Paper One

1. Introduction

Agricultural research and development (R&D) is a crucial determinant of agricultural productivity and production, and therefore food prices (Pardey *et al*. 2013). Hence, agricultural productivity, sustained growth is vital for most African economies, given that the agricultural sector accounts for more than 70 percent of the total labour force within the continent (World bank, 2000). Given that mean temperatures across Africa have witnessed an increase of about 0.5^{o}C over the past years, and it is further estimated to increase by 4^{o}C by the end of the twenty-first century, one of the most important instruments that developing economies possess to achieve sustained agricultural production and food security are effective and efficient public spending in the agricultural sector (Mogues and Anson, 2015; Salim and Islam, 2010). Furthermore, the United Nations Sustainable Development Goals (SDGs) underscore the need for governments to increase spending and investment in agriculture, particularly, agricultural research and extension services, and technology development in order to increase agricultural productivity (UN, 2015). Therefore, public spending on agricultural R&D today is essential for future food security (Andersen, 2015).

Given deteriorating climatic conditions and the need to ensure food security, many governments in Sub-Saharan Africa (SSA) have committed to the African Unions' declaration in Malabo in 2003 to increase their annual spending on agriculture to 10 percent of their total national expenditure. However, there is little evidence to show whether national spending on R&D in agriculture has achieved the intended purpose. To affect the course of this strategic course, more analyses with high quality data and rigorous approaches are called for.

Current studies (Bathla *et al*, 2019; Khan *et al*. 2018; Andersen, 2015; Bervejillo *et al*. 2012; Alene, 2010; Salim and Islam, 2010) on the relationship between public investments in agricultural R&D and agricultural productivity have been undertaken mostly for high-income countries for which relatively good data are available with a few studies on middle/lower-income economies. While Bathla *et al*. (2019) found that public investments in agricultural research and development and subsidies have the highest marginal returns on agricultural productivity in low-income states in India, Andersen (2015) showed that real rate of return to public investments in agricultural R&D in the United States was 10.5% per annum. Salim and Islam also showed that both R&D and climate matter for long-run productivity growth in agriculture with the long-run elasticity of total factor productivity with respect to R&D expenditure being 0.497 in Western Australia. However, our study uses a different approach to explicitly explain the exact interaction effect between R&D and climate variability (proxied by rainfall) on agriculture output (productivity) using cross-country panel econometrics on selected Sub-Saharan African (SSA) countries.

The aim of our paper is to examine whether government spending on R&D mitigate the effects of climate variability on agriculture output (productivity). Our contribution is threefold. First, we contribute to the literature seeking to investigate the interaction effect between government expenditure on research and development (R&D) in agriculture and climate variability (rainfall and temperature) on crop yield, and the degree to which this interaction effect varies between countries. This is crucial since risk-averse farmers cannot adapt to climate variability in the longer-term unless they can access credit, new technology, crop insurance and market information which most farmers do not have access to especially within Sub Saharan Africa. Since rainfall and temperature variability induces risk, farmers' anticipation of such climatic shocks might influence their cultivation decisions, such as the non-adoption of climate-smart technologies for farming with the aim of avoiding huge losses and thereby affecting crop yields. At the same time, it is anticipated that government spending on research and development will mitigate risk to yields and spur agricultural productivity. Hence, evidence regarding the interaction between research and development (R&D) and climate variability on agricultural output is desirable. Second, African leaders made a commitment in 2003 in Maputo to increase their annual spending on agriculture to 10 percent of total national expenditure, which was subsequently reaffirmed in the Malabo declaration in 2014. However, there is little evidence examining the returns to government spending on research and development (GR&D) in deteriorating climatic condition on agricultural output (productivity). Our study lends evidence to inform policy by governments. Third, we lean on the Fixed Effect Instrumental variable (FE-IV) as the benchmark to cater for the problem of endogeneity and country specific fixed effects in our model.

The rest of the paper proceeds as follows. Section 2 provides an overview of agriculture in Sub-Saharan Africa (SSA) followed by a critical review of the recent literature in Section 3. Data sources is provided in Section 4. Section 5 presents the analytical framework followed by an analysis of empirical results in Section 6. Summary of findings and policy implications are provided in the final section.

2. An overview of agriculture in Sub-Saharan Africa

Agriculture in Sub-Saharan Africa (SSA) differs from agriculture in the rest of the world. Agriculture accounts for 35% of gross domestic product (GDP) and employs 70% of the population in SSA (World Bank, 2000). At the same time, more than 95% of the farmed land is rainfed (FAOSTAT, 2005). With little or no water management, yields are determined by climatic conditions. This uncertainty influences the strategies adopted by farmers, who are reluctant to invest in intensive agriculture. Despite large strides made in improving agriculture productivity, agricultural production has been unable to meet the higher and more diversified food requirements of the population in SSA. In fact, in many countries, population growth has exceeded growth in agricultural production exposing a great number of people to hunger, food insecurity and malnutrition. In terms of export, the relative share of agricultural exports has declined from 8 percent in 1971-80 to 3.4 percent in 1991-2000 in the world market whereas agricultural imports account for about 15 percent of total imports (NEPAD, 2003). From being self-sufficient for cereals in the 1960’s, the region has become a net importer of food.

3. Review of literature

Following the work of Griliches (1958), several studies have included research and expenditure (R&D) as explanatory variables in productivity or production outcomes. Hall and Scobie (2006) observes that higher productivity may result from many sources but increase in the stock of knowledge is seen widely as the primary source of productivity. Hence, investments in research and development (R&D) can lead to a change in productivity by changing the quality of conventional inputs and outputs (Fan, 2000). In the article by Griliches (1979) on assessing the contribution of R&D to Productivity Growth, he opines that since it is not possible to quantify the amount of knowledge stock, it is appropriate therefore to take spending on R&D as a proxy for knowledge stock. In evaluating some of the factors that may affect agriculture productivity, Antle and Mullen (2008) observes that climate variability plays a significant role in agriculture productivity given that agriculture activity is one of the major contributors to climate change in recent times.

3.1 Public spending on R&D and agricultural productivity

Fan *et al.* (2008) observes that the main reason for government allocation of resources to the agricultural sector is premised on its public good nature. Hence, government expenditure on agriculture is a means through which the government pursue developmental as well as welfare policies by increasing capital stock (Armas *et al*. 2012). Fan (2000) measured economic returns to research and development (R&D) investment in Chinese agriculture using the production function approach. The study shows that rates of return to investment in R&D in Chinese agriculture are high, ranging from 36 percent to 90 percent within the study period, and that the rates increase over time.

Alene (2010) measured and compared total factor productivity growth in African agriculture under contemporaneous and sequential technology frontiers over the period 1970–2004. Using a fixed-effects regression model and a polynomial distributed lag structure, the study examined sources of agricultural productivity growth. While their conventional estimates showed an average productivity growth rate of 0.3% per annum, their improved measure under sequential technology showed that African agricultural productivity grew at a higher rate of 1.8% per annum. Their results observed that technical progress, rather than efficiency change, was the main source of productivity growth. At the same time, agricultural R&D, weather, and trade reforms turned out to have significant effects on productivity in African agriculture. R&D turned out to be a socially profitable investment in African agriculture, having a rate of return of 33 percent per annum. The study further showed that a strong R&D expenditure growth of about 2 percent per annum in the 1970s yielded strong productivity growth after the mid-1980s. However, a stagnation in R&D expenditure in the 1980s and early part of the 1990s led to slower productivity growth in the 2000s.

Salim and Islam (2010) explored the impact of R&D and climate change on agricultural productivity growth in Western Australia during the period from 1977 to 2005. In this study, they adopt the augmented Cobb-Douglas production to estimate the equilibrium relationship to output as well as to productivity growth in the long run. They conclude that both R&D and climate change matter for long run productivity growth. The long run elasticity of total factor productivity with respect to R&D expenditure is 0.497. Further, they show that increase in R&D investment in deteriorating climatic condition in the agricultural sector improve the long run prospects of productivity growth.

Bervejillo *et al*. (2012) using newly constructed data modeled and measured agricultural productivity growth and the returns to public agricultural research (R&D) in Uruguay from the period 1961–2010. They showed that public funding for agricultural R&D spurred sustained growth in agricultural productivity when productivity growth was stagnating in many other countries. Their study further revealed that benefit-cost ratio varied significantly across models with different lag structures and that internal rate of return on R&D was very stable, ranging from 23 percent per annum to 27 per cent per annum within the study period. Andersen and Song (2013) examined the relationship between public investments in agricultural research and development and the productivity-enhancing benefits they generate in the US. In particular, they find that the real rate of return (RRR) to public investments in agricultural R&D in the US ranged between 8 to 10 percent per annum.

To better understand the relationship between public investment in agricultural R&D and productivity, Andersen (2015) using R&D expenditure data from 1949-2002 in the United states showed that the real rate of return to public spending on agricultural R&D was 10.5% per annum, indicating that government spending in agricultural R&D earn healthy economic return that justifies these expenditures to the general public and policy makers.

Recently, Khan *et al*. (2018) using a unique state-level dataset covering the period 1995–2007 to examine the role of research and development (R&D) in Australia's broadacre farming, found that R&D investments significantly increase output. Their results also showed that there are substantial variations in the impacts of R&D on output across the state-level average farm through technology parameters as well as through technical inefficiency. Jaijit *et al* (2019) explored the economic, social and environmental impact of Thai rice research expenditure using the simultaneous equation modeling technique. Their results showed that production-research expenditure was the most explicit to reduce the amount of nitrogen fertilizer usage, while breeding-research expenditure was the most explicit in terms of increasing farmers' economic status from planting rice.

In a recent study on India agriculture, Bathla *et al.* (2019) using data on public investment from 1981-1982 to 2013-104 found that public investment in agricultural R&D have the highest marginal returns in low-income states in India. Therefore, the general conclusion that emerges from the literature is that research and development (R&D) yield significant returns.

3.2 Climate change and agriculture productivity

In recent years, a large number of studies (Chang *et al*. 2016; Salim and Islam, 2010; Schlenker and Roberts, 2009) have shown that in addition to research and development (R&D), climate variability plays an important role in agricultural productivity. Therefore, there is a wide range of empirical studies analyzing the effects of climate variability on agricultural productivity in the literature. Our study reviews some of the past and most recent studies on the relationship between climate variability and agricultural productivity. Barrios *et al*. (2008) examined the impact of climatic change on the level of total agricultural production of Sub-Saharan Africa (SSA) and non-Sub-Sahara Africa (NSSA) developing countries. In doing so, they used a new cross-country panel climatic dataset in an agricultural production framework. Their results showed that climate, measured as changes in country-wide rainfall and temperature, has been a major determinant of agricultural production in SSA. In contrast, NSSA countries appear not to be affected by climate in the same manner.

Schlenker and Roberts (2009) pairing a panel of county-level yields for corn, soybeans and cotton with a new fine-scale weather dataset that incorporates the whole distribution of temperatures within each day and across all days in the growing season found that yields increase with temperature up to 29° C for corn, 30° C for soybeans, and 32° C for cotton. However, temperatures above these thresholds are very harmful to crop productivity. The study showed that holding current growing regions fixed, area-weighted average yields are expected to decrease by 30–46% before the end of the century.

Knox *et al.* (2012) analyzed the impacts of climate change on the yield of eight major crops in Africa and South Asia using a systematic review and meta-analysis of data in 52 original publications. They showed in their study that average change in yield of all crops will hit -8percent by the year 2050 within Africa and Asia. Particularly for Africa, average yield variations were estimated to be around -17percent for wheat production and -5percent for maize.

Chen *et al*. (2015) estimated the relationship between weather elements and crop yields in China using an empirical framework. Their study discovered that there is a non-linear relationship between crop yields and weather variables. Also, their study further showed that weather variability has caused an economic loss of about $820million to China's corn and soybean sectors in the past decade. Ma and Maystadt (2017) examined the impact of weather variations on maize yields and household Income in China. They observe that temperature, drought, wet conditions, and precipitations have detrimental effects on maize yields. Their study revealed that impact is stronger in the Northern spring where one standard deviation in temperature and drought conditions decreases maize yields by 1.4% and 2.5% respectively.

In another study, Kuwayama *et al* (2018) estimate the impacts of drought on crop yields in the US between the time period of 2001-2013. They find negative and statistically significant effects of drought on crop yields equal to reductions in the range of 0.1 percent to 1.2 percent for corn and soybean yields. Amare *et al* (2018) notes that negative rainfall shocks have heterogeneous effects on crop-specific agricultural productivity and based on geographical zones. Using instrumental variables regression approach, where agricultural land productivity is instrumented with negative rainfall shocks, they find that a negative rainfall shock decreases agricultural productivity and hence decreases household consumption by 37 percent.

In a very recent paper, Bocchiola *et al.* (2019) examined the impact of climate change on agricultural productivity and food security in the Himalayas. They observed that climate variability will on average, decrease wheat −25%, rice −42% and maize −46% by the year 2100. However, under modified land use scenario, wheat yield would decrease by −38%, while rice and maize yield would improve very slightly (−22% , and −45%) in response to occupation of higher altitudes than now.

4. Data sources

Unbalanced panel data on R&D expenditure, agricultural production (maize and sorghum), rainfall and temperature and conventional agricultural inputs (land and labour) covering the period 2001 to 2016 for six selected Sub-Saharan African countries (Angola, Burkina Faso, Kenya, South Africa, Tanzania and Zambia) was used in this study. The panel data series are obtained from various sources. Specifically, rainfall and temperature data are sourced from the world bank Climate Change Knowledge Portal (henceforth, CCKP). All our agricultural data are taken from the FAO online database except labour which is obtained from ILOSTAT database. Data on government expenditure on research and development (R&D) is measured in millions of US$ in 2010 prices. For agricultural output we use the FAO measure of maize and sorghum yield in 1000’s per hectare. Agricultural land is measured as using land under permanent crops in thousand hectares. Agricultural labour is measured as a percentage of total employment modeled by the International Labour Organization (ILO).

5. Analytical framework

This paper employs a production function approach. This have been employed by several studies (Andersen, 2015; Chen *et al*, 2015; Salim and Islam, 2010; Barrios *et al,* 2008). A neo-classical production function of the following form is employed:

$Y_{it} = f(X_{it}, R\_Dagri_{it}, Climate_{it})$…………………………….……………………….…………. (1)

Where Y represents agricultural output for crop (*i*); *t* is a time index, that is, *t* = 2001, 2002, … 2016; X represents the use of inputs (land and labour) for a crop (*i*). R_Dagri denotes the stock of R&D expenditure in agriculture and Climate variability is proxied by rainfall and temperature.

Since the impact of R&D on agriculture output (yield) is non-linear, we specify our interaction model thus:

$Yield_{it} = C_t + \alpha_1 R\_Dagri_{it} + \alpha_2 Climate_{it} + X_{it} + \varepsilon_{it}$ …………………………………………... (2)

$Yield_{it} = C_t + \alpha_1 R\_Dagri_{it} + \alpha_2 Climate_{it} + \alpha_3 R\_Dagri_{it} * Climate_{it} + X_{it} + \varepsilon_{it}$ …………………. (3)

Where R_D*Climate denotes the interaction between R&D and rainfall (our main variable of interest); ε_{it} is the error term and α_1, α_2 and α_3 are parameters to be estimated.

From equation (3), we can compute the partial elasticities of Yield with respect to R_Dagri.

$\frac{\partial Yield}{\partial R\_Dagri} = \alpha_1 + \alpha_3 Climate_{it}$ ………………………………………………………………. (4)

We estimate Equation (3) as the baseline model and then estimate Equation (4) as total output equation to find whether R&D mitigate climate variability on agricultural output in selected countries in Sub Saharan Africa (SSA).

6. Analysis of empirical results

7. Conclusions and policy implications

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