and Blundell and Bond (1998). The results in Table 4 show that the lagged level of food availability has no effect on its current level (columns 2 and 3) and previous results are still robust. There is no inertia for food availability in developing countries.

Final, given that food security is a multidimensional concept, we use another complementary indicator (the proportion of undernourished people), to check the robustness of our results. Table 5 presents the results of the impact of rainfall variability on the proportion of undernourished people. Results show that rainfall variability increases the proportion of undernourished people. They are strengthened by adding additional control variables (rainfall squared, arable and cereal production lands).

## 5. Conclusion

This paper contributes to the existing literature on rainfall variability and food security. The main objective of the paper is to analyse the effects of rainfall variability on food security using panel data during the period from 1960 to 2016 for 71 developing countries. The results of our estimates are as follows: first, we show that rainfall variability has a negative effect on food security (food availability and proportion of undernourished people). Second, the adverse effect of rainfall variability on food security is exacerbated in countries under conflict and for countries that are vulnerable to food price shocks. Results are robust to robustness checks.

**Table 5. Effect of rainfall variability on proportion of undernourished people**

| Dependent Variable | Proportion of undernourished people | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Rainfall variability | 0.686*** | 0.673*** | 0.678*** | 0.685*** |
| | (22.89) | (22.32) | (22.72) | (22.86) |
| Rainfall | −0.000340** | −0.000305** | −0.000346*** | −0.000129 |
| | (−2.571) | (−2.307) | (−2.631) | (−0.351) |
| Income per capita | −0.0812*** | −0.0790*** | −0.0854*** | −0.0812*** |
| | (−3.416) | (−3.329) | (−3.609) | (−3.416) |
| Population growth | 0.0139** | 0.0123** | 0.0153*** | 0.0137** |
| | (2.421) | (2.149) | (2.679) | (2.383) |
| Democratic institutions | −0.0397* | −0.0399* | −0.0436** | −0.0397* |
| | (−1.821) | (−1.829) | (−2.007) | (−1.820) |
| Rainfall square | | 0.108 | | |
| | | (0.617) | | |
| Arable land | | | −0.122*** | |
| | | | (−4.929) | |
| Cereal production land | | | | −0.0572*** |
| | | | | (−3.063) |
| Intercept | 7.485*** | 8.195*** | 7.689*** | 6.216*** |
| | (25.46) | (21.91) | (26.03) | (2.991) |
| Observations | 1,123 | 1,123 | 1,123 | 1,123 |
| Countries | 71 | 71 | 71 | 71 |
| R-squared | 0.73 | 0.78 | 0.74 | 0.75 |

Note: t-statistics are presented in parentheses under the estimated coefficients. ***, ** and * indicate significance of the estimated coefficient at 1%, 5% and 10%, respectively. The study period is 1991–2016.

Our results are important in terms of recommendations for economic policies. An important intervention to reduce food insecurity would be the implementation of effective mitigation strategies of risks. In line with this, it is imperative to promote measures that enhance the food production systems in the developing countries in order to increase their capacity to withstand the rainfall variability. One approach would be to increase investments in agricultural research, extension and methods for reducing food production losses related to rainfall variability. Investments and help from regional agencies and international communities can be directed to the most vulnerable countries to conflicts and food price shocks.

**Author details**
Somlanare Romuald Kinda[1]
E-mail: skinda@univ-ouaga2.bf
ORCID ID: http://orcid.org/0000-0003-3735-9263
Felix Badolo[2]
E-mail: f.badolo@cgiar.org
[1] Department of Economics, Universite Ouaga 2, Ouagadougou, Burkina Faso.
[2] International Crops Research Institute for the Semi-Arid Tropic (ICRISAT), Bamako, Mali.

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**Notes**
1. Entitlement is defined as “the set of all possible combinations of goods and services that a person can obtain using the totality of rights and opportunities”.
2. The *endowments* are the combination of all resources legally owned by people, which include both tangible assets (such as land, equipment, animals, etc.) and intangible assets such as knowledge and skill, labour power, membership of a particular community, etc. In developing countries, an important part of a household’s resources comes from labour activities.
3. *Exchange conditions* allow people to use their resources to access the set of commodities through trade and production and the determination of relative prices of products or goods.

4. The global hunger index is currently considered as one of the best indicators of food security because it take into account four dimensions (availability, accessibility, stability and utilization) of food security. However, it is not available over the long period of time (1970–2008).
5. CERDI Centre d'Etude et de Développement sur le Développement International (CERDI).
6. To calculate this index, we use the principal component analysis (PCA) applied to three variables.
7. Cereals include wheat, rice, maize, barley, oats, rye, millet, sorghum, buckwheat and mixed grains.

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## Appendices
## Appendix 1. Variables definition and sources

| Variables | Definition | Source |
|---|---|---|
| Food availability per capita | Food availability refers to the total amount of the commodity available as human food during the reference period. Food availability are the total of food Production + food import- food exports+ food stocks variation. We focus on the main cereals (maize, rice, sorghum, millet and wheat), soybeans and sugar. They represent an important proportion in the population's food in most of developing countries. | FAO (2019) |
| Civil conflicts | Civil conflicts are defined as the magnitude score of episode(s) of civil warfare involving that state in that year. | Center for Systemic Peace, (2017) |
| Democratic institutions | The Polity Score captures the regime authority spectrum on a 21-point scale ranging from −10 (hereditary monarchy) to +10 (consolidated democracy). | Polity IV (2017) |
| Rainfall variability | Rainfall variability is defined as the five-year rolling standard deviation of the growth rate of rainfall series. | CERDI[5] |
| Food price vulnerability | The FPV index is a weigted[6] average of the following variables: the ratio of food imports to total household consumption; the ratio of total food imports to total imports of goods and services and the inverse of the level of GDP per capita. | WDI (2019) |
| Income per capita | Gross Domestic Product per capita | |
| Population growth | annual population growth rate | |
| Arable land | Arable area as percentage of total land area | |
| Cereal production land | Cereal[7] production area refers to harvested area or Land under cereal production | |
| Percentage of total undernourished population | The percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously. | |

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## Appendix 2. Descriptive statistics of variables

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Food availability | 137.4605 | 43.44,609 | 16.09 | 309.04 |
| Rainfall variability | 3.306,602 | 2.742,387 | .1,112,826 | 16.71,544 |
| Rainfall mean deviation | 5.310,545 | 1.185,919 | −4.605,309 | 7.224,394 |
| Rainfall | 1247.163 | 436.3343 | 181.4366 | 2619.67 |
| Food Shock price vulnerability | 10.6104 | 5.581,212 | 0.7,146,384 | 46.80,371 |
| Civil conflict | .071591 | .4,367,555 | 0 | 4 |
| Per capita GDP | 10,634.51 | 17,056.82 | 131.6464 | 191,586.6 |
| Population growth | 1.813,871 | 1.532,924 | −10.95,515 | 19.59,727 |
| Democratic institutions | 1.03715 | 7.407,377 | −10 | 10 |
| Cereal production land | 3.02e+07 | 8.27e+07 | 0 | 7.33e+08 |
| Arable land | 13.1413 | 12.90,648 | .0011706 | 73.38,865 |
| Undernourished population | 12.71,612 | 11.4714 | 2.5 | 71.5 |

Source: calculations of the authors.

## Appendix 3. Countries

| | | | | | |
|---|---|---|---|---|---|
| Albania | Cote d'Ivoire | Honduras | Lithuania | Nicaragua | Togo |
| Argentina | Cameroon | Croatia | Morocco | Nepal | Thailand |
| Azerbaijan | Colombia | Haiti | Moldavia | Pakistan | Trinidad and Tobago |
| Burundi | Costa Rica | Indonesia | Madagascar | Panama | Tanzania |
| Burkina Faso | Algeria | India | Mexica | Peru | Uganda |
| Bangladesh | Ecuador | Iran | Mali | Philippine | Ukraine |
| Bulgaria | Egypt | Jamaica | Mongolia | Paraguay | Uruguay |
| Bolivia | Ethiopia | Kenya | Mozambique | Rwanda | Venezuela |
| Brazil | Fiji | Kowait | Mauritania | Sudan | South Africa |
| Botswana | Gabon | Liberia | Malaysia | Senegal | Zambia |
| Chile | Ghana | Libya | Niger | El Salvador | Zimbabwe |
| China | Guatemala | Sri Lanka | Nigeria | Syria | |