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An Empirical Analysis on The Influence of Agricultural Research and Development on
Agricultural Output in Sub-Saharan Africa: An Endogenous Growth and Public Choice Theory
Approach

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ABSTRACT

Since independence, many sub-Saharan African (SSA) countries have strived to find permanent solutions to persistent patterns of sluggish economic growth and endemic poverty. For some of these economies, the solution to the problem demands the use of fiscal policy to build up quality and durable critical infrastructures, such as public health facilities, educational facilities, transportation networks, reliable energy supply and many others. According to countries like Ghana and Nigeria, the rationale for this growth strategy is the idea that building and utilizing these critical infrastructures create new employment opportunities and enhance economic productivity. For other economies, including Senegal and the Gambia, amplifying the role of monetary policy to bolster economic activity by controlling interest rates and inflation is seen as an equally important alternative growth strategy, and as a complement to the fiscal policy approach. Despite modest economic improvements after more than five decades, these challenges persist – economic growth continues to be sluggish, poverty rate has consistently failed to fall below the global average, infant mortality rate has not seen significant improvement, quality critical public infrastructures remain lacking, and most of the economies continue to be characterized by inefficiency. With the intention of exploring other growth alternatives for sub-Saharan African countries, the paper adopts a Two Sample Independent T-Test to empirically analyze the role of agricultural research and development (AR&D) in facilitating a sustainable and inclusive economic growth in the sub-continent. Using two groups of four sub-Saharan African countries as case studies – Group 1 (Togo and Sierra Leone) and Group 2 (Madagascar and Kenya) – the paper’s empirical analysis finds that a methodical investment in agricultural research and development has a strong potential to facilitate economic growth through an increase in the value of agricultural output.

KEYWORDS

Sub-Saharan Africa, Endemic Poverty, Economic Growth, Fiscal Policy, Monetary Policy, Poverty Rate, Mortality Rate, Agricultural Research and Development (AR&D), Two Sample Independent T-Test, Agricultural Output.

TABLE OF CONTENTS

| | |
|-------------------------------------------------------------------------------|-----|
| ABSTRACT | ii |
| KEYWORDS | ii |
| TABLE OF CONTENTS..... | iii |
| LIST OF FIGURES | iv |
| TABLES | iv |
| ACKNOWLEDGEMENT | v |
| ACRONYMS | vi |
| SECTION 1 | 1 |
| INTRODUCTION | 1 |
| AGRICULTURE AS A PATHWAY FOR ECONOMIC GROWTH | 6 |
| THEORETICAL FRAMEWORK..... | 12 |
| Endogenous Growth Theory – Paul Romer’s Model..... | 12 |
| Public Choice Theory | 14 |
| LITERATURE REVIEW..... | 16 |
| SECTION 2 | 20 |
| METHODOLOGY..... | 20 |
| Data Description | 20 |
| Methodological Operations..... | 27 |
| Checking for Normality of Data..... | 27 |
| Checking for Equal or Unequal Variance..... | 33 |
| T-Test Results..... | 37 |
| SECTION 3 | 44 |
| DISCUSSION AND POLICY OPTIONS FOR SUB-SAHARAN AFRICA..... | 44 |
| Strategically Increase National Levels of Investment in Agricultural R&D..... | 44 |
| Improve Efficiency of R&D Expenditure within the Public R&D Sector..... | 49 |
| CONCLUSION..... | 52 |
| BIBLIOGRAPHY..... | 53 |
| APENDIX | 56 |

LIST OF FIGURES

| | |
|--------------------------------------------------------------------------------------|----|
| Figure 1: Armed Conflict by region, 1946-2020..... | 2 |
| Figure 2: One-sided (Armed Conflict) Actors by region, 1989-2000..... | 3 |
| Figure 3: Poverty headcount ratio (% of population) 1988-2018..... | 3 |
| Figure 4: Agricultural Labor Estimate | 24 |
| Figure 5: Agricultural Land Estimate | 25 |
| Figure 6: Togo’s AR&D and Agricultural Output Trend | 41 |
| Figure 7: Sierra Leone’s AR&D and Agricultural Output Trend | 42 |
| Figure 8: Madagascar’s AR&D and Agricultural Output Trend..... | 42 |
| Figure 9: Kenya’s AR&D and Agricultural Output Trend..... | 43 |
| Figure 10: Agricultural R&D Intensity Among selected SSA countries..... | 46 |
| Figure 11: Public Provision of Incentives for Agricultural R&D (Counterfactual)..... | 48 |
| Figure 12: Nigeria Agricultural R&D Expenditure Types..... | 50 |
| Figure 13: Ghana Agricultural R&D Expenditure Types..... | 51 |
| Figure 14: Sierra Leone Agricultural R&D Expenditure Types..... | 51 |

TABLES

| | |
|------------------------------------------------------------------------|----|
| Table 1: Growth trends among world regions in the past 7 decades | 4 |
| Table 2: List of Sub-Saharan African countries..... | 7 |
| Table 3: Brief Country Description (Group 1) | 22 |
| Table 4: Brief Country Description (Group 2) | 23 |
| Table 5: T-Test Agricultural Output Datasets | 25 |
| Table 6: Agricultural R&D (2011 Constant US Dollars) | 26 |
| Table 7: Madagascar K-S Test Results | 28 |
| Table 8: Kenya K-S Test Results | 29 |
| Table 9: Togo K-S Test Results | 30 |
| Table 10: Sierra Leone K-S Test Results | 31 |
| Table 11: K-S Test Descriptive Statistics | 32 |
| Table 12: Variance Calculation Values (Group 1) | 34 |
| Table 13: Variance Calculation Values (Group 2) | 34 |
| Table 14: T-Stat Operation Values | 38 |

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ACRONYMS

| | |
|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| A-R&D: Agricultural R&D | MEPZ: Mauritius Export Processing Zone |
| AU: The African Union | NGO: Non-governmental Organization |
| AGDP: Agricultural GDP | NEPAD: The New Partnership for Africa's Development |
| ASTI: Agricultural Science and Technology Indicators | OECD: Organization for Economic Co-operation and Development |
| AfDB: African Development Bank | OCHA: United Nations Office for the Coordination of Humanitarian Affairs |
| BTI Index: Bertelsmann Stiftung's Transformation Index | PPP: Purchasing Power Parity |
| CAADP: Comprehensive Africa Agriculture Development Programme | PC Theory: Public Choice Theory |
| ECOWAS: Economic Community of West Africa | (r)-GDP: real-Gross Domestic Product |
| EU-15: Members of the EU prior to May 2004 ten accession countries | R&D: Research and Development |
| EDF: Empirical Distribution Function | SENCHEM: Chemical Commercialization Company |
| ECHO: The European Civil Protection and Humanitarian Aid Operations | SPIA: Agricultural Products Company |
| ECCAS: The Economic Community of Central African States | SSA: Sub Saharan Africa |
| EAC: The East African Community | SADC: The Southern African Development Community |
| F-Calc: F-Calculated | TFP: Total Factor Productivity |
| FDI: Foreign Direct Investment | USD \$: US Dollars |
| FAO: Food and Agriculture Organization of the UN | USAID: The U.S. Agency for International Development |
| FAOSTAT: Food and Agriculture Organization Corporate Statistical Database | UNIDO: United Nations Industrial Development Organization |
| GERD: Gross domestic Expenditure on R&D | UNESCO: United Nations Educational, Scientific and Cultural Organization |
| IFAD: International Fund for Agricultural Development | UNCTAD: The United Nations Conference on Trade and Development |
| ILO: International Labour Organization | WITS: World Integrated Trade Solution |
| IMF: International Monetary Fund | WDI: World Development Indicators |
| IGAD: Intergovernmental Authority on Development | K-S Test: Kolmogorov-Smirnov Test |

SECTION 1

INTRODUCTION

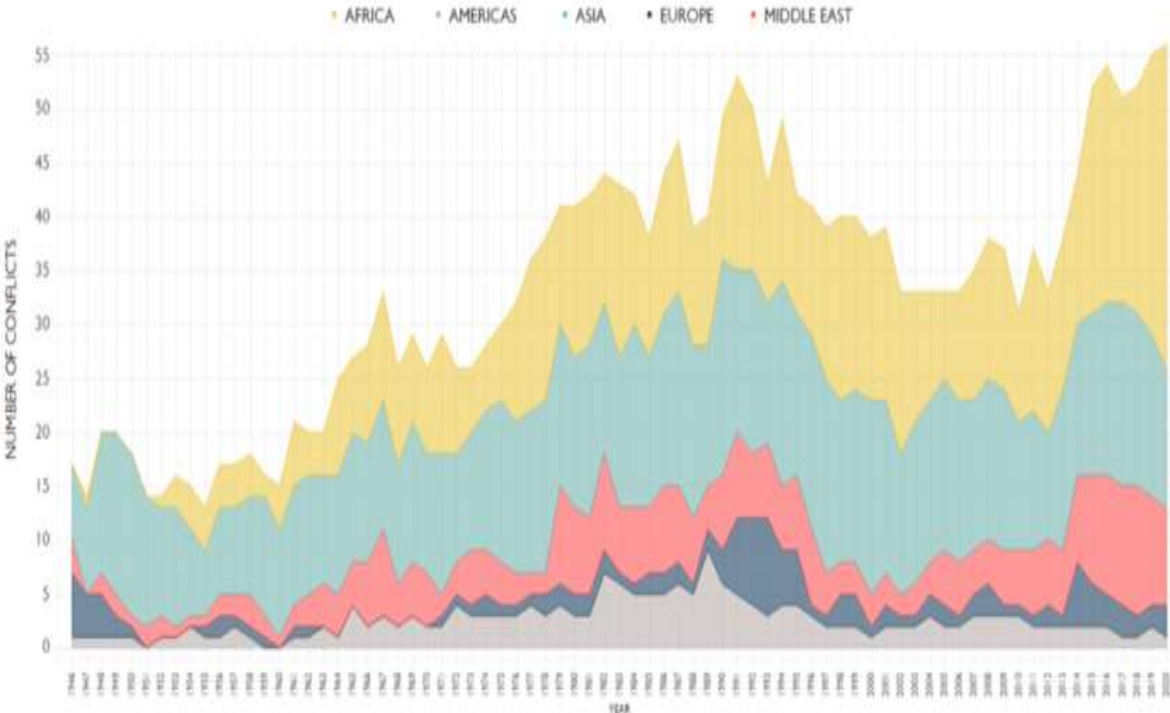
Many sub-Saharan African (SSA) countries since independence have been confronted with a countless number of development and economic growth challenges. Food insecurity, civil wars, political unrests, health crisis (i.e., malaria, tuberculosis, HIV/AIDS and Ebola), to name a few have all undermined economic growth prospects and the lives of the population in the region. Global actors like the United Nations (UN), the U.S. Agency for International Development (USAID), the European Civil Protection and Humanitarian Aid Operations (ECHO), and many NGOs have all reiterated in their respective reports and policy documents of the economic and human security concerns these challenges have and continue to pose to the sub-continent over the past few decades. (See appendix 1). *The Economist* in its controversial May 2000 article publication referred to Africa (and sub-Saharan Africa by implication) as “The Hopeless Continent”, invoking evidence of stagnant growth, under-development, political instability, and several others including those outlined above. (See appendix 2).

“Floods in Mozambique, threats of famine in Ethiopia, mass murder in Uganda, the implosion of Sierra Leone, and a string of wars across the continent, the new millennium has brought more disaster than hope to Africa. Worse, the few candles of hope are flickering weakly” (*The Economist*, May 2000).

As evident in figures 1 and 2, the region at the time of *The Economist*'s publication was indeed facing crisis at several fronts as a number of violent civil wars – the Rwanda Civil War (1990-1994), the 2000 Titanic Express Massacre in Burundi, the Republic of Congo Civil War (1997-1999), and the 1991-2002 Sierra Leone Civil War – had all imposed a great toll on the region

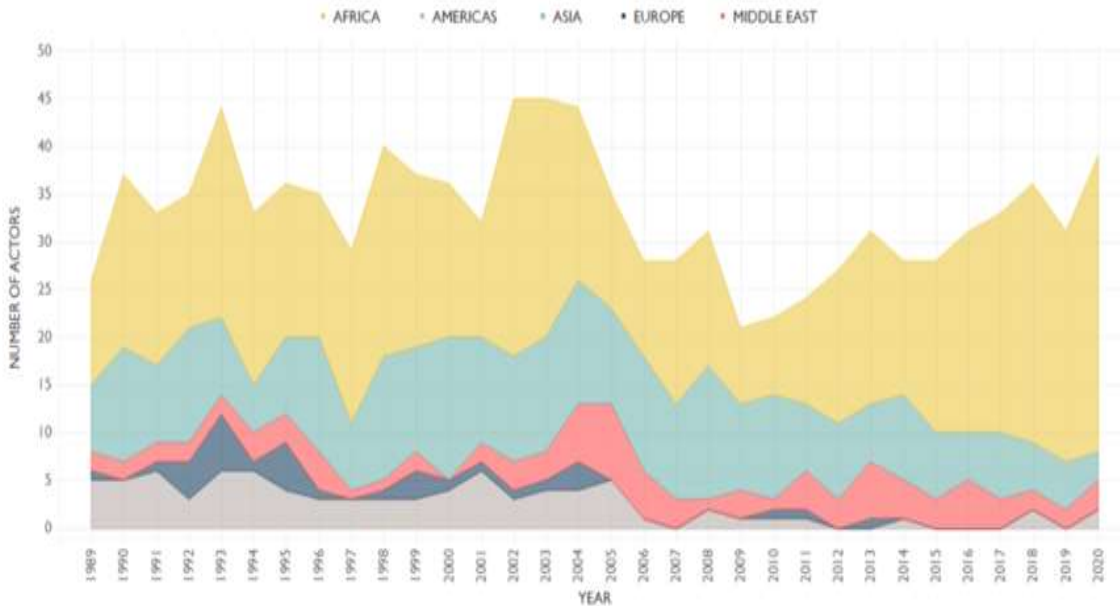
with regards to disruption in economic activity, human casualty, and destruction of property. *The Economist's* gloomy characterization of the reality of the sub-continent just as many bleak perceptions in academia and policy arenas in the developed world are however overstated and ignore the political and socio-economic improvements that have been evolving in the region since the mid 1990s. The most prominent among such improvements were countries like Malawi and Ghana pivoting from a centralised economic control and authoritarian regime to multi-party democratic states in 1993 and 1996 respectively, while simultaneously establishing a robust free market economy. Poverty rates as a percentage of the population have also seen encouraging improvements, with a decline at its peak in 1994 (61%) to 58% in 2000, and a continued downward trend to 40% in 2018. (See figure 3)

Figure 1: Armed Conflict by region, 1946-2020



Based on UCDP 21.1 data
Source: Uppsala Conflict Data Program, “Armed Conflict by region 1946-2020,” Uppsala University, Department of Peace and Conflict Research, (accessed August 13, 2021), <https://www.pcr.uu.se/research/ucdp/charts-graphs-and-maps/>.

Figure 2: One-sided (Armed Conflict) Actors by region, 1989-2000



Based on UCDP 21.1 data

Source: Uppsala Conflict Data Program, “One-sided (armed conflict) by region 1989-2020,” Uppsala University, Department of Peace and Conflict Research, (accessed August 13, 2021), <https://www.pcr.uu.se/research/ucdp/charts-graphs-and-maps/>.

Figure 3: Poverty headcount ratio at \$1.90 a day (2011 PPP) (% of population) 1988-2018



Source: “Poverty headcount ratio at \$1.90 a day (2011 PPP)(% of population),” The World Bank Data, The World Bank, (accessed August 13, 2021), <https://data.worldbank.org/topic/poverty?end=2018&locations=ZG-1W&start=1988>.

Eleven years later in 2011, *The Economist* changed its tune from Africa as a “Hopeless Continent” to “Africa Rising” by citing evidence of growth rates that averaged 5.8% a year between 2002 and 2011, and pointing to Ghana as among the decade’s outstanding economic

performers. (*The Economist*, Dec 2011; See appendix 2) Nonetheless, events like Ghana’s 2015 IMF’s bailout, the sub-region’s low GDP-per capita growth, and economic migrants risking life and limbs to undertake the dangerous journey from sub-Saharan Africa across the Sahara through war-torn Libya into Europe truly puts into question, the plausibility of the “Africa Rising” narrative. As highlighted in Table 1, except for South Asia, sub-Saharan Africa’s GDP per capita has lagged behind all the other regions in the past seven decades. When compared to the top three performing regions (North America, Europe & Central Asia, and East Asia & Pacific), the region’s growth rate over that period is exponentially lower; and when compared to the bottom three regions (South Asia, Middle East & North Africa, and Latin America & Caribbean), the region still underperforms.

Table 1: Growth trends among world regions in the past 7 decades (GDP per Capita)

| Decade | Regional (per the World Bank’s Regional Classification) GDP per capita in constant 2010 US\$ | | | | | | | |
|--------|----------------------------------------------------------------------------------------------|---------|------------|----------------------------|---------------------------|---------------------|-----------------------|---------------|
| | Sub-Saharan Africa | World | South Asia | Middle East & North Africa | Latin America & Caribbean | East Asia & Pacific | Europe & Central Asia | North America |
| 1960 | \$11245 | 3733.4 | \$331.91 | No Data | 3692.3 | 1278.86 | No Data | 17554.85 |
| 1970 | \$1384.4 | 5181.92 | \$403.80 | (1975) \$6071.81 | 4876.23 | 2222.88 | 11477.6 | 23076.5 |
| 1980 | \$1516.39 | 6280.92 | \$431.21 | 6154.1 | 6928.07 | 2957.42 | 14656.79 | 28330.28 |
| 1990 | \$1309.80 | 7179.42 | \$584.10 | 5050.23 | 6568.44 | 4195.68 | 17621.8 | 35630.37 |
| 2000 | \$1227.7 | 8177.43 | \$799.1 | 5848.68 | 7526.3 | 5357.4 | 20309.5 | 44217.95 |
| 2010 | \$1592.95 | 9558.49 | \$1257.50 | 7172.94 | 9075.90 | 7698.98 | 23640.66 | 48387.21 |
| 2018 | \$1681.4 | 10935.4 | \$1880 | 7757.72 | 9613.64 | 10329.4 | 26354.8 | 54632.60 |

Source: “GDP per capita 1960 – 2020 (constant 2010 US\$) – Sub-Saharan Africa, World, North America, Europe & Central Asia, East Asia & Pacific, South Asia, Latin America & Caribbean, Middle East & North Africa” World Bank National accounts Data, and OECD National Accounts data files, The World Bank, retrieved July 3, 2021, <https://data.worldbank.org/indicator/NY.GDP.PCAP.KD?locations=ZG-1W-8S-ZI-ZQ-XU-Z7-ZA>.

So, what is the point of the paper’s emphasis on *The Economist’s* two contrasting narratives about sub-Saharan Africa? As short-sided as *The Economist* was in both instances in 2000 and 2011, the two opposing narratives, nevertheless, highlight fundamental opportunities and risks that warrant the uttermost attention of policymakers in the sub-continent. The short-term growth successes of countries like Ghana, or long-term growth success of others like Mauritius with its

exceptional textiles and apparel industry give a glimpse of the economic potential for sub-Saharan African countries to rise above the challenges that plague the sub-continent and ultimately achieve sustainable economic growth at the benefit of their populace. Conversely, perhaps not as “hopeless” as *The Economist’s* characterization, but there also remains the danger of the region succumbing to abysmal growth in the long run if strategic economic policies are not taken in the short to medium term. Policymakers can ignore these risks at the peril of continuous stagnant growth with far-reaching implications for socio-political stability, or pragmatically embrace the opportunities with actions rather than words in achieving sustainable economic growth. Within the context of making sub-Saharan African countries’ economic growth inclusive and sustainable, this paper empirically investigates the best economic policy options in achieving this objective. Paul Romer’s innovation-based endogenous growth theory is specifically adopted in conjunction with Public Choice theory. While Romer’s endogenous growth theory is investigated as a potential “solution”, public choice theory ensures the decisions of political agents and policy makers that are involved in the policy formulation and implementation of the “solution” to the greatest extent possible are free of foreseeable biases, failures and errors that can undermine policy efficiency and efficacy. The agricultural sector of four sub-Saharan African economies – Togo, Sierra Leone, Madagascar, and Kenya – are used as case studies to put to the test, the appropriateness and effectiveness of Romer’s model of growth in the region. It is the hope of the study that, such comparative analysis will offer invaluable lessons which countries across the sub-continent can apply to their own respective agricultural sectors or replicate similar growth strategy in other sectors (i.e., Manufacturing and services sectors), as well as within the broader economy. The paper is unique in its contribution to the long-standing debate about Africa’s pathway to sustainable economic growth by integrating endogenous

growth theory together with public choice theory to offer a distinctive perspective. The closest paper to have adopted a similar approach in examining the topic is Van Germinal's *A Mathematical Theory of Economic Growth: The Public Choice Growth Model (2020)*. Van Germinal's paper combines Solow's model of economic growth and Public Choice theory to analyze how the two theories can help explain development processes in developing countries, using Cote Ivoire as a case study. He finds that developing countries' pathway to growth is dependent on human capital and "exogenously" determined technological growth. (Van Germinal, p. 29, 2020) However, the study is constrained in its inability to address other important growth factors, such as the role of spill-over from "endogenously" determined technological change that has played a critical role in facilitating and sustaining economic growth in countries like Mauritius and South Africa. The paper is divided into three key sections. Section 1 – Introduction – sketches a detailed explanation of important theories that are referenced in the paper, and an overview of an extensive literature on the topic. Section 2 – Methodology – utilizes Two Sample Independent T-Test to empirically analyze the relationship between agricultural R&D and agricultural output. The final and third section – Discussions and Policy Options for Sub-Saharan Africa – offers recommendations to sub-Saharan African countries on their optimal adoption and implementation of R&D-driven growth strategy.

AGRICULTURE AS A PATHWAY FOR LONG RUN ECONOMIC GROWTH

Sub-Saharan Africa, the geographical and ethnocultural region of the African continent that lies south of the Sahara consists of four vast and distinct regions – Central Africa, East Africa, West Africa, and Southern Africa. Namely, the sub-continent consists of all African countries except

those in North Africa. It is home to a large diversity of agro-ecological climates, ranging from the drylands of northern Mali to the humid tropics of the Democratic Republic of Congo.

Table 2: List of Sub-Saharan African countries according to the World Bank.

| Sub-Saharan Africa | | | |
|---------------------------------|--------------------|--------------------|------------------------|
| Central Africa | West Africa | East Africa | Southern Africa |
| Cameroon | Benin | Burundi | Angola |
| Central African Republic | Burkina Faso | Comoros | Botswana |
| Chad, | Cape Verde | Djibouti | Lesotho |
| Congo Republic- Brazzaville | Cote D'Ivoire | Eritrea | Mozambique |
| Democratic Republic of Congo | Gambia | Ethiopia | Namibia |
| Equatorial Guinea | Ghana | Kenya | South Africa |
| Gabon | Guinea | Madagascar | Swaziland |
| Sao Tome & Principe | Guinea-Bissau | Malawi | Zambia |
| | Liberia | Mauritius | Zimbabwe |
| | Mali | Reunion | |
| | Mauritania | Rwanda | |
| | Niger | Seychelles | |
| | Nigeria | Somalia | |
| | Senegal | Somaliland | |
| | Sierra Leone | Tanzania | |
| | Togo | Uganda | |

Source: "Sub-Saharan Africa," The World Bank Data, The World Bank, accessed September 2, 2021, <https://data.worldbank.org/country/ZG>.

The sub-continent is the world's most least developed region, although a few countries like Mauritius, South Africa, Seychelles, and Gabon have experienced high performing economies over the past four decades. The region also consists of countries with varying degrees of democracy, ranging from countries with strong democracies (i.e., Ghana, Mauritius, Botswana); those that are firmly rooted in authoritarianism (i.e., Cameroon, Uganda, and Rwanda), and those that are defective democracies, but nonetheless have the potential to consolidate over time (i.e., Tanzania, Ethiopia, Zimbabwe). According to the 2020 Freedom House's report, of the 12 largest democratic declines globally, seven were in sub-Saharan Africa, and of the seven largest improvements, six were in the region. (Freedom House, p.11, 2020) Strong democratic regimes, however, appears to cluster around Western and Southern Africa, while illiberal political

regimes are concentrated in Central Africa. East Africa on the other hand is characterized by neither the strong democratic regimes of Western Africa nor the illiberal regimes of Central Africa, but rather hover between the two extremes. One of the reasons for such variations in democratic consolidation among the four sub-regions can be attributed to the competence of their respective economic communities on the issue of governance. The Economic Community of West African States (ECOWAS), when compared to the other three sub-regional communities has a strong legal framework to address political crisis. (See Appendix 3).

Agriculture for a long time in human history has been identified as a proven path to economic prosperity. No region or country in the world has developed a diverse and modern economy without first establishing a successful and resilient foundation in agriculture, and this is no different for sub-Saharan African countries, where the sector has a massive economic and social footprint. As such, the agricultural sector without a doubt remains one of the ideal candidates for sub-Saharan African countries to grow an inclusive and sustainable economy. There are good reasons to be pessimistic about the region's economic growth potential in the other economic sectors like the manufacturing and service sectors. In a time when China and Asian manufacturing powerhouses like India and Vietnam are flooding international markets with low cost manufactured goods, it becomes very difficult for new entrants, especially those from the sub-region to compete with them on the international, regional, and sometimes even in the domestic markets, let alone utilize the sector as a pathway to sustainable growth. Specialized markets, including the textiles and apparel industry undoubtedly exist for countries like Togo, Mauritius, Kenya, and Lesotho to develop export manufacturing, and those opportunities should indeed be pursued. However, their growth ceiling within the regional and international markets are constrained by the dominance of the Asian textiles and apparel giants (i.e., China, Hong

Kong [Special Administrative Region], Vietnam, Bangladesh, and India). These Asian exporters are leaders and trend setters in the textiles and apparel industry; thus, are able to capture the largest market share at the expense of sub-Saharan African exporters. (ILO, 2017). In addition, the manufacturing sector in the region is also constrained by unreliable energy sources, inadequate access to finance, poor business environment and red tape. (Bhorat et. al, 2017)

According to the World Bank, only 46.75% of sub-Saharan African populations have access to electricity – a 20.72% improvement from the 2000 level of 26.03%. (WDI, 2022) This electricity access statistic is as a matter of fact inflated than the “true access” when the intensity of constant rolling blackouts is taken into account. Adequately developed urban centers like Kumasi & Koforidua in Ghana, Ibadan & Kano in Nigeria, Bouake in Cote D’Ivoire, along with most urban and rural areas in the sub-continent are continuously faced with hours and days of routine blackouts despite having access to electricity. (Aidoo, 2018; Blimpo, 2019). As a result, sub-Saharan African countries’ economic growth potential within the manufacturing sector is constrained by a fierce external competition at the international and regional stage, as well as an internal structural challenge to thrive in the manufacturing sector at this stage of their economic development. The services sector also does not appear to offer any reliable opportunities of sustainable economic growth for the sub-region. Although the sector remains the largest contributor to national output with a share of approximately 48.91% in 2020 (see appendix 4), it is nevertheless dominated by the informal sector, often in trades and personal services with relatively low productivity and high labor intensiveness. Among these services include mining activities, various forms of repair, street vendors, hawkers, artists, petty traders that sell anything from groceries to building hardware, private taxi services and many others. (Kiaga & Leung, 2020). Since the output of the sector is produced mainly for the domestic market, its growth is

hamstrung by growth in national demand. National demand in turn is driven by growth in national per capita incomes, changing consumption patterns associated with rural-urban migration lifestyles, and population sizes. This pattern of economic growth does not offer realistic pathway to creating the quantity and quality of productive jobs that are needed to raise the living standards for most of the populace on the sub-continent in the long run. Thus, the service sector can only take the region so far and will at best lead to modest rates of national economic growth.

Conversely, there are very good reasons to be optimistic about the agricultural sector as a vehicle for sustainable growth. Particularly, the prospect for sub-Saharan African agriculture looks favorable, and several international indicators point to the region being ready for takeoff. First, the African food market continues to grow with the World Bank's estimates forecasting it could be worth \$1 trillion by 2030 – up from the 2013 level of \$313 billion. (The World Bank, 2013). Global demand for food is projected by the Food and Agriculture Organization (FAO) to at least increase between 59% and 98% from the 2013 level by 2050, with much of the projected global food demand expected to come from rising consumer incomes in Asia, Eastern Europe, and Latin America. (FAO, 2006; Valin et al, 2013) Agricultural output yield in the region is also estimated to be 20% less of what could be achieved due to over-reliance on the natural environment and extensive farming practices. (Van Ittersum et al., 2016) These trends, when combined with the sub-continent's net food import bill of negative \$US 2,666,026,270 (WITS, 2019), indicate that an opportunity exists for sub-Saharan Africa's agricultural sector. Second, the sector is the most appropriate for addressing much of the remaining poverty in the region. It employs 52.87% of sub-Saharan Africa's labor population as of 2019, most of whom are low-income smallholder farmers in the rural areas. (See appendix 5) Smallholder farming systems, which refers to farms

under 2 hectares are characterized by staple crop production, often rain-fed, small-scale production, sometimes produced for household consumption, and primarily dependent on family labor. (Salami et, al, 2010). Finding new ways of improving the quality and quantity of agricultural output will therefore have a significant impact on poverty reduction and economic growth in the region. There are a few rationales for this proposition. An increase in output for smallholder farmers will mean an increase in income from either the surplus from household consumption which can be sold at the market, or an increase in output for smallholder commercial farmers. Output increase will also lower food costs for the non-farming population, who spend a relatively significant portion of their income on food (Jimbira S. & Hathie, 2020). The savings from food consumption will also promote broader economic growth by stimulating demand for non-farm goods and services; hence, creating income for the population that are engaged in the non-agricultural sector. Finally, increase in the quality and quantity of agricultural output enables import substitution and export potential by creating new income streams for the farmers, as well as increase government revenue through taxation. Several empirical studies that compare growth-poverty elasticities across sectors in Sub-Saharan Africa have usually found much higher elasticities for agriculture than for non-agriculture sectors. Christiaensen et al (2011) argues that for the poorest population in the region, agricultural growth reduces poverty 11 times more than non-agricultural growth. Thirtle et, al, (2003) also estimate a 1% increase in crop productivity reduces the number of poor people by 0.72% in Africa and by 0.48% in Asia. Hence, at this stage of development in sub-Saharan Africa, the productive and competitive transformation of the agricultural sector remains one of the most important and promising options for sustainable long-run economic growth.

THEORETICAL FRAMEWORK

Endogenous Growth Theory – Paul Romer’s Model:

Why has the United States’ standard of living throughout history been better than those of sub-Saharan African countries in greater proportion? Why is the standard of living for the population of Japan and South Korea better than that of Nigeria, despite the two countries being less endowed in natural resources than Nigeria? These are the types of questions that underpin the concept of economic growth. Until recently, the Solow growth model (1956) served as the basis of contemporary theory in explaining economic growth. Under this theoretical framework, capital accumulation and exogenously determined changes in an economy’s technological progress was seen as the most important determinant of economic growth. (Solow, p.67, 1956) In other words, the United States, Japan and South Korea within the model for example all experienced their impressive economic growth due to a growing labor force, and a “coincidental” discovery of technology that improved the productivity of labor and/or production process. However, evidence of the accelerating growth rate elsewhere among industrialized and the Organization for Economic Co-Operation and Development (OECD) economies when compared to the slower growth of sub-Saharan African economies do not conform to the presuppositions of the Solow model. Endogenous growth model, an alternative theoretical framework to the Solow model has emerged as the best theory in explaining long-run economic growth by addressing the technological exogeneity question. According to the model, innovation or technological growth happens because of deliberate decisions of economic agents to invest in producing new knowledge, which in turn drives economic growth. Romer’s innovation-based growth theory, a sub-category and one of the most advanced versions of endogenous growth model sees “knowledge/ideas”, largely from investment in R&D as the ultimate determinant of long-run

growth. (Romer, p.3, 1994). Hence, any public policy including tax policy and funding that affects economic agents' incentives to conduct R&D can potentially influence the long-run growth prospects of an economy. Knowledge/idea in this regard does not necessarily have to be complex or cutting edge like the discovery of the wheel, the computer, the aircraft, and the cell phone; they can be as simple as the invention of the pencil. In addition, knowledge does not have to be "new" to the world, as it can be imported from one country to another (i.e., the introduction of GPS technology from the USA to Nigeria); or from an industry to another industry (i.e., the application of cell phone technology in the automobile industry); or an improvement upon existing knowledge (i.e., transformation of 3G network to 5G network). The four key characteristics of Romer's model that are worth emphasizing include the partial excludability of knowledge, non-rivalry of knowledge, increasing returns to scale and non-depreciation of knowledge. (Romer, p.15,1994) Goods and services in classical economics are rival in the sense that, given the existence of scarcity, as more people use such goods or services, there are less of them to be used by others. In a country with fifty neurological surgeons for example, one neurological surgeon operating on a patient at 12:30 pm is one less surgeon to operate on another patient at that specific point in time. Within the context of Romer's model, this is not the case. There are not less of Einstein's theory of relativity or Pythagoras' theory or Quantum mechanics knowledge to go around as one scientist uses any of such knowledge. It is this non-rivalry characteristic of knowledge that gives rise to "increasing returns to scale" – the specific knowledge can increasingly be used by every human or scientist without a decline in its utility. (Romer, p.12, 1994) As more people use the specific knowledge, it generates new ideas which sometimes might be different from the original idea/knowledge. For instance, Alexandre-Ferdinand Godefroy's invention of the first hair dressing device in 1888 was based on prior

knowledge about the vacuum cleaner. (Hart, 2017). Knowledge in Romer's model is also only partially excludable – meaning, patents and other forms of intellectual property rights allow the inventor of a new knowledge to enjoy the benefits of his or her invention for a specific period of time, after which others can invent their own version through patent documentation and the scientific literature. Finally, unlike physical capital or durable goods that depreciates overtime, and requires a minimum of constant proportionate rate of replacement of such capital to sustain or improve aggregate output, knowledge does not depreciate. (Romer, p.14, 1989) It is rather the “usefulness” of knowledge that declines over time, with the decline always due to the specific knowledge being superseded by an even better and modern knowledge. The knowledge of how to produce the first automobile in 1886 is only less useful in 2022 because it has been surpassed by an even more modern knowledge of automobile production, most of which builds upon the original knowledge. Therefore, when compared to physical capital and other production inputs, knowledge/ideas from R&D can be an important driver of economic growth through unlimited creation and re-creation of goods and services that both qualitatively and quantitatively increases output and productivity.

Public Choice Theory:

Political behavior is immensely integral to the paper's analysis. Particularly, it involves an investigation of government's role in stimulating innovation activities within a country – whether by addressing market failures that constraint the private sector's optimal investment in R&D, or direct and indirect support to push up the national aggregate of investment in R&D. Sub-Sahara African countries just as any other country do not have unlimited financial and human resources to finance a boundless number of productive R&D across the economy. As a result, decisions need to be made by policymakers about which agricultural sub-sector (i.e., crops, animals,

fisheries, and forestry) need to be prioritized as the vehicle for their respective innovation-based growth, by how much, and which regions/states/provinces or districts should be given greater priority. In addition to these obvious practical concerns, policymakers may also face direct pressures from interest groups and indirectly on the need to satisfy certain coalition of voters with innovation policy and spending. These challenges and pressures can create government failure whereby a well-thought AR&D investment decision and policy becomes undermined by non-market considerations. As a consequence, a theoretical framework that can help set an appropriate limit on the degree of government's involvement in a country's agricultural R&D activity, as well as aid in identifying the most optimal innovation initiatives that are purely growth enhancing and to a greater degree, free of policy makers' biases and non-market interests is needed. Public Choice theory, a branch of economics that employs economic methods and theories to analyze political behavior does just that. Prior to the emergence of public choice theory, a conventional held assumption about public officials is that of benevolent agents whose primary goal is to "help" the citizens as is usually articulated in campaign slogans during elections; or the government as a "non-human superstructure" that have only the best interest of society at heart. James Buchanan, one of the leading proponents of public choice theory refers to such perceptions of policymakers as "Romantic and illusory ... notions about the workings of governments" (Buchanan, p.3-7, 1979). In other words, no "government" thinks or acts, but rather individuals within the government as bureaucrats, appointed officials or elected officials are the ones that think and act. Just as economic agents, these public officials are also self-interested since their actions and decisions are predominantly towards winning elections, maintaining their positions within the government to enjoy all the benefits that comes with it (i.e., financial, reputational, and power), winning projects and gaining promotion. (Buchanan &

Tollison, p.87, 1984) Therefore, it is very important to apply the same rational behavior and individual incentives in the making of economic decisions at marketplace to policy-makers' decision making processes within the political arena. By having such a critical outlook about policymakers and their decision-making process as supposed to a "romantic" outlook, one can anticipate and address upfront potential biases and/or deliberate errors of policymakers that could undermine the successful implementation of growth enhancing agricultural R&D.

LITERATURE REVIEW

The importance of innovation as a driver of economic growth has made innovation policy one of the most debated topics in economics and political economy. A significant number of the most cited literature on the topic find a positive relationship between investment in R&D and economic growth, or investment in R&D and an increase in quantity and/or quality of specific output produced. The seminal work of Freire-Seren (1999) in a study of 21 OECD countries between 1965 and 1990 investigated the importance of aggregate R&D investment to economic growth by introducing an innovative technology. By emphasizing long run economic growth rate as a result of physical capital accumulation and R&D investment subsidies, she discovered a strong positive relationship between R&D and growth, whereby a 1% increase in total R&D expenditures increased real-Gross Domestic Product (r-GDP) by 0.08%. Akinwale et. al, (2012) in a similar work also focused on the impact of gross domestic expenditure on R&D (GERD), labor, and capital on economic growth in Nigeria. The authors find a significant positive relationship between R&D expenditure and economic growth in the country, but also observed an inverse relationship between them, pointing to high corruption practices, poor coordinating system between academia and industry, and weak institutions. This finding implies that

expenditure on R&D in itself is not sufficient to observe a maximum and optimal influence of R&D on growth. Accordingly, if governments can create an enabling environment with strong institutions, and improved interactions between R&D producers and R&D consumers, then R&D investment will indeed have an impact on growth as it is intended to.

Using panel data of twenty OECD countries and ten non-OECD countries for the period of 1981-1997, Ulku (2004) examined the relationship between R&D, innovation, and economic growth. He concluded that, for both OECD and non-OECD economies, there was a strong relationship between innovation created by the R&D sector and GDP per capita growth. He observed a 1% increase in innovation raises per capita income by around 0.05% among the two groups of economies. A considerable number of empirical studies about the effects of R&D on total factor productivity (TFP) are also prevalent in the literature. Employing data of 65 countries between 1965-2005, Bravo-Ortega and Marin (2011) utilized Granger causality test to investigate the nature of the relationship between R&D and TFP, with three measures of R&D – the level of R&D measured in constant purchasing power parity (PPP) dollars, R&D as a share of GDP, and R&D per capita in constant PPP dollars. While all three measures of R&D were positively correlated with increases in TFP, R&D per capita was found to be the most significant among the three measures with strong positive correlation with TFP. In addition, while controlling for confounding variables like openness to trade, terms of trade, financial market development, foreign direct investment and institutional variables, the authors still found R&D expenditure per capita as the most important productivity determinant of TFP. Using Vector Autoregression and cointegration analyses for the period between 1960-1991, Teixeira and Fortuna (2004) also estimated a long-run relationship between total factor productivity, human capital stock, internal innovation capability (indexed by the real accumulated expenditures on firms R&D), and

absorption capability within the Portuguese economy. Their results obtained 0.42 long-run estimate for human capital elasticity, 0.30 long-run estimate for internal knowledge elasticity, and 0.40 long-run estimate for the elasticity related with the composite variable that measures the interaction between human capital and innovation capability. This indicates that human capital stock is important in explaining the productivity and economic growth in the Portuguese economy. Finally, a number of studies have also stressed the role of technology transfer from innovation leader countries to innovation follower countries as an important and efficient driver of economic growth, especially for developing countries, including those in sub-Saharan Africa. Vogel (2012), in his paper examined the effects of R&D and human capital development on total factor productivity growth in the manufacturing sector of 159 regions of the European Union-15 (EU-15) countries from 1992 – 2005. He allowed R&D expenditure and human capital to both have a dual effect on transitional growth, which reflects an economy's independent innovation, and the imitation of frontier technology (i.e., advanced economies). His empirical results show that there is a direct and indirect effect of R&D activity on total factor productivity growth for the EU-15 regions through trade induced localized technology spillovers. He finds that, not only does trade integration facilitate innovation driven TFP improvement through technology transfer and FDIs, but also through efficiency improvements via greater product market competition, larger market size, and other forms of technology transfer through reverse engineering of imported goods. Vogel's (2012) findings are consistent with Paul Romer's (1992) study on the benefits of FDI and its favorable economic growth implications for developing economies. Using Mauritius as case study, Romer discovered Mauritius' historic economic growth in the early 1980s that was instigated by the textiles and apparel sector was achieved through technology transfer and diffusion from Hong Kong-based textiles and apparel firms. (Romer, p.103, 1992).

Specifically, Hong Kong-based textiles and apparel FDIs transferred new textiles and apparel manufacturing knowledge/ideas from Hong Kong to the Mauritian Export Processing Zones (MEPZ), after which the knowledge/ideas were subsequently spilled over beyond the MEPZ and the textiles and apparel industry into the larger economy. A similar study by Griffith, et. al, (2001) explored the roles of R&D activities and human capital in total factor productivity growth using a panel of 12 OECD countries between 1974-1990. He concluded that R&D and human capital play a critical role in productivity growth by not only raising the steady-state rate of TFP growth in the frontier, but also raises steady-state TFP growth in non-frontier countries. (Griffith, et. al, p.2-3, 2001). Griffith, et. al, (2001) just as Romer (1992) and Vogel (2012) distinguishes between R&D for the purposes of independently discovering new knowledge or invention, and R&D for the purposes of acquiring “tacit knowledge” so as to facilitate the efficient imitation of others’ discoveries— what they refer to as the “two faces of R&D”. (Griffith, et. al, p.32-33, 2001,). Tacit knowledge is simply the deliberate actions of a country’s R&D sector to engage in R&D in a particular and specific intellectual or technological field, so they can easily understand and assimilate the discoveries of others in that specific field. The authors allowed the size of quality improvements in intermediate goods that is induced by innovation in a follower country’s R&D sector to be a function of its distance to the innovation leader and introduced, as well as a role for the country’s independent research activity in facilitating technology transfer. According to Griffith, et al, R&D investment for the purposes of imitation is more impactful and significant for countries like those in sub-Saharan Africa that are farther behind the leaders of innovation. (Griffith, et. al, p. 22, 2001) Thus, sub-Saharan African countries that are farther behind the innovation frontier countries for instance will be better served if their R&D investment strategy is focused on amassing tacit knowledge in relevant sectors and fields of economic interests so

they can easily assimilate, transfer and diffuse innovation and technology in that specific field/sector from industrialized countries, rather than trying to compete with the industrialized countries in discovering such new knowledge.

SECTION 2

METHODOLOGY

Data Description

Panel data covering four sub-Saharan African countries over the period of 1981-2016 (Madagascar and Kenya) and 2001-2016 (Togo and Sierra Leone) are used for the study's empirical analysis. The variable of selection, countries of selection, and study period are all based on data availability and the need to sample over sufficiently large observations. Having an exhaustive dataset that truly encapsulates the national aggregate of AR&D expenditure over the study period would have been very much instrumental for the study's analysis. Unfortunately, there are no such dataset available for countries in the sub-continent. Instead, the only comprehensive dataset that is closest to a national aggregate of AR&D comes from the Agricultural Science and Technology Indicators (ASTI) database. The database has an extensive AR&D expenditure for sub-Saharan African countries, but only includes expenditure contributions from the government, higher education, non-profit, and foreign donors at the exclusion of private for-profit contributions. This creates challenges for a proper comparative analysis, especially within the context of the impact of AR&D expenditure on agricultural output. Particularly, a few African countries like Mauritius, South Africa, Senegal, Seychelles, and many others have a strong private for-profit agricultural R&D activity via routine investments by the countries' largest commercial exporting farms, and intermediate goods

producing firms within the agricultural sector. (Pray et al., p.175 & 186, 2016) Therefore, the reported national aggregate from ASTI may be an under-estimation of the actual national aggregate of AR&D investment. An analysis of the influence of agricultural R&D on agricultural output, when comparing those countries with other sub-Saharan African countries that do not have such level of strong private for-profit AR&D investments (including Ghana, Togo, Ivory Coast, Uganda etc.) can lead to erroneous conclusions. To remedy this methodological issue, the paper's choice of countries for analysis have been limited to countries with weak or very limited private for-profit AR&D investments. Not only does this guarantees consistency in comparison among the countries of analysis, but also ensures the ASTI dataset becomes a true representation of the national AR&D aggregate. In addition, there are also obvious exogenous factors that can significantly influence the level of agricultural output as supposed to agricultural R&D expenditure shocks. The main factors within the context of the agricultural sector include inputs like agricultural land, climate/environmental conditions, natural disasters (i.e., droughts, floods etc.), agricultural labor (i.e., farmers), and political/social stability. For instance, the magnitude of increases in agricultural output by one country over another could be due to a significant increase in its use of expansive agricultural land or total number of farmers, rather than solely due to agricultural R&D expenditure shock. Similarly, a country can suffer an agricultural output gap due to civil wars, unfavorable agricultural climate, and natural disasters in comparison to other countries that are relatively less plagued by these challenges. As a result, the choice of countries for analysis are further narrowed down to sub-Saharan countries with similar measurable conditions of these exogenous factors. To account for these exogenous factors in the selection of countries for analysis, certain international metrics and indexes were utilized. The World Development Indicator's (WDI) "Agricultural land (sq/km)" statistic was used for

agricultural land comparison, and the Food and Agriculture Organization’s (FAOSTAT) “labor ILO Estimates” was also used for the total number of agricultural labor comparison. The remaining factors including political/social stability, natural disasters and agricultural climate/environmental considerations were based on factual research and analysis from the World Bank’s Climate Change Knowledge Portal, the BTI Transformation Index and extensive literature review. (See appendix 6 for a brief description of the metrics). Controlling for these exogenous factors that have been highlighted thus far do not make the paper’s analysis perfect, but rather helps eradicate many potential factors that could undermine the study’s empirical analysis. Overall, two-country groups of two with comparable exogenous factors were finalized for our analysis. Each group has one country with positive AR&D expenditure shock and another country without AR&D shock. The groups include Group 1 – Togo (without AR&D shock) and Sierra Leone (with AR&D shock), and Group 2 – Madagascar (without AR&D shock) and Kenya (with AR&D shock). (See figures 4 & 5 and tables 3 & 4 for a brief description and comparison among the four countries)

Table 3: Brief Country Description (Group 1)

| GROUP 1 | |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Togo | <p>Political/Social Stability: Togo has been an autocratic regime since 1967 under the Eyadema family. Sergeant Etienne Gnassingbe Eyadema after his successful coup in 1967 to overthrow President Sylvanus Olympio ruled as a president until his death in 2005. His son, Faure Gnassingbe has ruled over the country since then. The country is authoritarian in nature with swift suppression of human rights, opposition and decent by the ruling government. However, the country has remained stable with the government’s stronghold of power without violent ethnic, social, political and religious conflict or confrontation. Although, recently, the Islamic violent extremism in the Sahel since 2014 have extended past the Sahel and has reached Togo’s Northern border with Burkina Faso, Togo’s mobilization of its military forces as well as defense coordination and cooperation with bordering states like Ghana and Benin has eradicated the influence of the extremist group in Togo or onslaught of any potential violent activity. Hence, no political/social violence or conflict have occurred in the country during the study period.</p> <p>Environment/Climate: Togo is prone to river floods, water scarcity and extreme heat with increasingly negative impact on the population. Togo currently occasionally faces high temperature and a decrease in rainfall. Periodic droughts occur in the north. The number heat waves have also become common across all regions of the country, with significant impacts on agriculture. The main climate risks to Togo include winds, coastal erosion, poor distribution of rain, and late rains, with flooding and droughts remaining the greatest threats.</p> <p>Sources: BTI Transformation Index The World Bank’s Climate Change Knowledge Portal</p> |

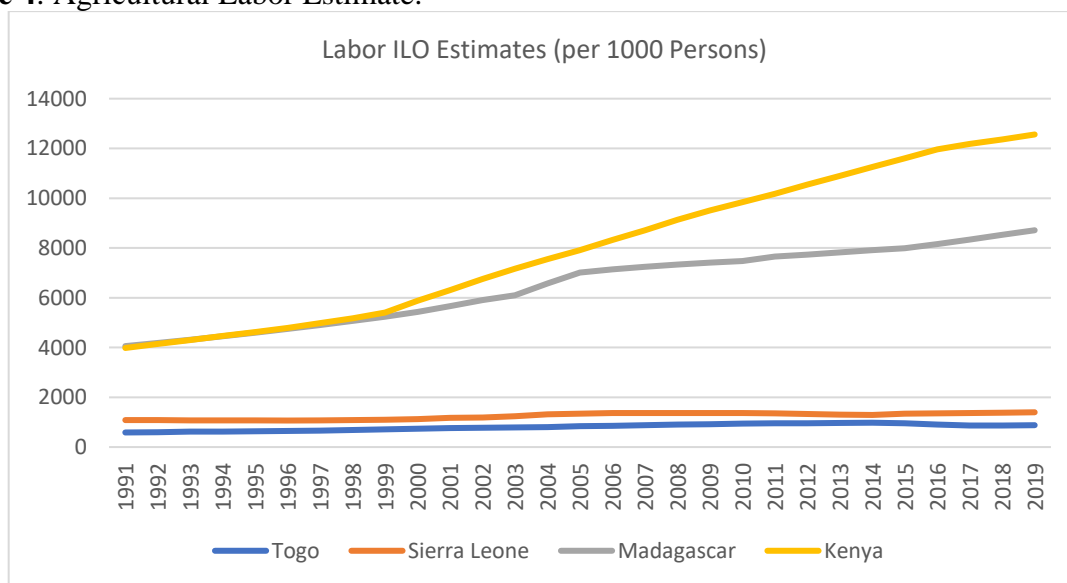
| | |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sierra Leone | <p>Political/Social Stability: Sierra Leone has made modest progress in postwar reconstruction. From the ashes of the civil war between 1991-2002, Sierra Leone with the support of the UN and a range of individual countries (UK in particular) has sought to stabilize the country. The legal framework and institutional arrangements are based on secular norms and principles. The constitution provides for the separation of state and religion. Political institutions and legal order as a result are not guided by religious dogmas. Sierra Leone is predominantly Muslim (estimated 80%) and the remaining Christians (approximately 20%), and miniscule section of the population that practice the traditional religions. The relations between adherents of the various religions are good, inter-religious violence is extremely rare, and organizations like the Inter-Religious Council of Sierra Leone (IRCSL) foster mutual respect and understanding. However, there have been reports of inter-religious tensions. For example, in early 2019, unrest erupted in Kambia District over perceived provocations between Muslims and Evangelical Christians, whose ceremonies involving loud music were held during Muslim prayer times. In a different incident, members of the Poro Secret Society attacked a Muslim community (to initiate young males by force) and a police station near Kenema – the third largest city in the country – to protest a new government ban on initiation rites. Universal suffrage has been in force since the 2002, and peaceful and successful general elections (free, fair and transparent) have been organized in 2002, 2007, 2012 and 2018. Local elections have also been peaceful and successful. Over time these elections have all strengthened Sierra Leone’s democratic process. However, there have been UN reports and international observers of the two dominant political parties exploiting and mobilizing electorates along ethnic divides during elections.</p> <p>Environment/Climate: The country has fertile agricultural land, and several rivers with significant irrigation potential to support the production of food. However, extreme changes in precipitation and temperature affects the country’s agricultural production due to the increasing risk of droughts, floods, and rising sea level.</p> <p>Sources: BTI Transformation Index The World Bank’s Climate Change Knowledge Portal</p> |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 4: Brief Country Description (Group 2)

| GROUP 2 | |
|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Madagascar | <p>Political/Social Stability: The 2001 elections gave rise to a conflict between acting President Ratsiraka and Marc Ravalomanana, the mayor of Antananarivo. After six months of social, political, and economic conflicts, Ravalomanana was recognized as the president of the Republic. Although he was re-elected in 2006, his domination of both the political and economic spheres led to conflict and political unrest. In 2009, President Ravalomanana relinquished control to a military directorate, who then gave the power to Andry Rajoelina. In July and December 2015, Rajaonarimampianina’s political party, the New Forces for Madagascar won a majority in the local and senate elections. Demonstrations against electoral laws occurred in April 2018. After both international and national mediation, and the establishment of a consensus government in June 2018, the presidential election took place in November 2018. Marc Ravalomanana accepted defeat and called on his supporters to stop demonstrations to promote solidarity and national reconciliation. Political polarization also remains salient, although, not ideological.</p> <p>Environment/Climate: Madagascar is very rich in biodiversity. However, climate change induced variable precipitation, intense cyclones and rising sea levels pose a risk for the country’s agricultural output. Agricultural stressors vary regionally with drought being significant issue in southern Madagascar, and flooding being significant concern in the eastern part of the island.</p> <p>Sources: BTI Transformation Index The World Bank’s Climate Change Knowledge Portal</p> |

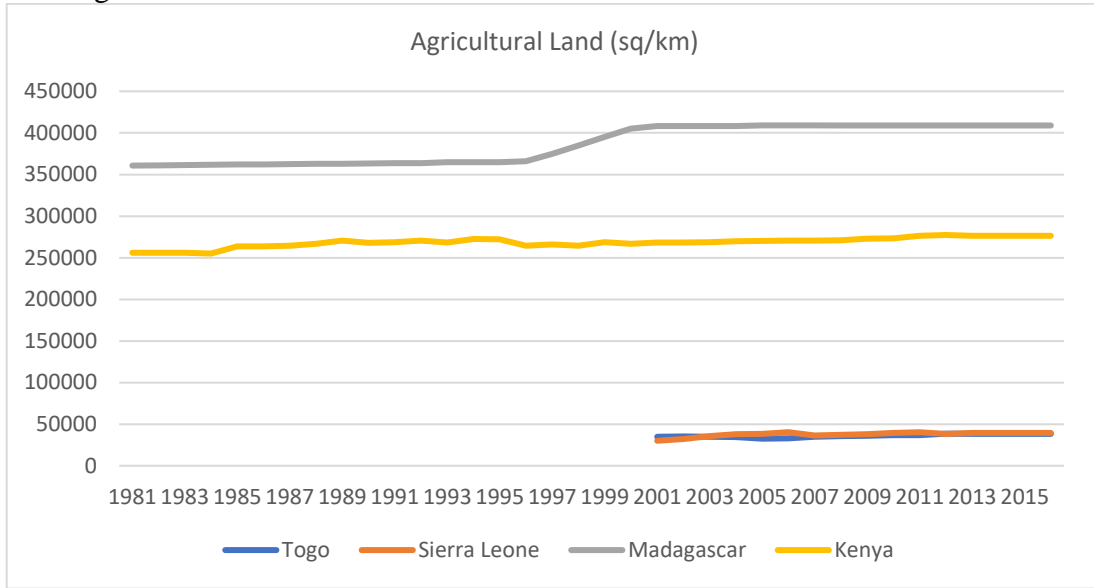
| | |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Kenya</p> | <p>Political/Social Stability: There has historically been political antagonism between the Kikuyu and the Luo ethnicities over the 1966 dismissal of Kenyatta’s Luo Vice President – Oginga Odinga. The tension was worsened by a discarded political memorandum of understanding between Mwai Kibaki and Raila Odinga (son of Oginga Odinga) in 2002. This broke up an attempted political alliance and a power sharing arrangement between the two rival ethnic groups. The resulting political squabbling within the government that brought President Moi’s long rule to an end culminated in a highly disputed election in 2007, arguably won by Raila Odinga. Incumbent president, Kibaki declared victory and swore himself in. This triggered violence on an unprecedented scale, leaving some 1300 people dead and nearly 700,000 displaced. Only an international diplomatic intervention, led by former UN Secretary general Kofi Annan, ended the crisis and oversaw the formation of a government of national unity, with Kibaki as president and Odinga as prime minister. The grand coalition (2008-2013) managed to complete the constitutional review process, and the progressive new constitution was ratified by a referendum and implemented. Political parties and coalitions continue to be temporary purpose vehicles, which from one election to the other serve the interest of strongmen, built around ethnic loyalties and patronage rather than platforms for wider interest articulation. Party politics are characterized by a high degree of polarization and volatility. Political parties have very weak ideological grounding, with party formations reflecting the ethno-regional alliances built by political leaders. Relations with other interest groups are limited and at best ad hoc. Parties do not aggregate interests that are expressed in social, cultural or economic terms. Instead, leaders use political parties and coalitions to channel and reengineer their individual and ethno-regional interests and rally the support of their ethnic communities.</p> <p>Environment/Climate: Extreme climatic events threaten agricultural production in Kenya. Change in precipitation patterns and temperature regimes, and extreme weather events affects agriculture. This leads to among other things, unsustainable agricultural water management. Precipitation in Kenya sometimes takes time to occur and when it does occur, the soils are too dry and loose to retain any of the moisture or nutrients. Approximately 85% of Kenya’s land area is classified as a fragile arid and semi-arid ecosystem, which is largely pastoral. The country’s highlands are relatively cool and agriculturally rich and are largely dominated by commercial and smallholder farms.</p> <p>Sources: BTI Transformation Index The World Bank’s Climate Change Knowledge Portal</p> |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Figure 4: Agricultural Labor Estimate:



Source: Chart generated by author from FAOSTAT – Labor ILO Estimates

Figure 5: Agricultural Land Estimate



Source: Chart generated by author from the World Development Indicators dataset, <https://data.worldbank.org/indicator/AG.LND.AGRI.K2?locations=GH-TG-SL-GM-MU-MG-ZW-GN>

Table 5 below highlights the main dataset (i.e., agricultural output) that is used for the paper’s T-Test analysis. The data comes from the United Nations’ Food and Agriculture Organization (FAO). The AR&D dataset on the other hand was taken from the Agricultural Science and Technology Indicators (ASTI). The original dataset for “agricultural output” for all four countries ranges from 1961-2018. However, to allow for the output level to reflect the presence or absence of positive AR&D shock, the paper’s datasets were limited to 2001-2016 for Group 1, and 1981-2016 for Group 2.

Table 5: T-Test Agricultural Output Datasets (Gross Production Value [Constant 2014-2016 thousand US\$])

| GROUP 1 | | | GROUP 2 | | |
|---------|-------------|--------------|---------|-------------|-------------|
| Year | Togo | Sierra Leone | Year | Madagascar | Kenya |
| 2001 | \$1,261,844 | \$916,492 | 1981 | \$2,620,674 | \$4,676,849 |
| 2002 | \$1,272,096 | \$1,075,121 | 1982 | \$2,620,311 | \$5,256,729 |
| 2003 | \$1,286,863 | \$1,807,323 | 1983 | \$2,682,963 | \$5,400,354 |
| 2004 | \$1,334,821 | \$1,984,212 | 1984 | \$2,777,938 | \$4,900,869 |
| 2005 | \$1,398,661 | \$1,805,868 | 1985 | \$2,842,269 | \$5,697,650 |
| 2006 | \$1,479,188 | \$2,207,102 | 1986 | \$2,958,192 | \$6,246,522 |
| 2007 | \$1,519,481 | \$2,022,589 | 1987 | \$2,881,271 | \$6,188,694 |
| 2008 | \$1,640,161 | \$2,159,182 | 1988 | \$2,983,068 | \$6,771,032 |

| | | | | | |
|------|-------------|-------------|------|-------------|--------------|
| 2009 | \$1,770,556 | \$2,757,400 | 1989 | \$3,073,195 | \$7,047,115 |
| 2010 | \$1,795,057 | \$3,130,246 | 1990 | \$3,070,243 | \$6,823,645 |
| 2011 | \$1,932,993 | \$3,327,801 | 1991 | \$3,112,145 | \$7,069,682 |
| 2012 | \$1,881,093 | \$3,427,495 | 1992 | \$3,113,226 | \$7,133,443 |
| 2013 | \$1,770,802 | \$3,614,290 | 1993 | \$3,227,036 | \$6,798,570 |
| 2014 | \$1,965,136 | \$3,656,402 | 1994 | \$3,180,594 | \$7,187,487 |
| 2015 | \$1,915,623 | \$3,585,060 | 1995 | \$3,253,063 | \$7,225,059 |
| 2016 | \$2,014,675 | \$3,345,007 | 1996 | \$3,310,261 | \$6,812,113 |
| | | | 1997 | \$3,368,756 | \$6,986,825 |
| | | | 1998 | \$3,324,301 | \$7,230,456 |
| | | | 1999 | \$3,372,630 | \$7,823,337 |
| | | | 2000 | \$3,319,777 | \$7,396,995 |
| | | | 2001 | \$3,270,499 | \$8,171,520 |
| | | | 2002 | \$3,216,218 | \$8,382,327 |
| | | | 2003 | \$3,288,670 | \$8,735,308 |
| | | | 2004 | \$3,397,380 | \$8,906,388 |
| | | | 2005 | \$3,756,924 | \$10,276,668 |
| | | | 2006 | \$3,852,919 | \$10,651,209 |
| | | | 2007 | \$3,907,452 | \$10,764,838 |
| | | | 2008 | \$4,043,155 | \$10,873,141 |
| | | | 2009 | \$4,275,992 | \$11,289,909 |
| | | | 2010 | \$4,365,012 | \$12,099,842 |
| | | | 2011 | \$4,385,354 | \$11,611,471 |
| | | | 2012 | \$4,539,742 | \$12,271,072 |
| | | | 2013 | \$4,277,324 | \$12,448,315 |
| | | | 2014 | \$4,372,824 | \$12,240,150 |
| | | | 2015 | \$4,346,493 | \$12,658,179 |
| | | | 2016 | \$4,424,230 | \$12,429,814 |

Table 6: Agricultural R&D (2011 Constant US Dollars)

| GROUP 1 | | | GROUP 2 | | |
|----------------|----------------|---------------------|----------------|-------------------|-----------------|
| Year | Togo | Sierra Leone | Year | Madagascar | Kenya |
| 2001 | \$6,365,302.75 | \$1,408,844.16 | 1981 | \$7,254,141.78 | \$63,293,733.34 |
| 2002 | \$6,326,341.32 | \$2,097,713.74 | 1982 | \$6,908,229.31 | \$66,271,055.29 |
| 2003 | \$5,207,202.88 | \$2,243,645.46 | 1983 | \$9,204,739.72 | \$68,509,201.31 |
| 2004 | \$4,999,599.48 | \$2,162,349.43 | 1984 | \$12,331,396.82 | \$68,160,566.57 |
| 2005 | \$6,083,486.17 | \$2,004,889.79 | 1985 | \$7,344,984.33 | \$65,140,499.20 |
| 2006 | \$5,293,884.30 | \$2,547,067.25 | 1986 | \$7,603,485.34 | \$66,572,347.36 |
| 2007 | \$5,000,951.96 | \$2,319,631.25 | 1987 | \$8,977,296.65 | \$80,014,040.12 |

| | | | | | |
|-------------|----------------|----------------|-------------|-----------------|------------------|
| 2008 | \$5,458,910.42 | \$3,216,360.58 | 1988 | \$7,118,213.82 | \$84,738,936.33 |
| 2009 | \$2,707,573.94 | \$3,597,847.15 | 1989 | \$11,017,235.72 | \$88,044,265.52 |
| 2010 | \$4,479,979.66 | \$3,533,516.85 | 1990 | \$11,107,462.78 | \$91,123,742.37 |
| 2011 | \$4,564,426.66 | \$3,416,385.45 | 1991 | \$8,871,885.40 | \$99,390,163.43 |
| 2012 | \$2,957,112.34 | \$3,435,413.93 | 1992 | \$10,245,761.49 | \$95,219,619.72 |
| 2013 | \$2,627,328.91 | \$5,378,427.25 | 1993 | \$9,422,880.16 | \$110,582,297.80 |
| 2014 | \$3,131,159.20 | \$5,255,998.31 | 1994 | \$8,330,581.06 | \$159,392,450.23 |
| 2015 | \$3,922,550.48 | \$4,587,530.40 | 1995 | \$7,159,704.21 | \$128,127,628.10 |
| 2016 | \$3,948,948.22 | \$4,633,390.96 | 1996 | \$6,318,623.28 | \$119,426,750.16 |
| | | | 1997 | \$13,852,356.22 | \$88,268,173.59 |
| | | | 1998 | \$6,027,981.00 | \$84,400,376.56 |
| | | | 1999 | \$4,750,325.49 | \$99,416,282.61 |
| | | | 2000 | \$4,427,612.93 | \$98,106,099.84 |
| | | | 2001 | \$4,606,235.40 | \$104,675,216.99 |
| | | | 2002 | \$3,639,938.23 | \$85,907,984.50 |
| | | | 2003 | \$4,572,384.79 | \$80,588,083.18 |
| | | | 2004 | \$4,841,747.53 | \$77,258,034.61 |
| | | | 2005 | \$4,802,490.61 | \$86,496,182.71 |
| | | | 2006 | \$4,442,674.61 | \$95,003,642.24 |
| | | | 2007 | \$4,266,566.10 | \$92,087,012.98 |
| | | | 2008 | \$4,701,358.89 | \$89,913,852.70 |
| | | | 2009 | \$3,769,422.70 | \$89,674,283.04 |
| | | | 2010 | \$2,835,092.77 | \$90,339,196.05 |
| | | | 2011 | \$2,757,641.65 | \$94,769,110.84 |
| | | | 2012 | \$3,054,756.07 | \$97,269,214.87 |
| | | | 2013 | \$3,325,495.87 | \$100,178,853.98 |
| | | | 2014 | \$3,399,956.42 | \$104,235,360.98 |
| | | | 2015 | \$3,375,329.34 | \$95,218,495.12 |
| | | | 2016 | \$3,447,028.04 | \$85,895,355.85 |

Methodological Operations

Checking for Data Normality

In order to conduct the Two Sample Independent T-Test for the case studies, a few methodological operations are required to validate the datasets, and confirm their fit for the paper's statistical analysis. First among these tasks is to verify that the datasets are "normally distributed". This is because the T-Test statistical model assumes the data of analysis are

normally distributed. The “Kolmogorov-Smirnov Test for Normality (K-S Test) with Lilliefors Significance Correction” is used to test whether the datasets fulfil the normality requirement or not. The K-S Test is simply based on the maximum vertical difference between the Empirical Distribution Function (EDF) and the normal cumulative distribution curve. The test function is given as:

$$D_{max} = \max_{1 \leq i \leq N} \left[F(Y_i) - \frac{i-1}{N}, \frac{i}{N} - F(Y_i) \right]$$

Whereby D_{max} is the K-S statistic,

F is the theoretical cumulative distribution of the distribution being tested.

The acceptance or rejection of the null hypothesis for the test at an $\alpha = 0.05$ is given as follow:

H_0 : The data comes from a normal distribution.

H_1 : The data does not come from a normal distribution.

We fail to reject the null hypothesis if the D_{max} falls within the acceptance region (i.e., $D_{max} \leq K - S \text{ Critical value}$). On the other hand, the null hypothesis is rejected if the D_{max} falls

outside the acceptance region (i.e., $D_{max} > K - S \text{ Critical value}$). Tables 7, 8,9 & 10 highlights the calculations for the D_{max} value for all four countries’ datasets.

Table 7: Madagascar K-S Test Results

| Madagascar | Cumulative | Expected | (Rank-1)/n | NORM.S.INV | Actual | Difference |
|----------------|------------|------------|------------|------------|------------|------------|
| \$2,620,311.00 | 1 | 0.02777778 | 0 | -1.9145058 | 0.07495117 | 0.07495117 |
| \$2,620,674.00 | 2 | 0.05555556 | 0.02777778 | -1.5932188 | 0.07503855 | 0.04726077 |
| \$2,682,963.00 | 3 | 0.08333333 | 0.05555556 | -1.3829941 | 0.09121159 | 0.03565603 |
| \$2,777,938.00 | 4 | 0.11111111 | 0.08333333 | -1.2206403 | 0.12063518 | 0.03730184 |
| \$2,842,269.00 | 5 | 0.13888889 | 0.11111111 | -1.0853249 | 0.14402327 | 0.03291216 |
| \$2,881,271.00 | 6 | 0.16666667 | 0.13888889 | -0.9674216 | 0.15960314 | 0.02071425 |
| \$2,958,192.00 | 7 | 0.19444444 | 0.16666667 | -0.8616341 | 0.19344281 | 0.02677614 |
| \$2,983,068.00 | 8 | 0.22222222 | 0.19444444 | -0.7647097 | 0.20526105 | 0.0108166 |
| \$3,070,243.00 | 9 | 0.25 | 0.22222222 | -0.6744898 | 0.24992487 | 0.02770265 |
| \$3,073,195.00 | 10 | 0.27777778 | 0.25 | -0.5894558 | 0.2515226 | 0.0015226 |
| \$3,112,145.00 | 11 | 0.30555556 | 0.27777778 | -0.5084881 | 0.27309869 | 0.00467908 |

| | | | | | | |
|----------------|----|------------|------------|------------|------------|------------|
| \$3,113,226.00 | 12 | 0.33333333 | 0.30555556 | -0.4307273 | 0.27371034 | 0.03184522 |
| \$3,180,594.00 | 13 | 0.36111111 | 0.33333333 | -0.3554904 | 0.3131064 | 0.02022693 |
| \$3,216,218.00 | 14 | 0.38888889 | 0.36111111 | -0.2822161 | 0.33487819 | 0.02623293 |
| \$3,227,036.00 | 15 | 0.41666667 | 0.38888889 | -0.2104284 | 0.34160549 | 0.0472834 |
| \$3,253,063.00 | 16 | 0.44444444 | 0.41666667 | -0.1397103 | 0.35799467 | 0.05867199 |
| \$3,270,499.00 | 17 | 0.47222222 | 0.44444444 | -0.0696849 | 0.36912465 | 0.07531979 |
| \$3,288,670.00 | 18 | 0.5 | 0.47222222 | 0 | 0.38084161 | 0.09138062 |
| \$3,310,261.00 | 19 | 0.52777778 | 0.5 | 0.06968492 | 0.3949064 | 0.1050936 |
| \$3,319,777.00 | 20 | 0.55555556 | 0.52777778 | 0.1397103 | 0.40115027 | 0.12662751 |
| \$3,324,301.00 | 21 | 0.58333333 | 0.55555556 | 0.21042839 | 0.40412765 | 0.1514279 |
| \$3,368,756.00 | 22 | 0.61111111 | 0.58333333 | 0.28221615 | 0.43365448 | 0.14967885 |
| \$3,372,630.00 | 23 | 0.63888889 | 0.61111111 | 0.35549042 | 0.43624773 | 0.17486338 |
| \$3,397,380.00 | 24 | 0.66666667 | 0.63888889 | 0.4307273 | 0.45287539 | 0.18601349 |
| \$3,756,924.00 | 25 | 0.69444444 | 0.66666667 | 0.50848806 | 0.68900692 | 0.02234025 |
| \$3,852,919.00 | 26 | 0.72222222 | 0.69444444 | 0.5894558 | 0.74417982 | 0.04973537 |
| \$3,907,452.00 | 27 | 0.75 | 0.72222222 | 0.67448975 | 0.77307862 | 0.0508564 |
| \$4,043,155.00 | 28 | 0.77777778 | 0.75 | 0.76470967 | 0.83640739 | 0.08640739 |
| \$4,275,992.00 | 29 | 0.80555556 | 0.77777778 | 0.86163412 | 0.91555199 | 0.13777422 |
| \$4,277,324.00 | 30 | 0.83333333 | 0.80555556 | 0.96742157 | 0.91590221 | 0.11034666 |
| \$4,346,493.00 | 31 | 0.86111111 | 0.83333333 | 1.08532491 | 0.93262797 | 0.09929464 |
| \$4,365,012.00 | 32 | 0.88888889 | 0.86111111 | 1.22064035 | 0.9366377 | 0.07552658 |
| \$4,372,824.00 | 33 | 0.91666667 | 0.88888889 | 1.38299413 | 0.93827239 | 0.0493835 |
| \$4,385,354.00 | 34 | 0.94444444 | 0.91666667 | 1.59321882 | 0.94082535 | 0.02415869 |
| \$4,424,230.00 | 35 | 0.97222222 | 0.94444444 | 1.91450583 | 0.94822187 | 0.00377742 |
| \$4,539,742.00 | 36 | 1 | 0.97222222 | | 0.96594593 | 0.00627629 |

Table 8: Kenya K-S Test Results

| Kenya | Cumulative | Expected | (Rank-1)/n | NORM.S.INV | Actual | Difference |
|-------------|------------|------------|------------|--------------|------------|------------|
| \$4,676,849 | 1 | 0.02777778 | 0 | -1.914505825 | 0.06499144 | 0.06499144 |
| \$4,900,869 | 2 | 0.05555556 | 0.02777778 | -1.593218818 | 0.07715708 | 0.04937931 |
| \$5,256,729 | 3 | 0.08333333 | 0.05555556 | -1.382994127 | 0.09993049 | 0.04437494 |
| \$5,400,354 | 4 | 0.11111111 | 0.08333333 | -1.220640349 | 0.11039485 | 0.02706152 |
| \$5,697,650 | 5 | 0.13888889 | 0.11111111 | -1.085324908 | 0.13449872 | 0.0233876 |
| \$6,188,694 | 6 | 0.16666667 | 0.13888889 | -0.967421566 | 0.18174676 | 0.04285787 |
| \$6,246,522 | 7 | 0.19444444 | 0.16666667 | -0.86163412 | 0.18792456 | 0.0212579 |
| \$6,771,032 | 8 | 0.22222222 | 0.19444444 | -0.764709674 | 0.24967196 | 0.05522752 |
| \$6,798,570 | 9 | 0.25 | 0.22222222 | -0.67448975 | 0.25318696 | 0.03096474 |
| \$6,812,113 | 10 | 0.27777778 | 0.25 | -0.589455798 | 0.25492512 | 0.00492512 |
| \$6,823,645 | 11 | 0.30555556 | 0.27777778 | -0.508488059 | 0.25641008 | 0.0213677 |

| | | | | | | |
|--------------|----|------------|------------|--------------|------------|------------|
| \$6,986,825 | 12 | 0.33333333 | 0.30555556 | -0.430727299 | 0.27789546 | 0.02766009 |
| \$7,047,115 | 13 | 0.36111111 | 0.33333333 | -0.355490418 | 0.2860502 | 0.04728313 |
| \$7,069,682 | 14 | 0.38888889 | 0.36111111 | -0.282216147 | 0.28913156 | 0.07197955 |
| \$7,133,443 | 15 | 0.41666667 | 0.38888889 | -0.210428394 | 0.29792095 | 0.09096793 |
| \$7,187,487 | 16 | 0.44444444 | 0.41666667 | -0.139710299 | 0.30546487 | 0.1112018 |
| \$7,225,059 | 17 | 0.47222222 | 0.44444444 | -0.06968492 | 0.31075886 | 0.13368559 |
| \$7,230,456 | 18 | 0.5 | 0.47222222 | 0 | 0.31152257 | 0.16069965 |
| \$7,396,995 | 19 | 0.52777778 | 0.5 | 0.06968492 | 0.33547442 | 0.16452558 |
| \$7,823,337 | 20 | 0.55555556 | 0.52777778 | 0.139710299 | 0.39970486 | 0.12807292 |
| \$8,171,520 | 21 | 0.58333333 | 0.55555556 | 0.210428394 | 0.45435097 | 0.10120459 |
| \$8,382,327 | 22 | 0.61111111 | 0.58333333 | 0.282216147 | 0.48793177 | 0.09540156 |
| \$8,735,308 | 23 | 0.63888889 | 0.61111111 | 0.355490418 | 0.54423201 | 0.0668791 |
| \$8,906,388 | 24 | 0.66666667 | 0.63888889 | 0.430727299 | 0.57127176 | 0.06761713 |
| \$10,276,668 | 25 | 0.69444444 | 0.66666667 | 0.508488059 | 0.76680401 | 0.10013734 |
| \$10,651,209 | 26 | 0.72222222 | 0.69444444 | 0.589455798 | 0.8101238 | 0.11567936 |
| \$10,764,838 | 27 | 0.75 | 0.72222222 | 0.67448975 | 0.82221962 | 0.0999974 |
| \$10,873,141 | 28 | 0.77777778 | 0.75 | 0.764709674 | 0.83328512 | 0.08328512 |
| \$11,289,909 | 29 | 0.80555556 | 0.77777778 | 0.86163412 | 0.8716299 | 0.09385213 |
| \$11,611,471 | 30 | 0.83333333 | 0.80555556 | 0.967421566 | 0.89668814 | 0.09113259 |
| \$12,099,842 | 31 | 0.86111111 | 0.83333333 | 1.085324908 | 0.92764577 | 0.09431244 |
| \$12,240,150 | 32 | 0.88888889 | 0.86111111 | 1.220640349 | 0.93507173 | 0.07396062 |
| \$12,271,072 | 33 | 0.91666667 | 0.88888889 | 1.382994127 | 0.93662584 | 0.04773695 |
| \$12,429,814 | 34 | 0.94444444 | 0.91666667 | 1.593218818 | 0.94415262 | 0.02748596 |
| \$12,448,315 | 35 | 0.97222222 | 0.94444444 | 1.914505825 | 0.94498192 | 0.00053747 |
| \$12,658,179 | 36 | 1 | 0.97222222 | | 0.95372274 | 0.01849949 |

Table 9: Togo K-S Test Results

| Togo | Cumulative | Expected | (Rank-1)/n | NORM.S.IN V | Actual | Difference |
|-------------|------------|----------|------------|----------------|-------------|-------------|
| \$1,261,844 | 1 | 0.0625 | 0 | -1.5341205 | 0.083137 | 0.083137 |
| \$1,272,096 | 2 | 0.125 | 0.0625 | -1.1503494 | 0.089031741 | 0.026531741 |
| \$1,286,863 | 3 | 0.1875 | 0.125 | -0.8871466 | 0.098061386 | 0.026938614 |
| \$1,334,821 | 4 | 0.25 | 0.1875 | -0.6744898 | 0.131976919 | 0.055523081 |
| \$1,398,661 | 5 | 0.3125 | 0.25 | -0.4887764 | 0.188519378 | 0.061480622 |
| \$1,479,188 | 6 | 0.375 | 0.3125 | -0.3186394 | 0.278084066 | 0.034415934 |
| \$1,519,481 | 7 | 0.4375 | 0.375 | -0.1573107 | 0.329598131 | 0.045401869 |
| \$1,640,161 | 8 | 0.5 | 0.4375 | 0 | 0.500321879 | 0.062821879 |
| \$1,770,556 | 9 | 0.5625 | 0.5 | 0.15731068 | 0.683747862 | 0.183747862 |
| \$1,770,802 | 10 | 0.625 | 0.5625 | 0.31863936 | 0.684068278 | 0.121568278 |

| | | | | | | |
|-------------|----|--------|--------|------------|-------------|-------------|
| \$1,795,057 | 11 | 0.6875 | 0.625 | 0.48877641 | 0.714951062 | 0.089951062 |
| \$1,881,093 | 12 | 0.75 | 0.6875 | 0.67448975 | 0.811354779 | 0.123854779 |
| \$1,915,623 | 13 | 0.8125 | 0.75 | 0.88714656 | 0.843589388 | 0.093589388 |
| \$1,932,993 | 14 | 0.875 | 0.8125 | 1.15034938 | 0.858345248 | 0.045845248 |
| \$1,965,136 | 15 | 0.9375 | 0.875 | 1.53412054 | 0.883093775 | 0.008093775 |
| \$2,014,675 | 16 | 1 | 0.9375 | | 0.914963005 | 0.022536995 |

Table 10: Sierra Leone K-S Test Results

| Sierra Leone (\$1000) | Cumulative | Expected | (Rank-1)/n | NORM.S.INV | Actual | Difference |
|-----------------------|------------|----------|------------|------------|------------|------------|
| \$916,492 | 1 | 0.0625 | 0 | -1.5341205 | 0.03741638 | 0.03741638 |
| \$1,075,121 | 2 | 0.125 | 0.0625 | -1.1503494 | 0.05384847 | 0.00865153 |
| \$1,805,868 | 3 | 0.1875 | 0.125 | -0.8871466 | 0.20829722 | 0.08329722 |
| \$1,807,323 | 4 | 0.25 | 0.1875 | -0.6744898 | 0.20875227 | 0.02125227 |
| \$1,984,212 | 5 | 0.3125 | 0.25 | -0.4887764 | 0.26828635 | 0.01828635 |
| \$2,022,589 | 6 | 0.375 | 0.3125 | -0.3186394 | 0.28224508 | 0.03025492 |
| \$2,159,182 | 7 | 0.4375 | 0.375 | -0.1573107 | 0.33456552 | 0.04043448 |
| \$2,207,102 | 8 | 0.5 | 0.4375 | 0 | 0.35378451 | 0.08371549 |
| \$2,757,400 | 9 | 0.5625 | 0.5 | 0.15731068 | 0.58882806 | 0.08882806 |
| \$3,130,246 | 10 | 0.625 | 0.5625 | 0.31863936 | 0.73592022 | 0.17342022 |
| \$3,327,801 | 11 | 0.6875 | 0.625 | 0.48877641 | 0.8012492 | 0.1762492 |
| \$3,345,007 | 12 | 0.75 | 0.6875 | 0.67448975 | 0.80643694 | 0.11893694 |
| \$3,427,495 | 13 | 0.8125 | 0.75 | 0.88714656 | 0.83014218 | 0.08014218 |
| \$3,585,060 | 14 | 0.875 | 0.8125 | 1.15034938 | 0.87000701 | 0.05750701 |
| \$3,614,290 | 15 | 0.9375 | 0.875 | 1.53412054 | 0.87662427 | 0.00162427 |
| \$3,656,402 | 16 | 1 | 0.9375 | | 0.88573708 | 0.05176292 |

Whereby,

“Cumulative” is the number of observations,

“Expected” is the Expected Cumulative Distribution Function,

“(Rank-1)/n” is the inverse of the standard normal cumulative distribution,

“Actual” is the actual cumulative distribution function,

“Difference” is the absolute value of the difference between the “Actual” and the inverse of the normal cumulative distribution (Rank-1/n)

The K-S stat (D_{max}) value is simply the largest value in the “Difference” column.

In order to accept or reject the null hypothesis, we need to test the calculated K-S stat (D_{max}) against the K-S Critical value, which can be obtained from the K-S distribution table and is based on the sample size of the dataset and the significance level. (See appendix 7 for the K-S Distribution table). The relevant values needed to test the null hypothesis are all included in Table 11. As can be observed in Table 11, the K-S stat for Group 1 datasets – Togo (0.184) and Sierra Leone (0.176) – all falls within the K-S critical region of 0.327 at a sample size of 16 and alpha level of 0.05. As a result, we fail to reject the null hypothesis of Togo and Sierra Leone. In other words, we accept the null hypothesis that Togo and Sierra Leone’s datasets are normally distributed. Similar to Group 1, the K-S Stat for Group 2 datasets – Kenya (0.165) and Madagascar’s (0.186) all falls within the K-S Critical region of 0.221 at a sample size of 36 and alpha level of 0.05. As a result, we fail to reject the null hypothesis that the individual datasets of Kenya and Madagascar are normally distributed. Having established the normality of the datasets, we can proceed with a parametric test like the Two Sample Independent T-Test for our empirical analysis.

Table 11: K-S Test Descriptive Statistics

| GROUP 1 K-S Summary: K-S Critical Value=0.327 ($\alpha = 0.05, n = 16$) | | | |
|---------------------------------------------------------------------------------------------|--------------------|---------------------|--------------------|
| TOGO | | SIERRA LEONE | |
| Observations | 16 | Observations | 16 |
| Mean | \$1,639,940.625 | Mean | \$2,551,349.375 |
| Stdv | 273136.7592 | Stdv | 917692.0698 |
| Maximum Difference | 0.183747862 | Maximum Difference | 0.176249199 |
| GROUP 2 K-S Summary: (K-S Critical Value=0.221 ($\alpha = 0.05, n = 36$)) | | | |
| KENYA | | MADAGASCAR | |
| Count | 36 | Count | 36 |
| Mean | 8457877.14 | Mean | \$3,467,002.81 |
| SD | 2497097.24 | SD | 588030.8463 |
| Maximum Difference | 0.16452558 | Maximum Difference | 0.186013495 |

Checking for Equal or Unequal Variance

In addition to determining the “normality” of the datasets, the final step before conducting the T-Test is to determine whether the countries in each group have equal or unequal variance. This step is very important to help determine which variation of the Degree of Freedom formulas (i.e., one that assumes “Equal Variance” or the alternative that assumes “Unequal Variance”) to use in the T-Test. F-Test is utilized to test whether the two datasets in each group have equal or unequal variance. The hypothesis testing for the F-Test is given as follows:

$$H_0: S_1^2 = S_2^2 \text{ (Equal Variance)}$$

$$H_1: S_1^2 \neq S_2^2 \text{ (Unequal Variance)}$$

The null hypothesis that the variance among the countries in each group is equal is rejected if the F-calculated value falls outside the F-Test critical region (i.e., $F - Calc > F - Critical\ value$).

The $F - Critical$ value can be obtained from the F-Distribution table at an alpha of 0.05 and a specific Degree of Freedom value ($n-1$). In contrast, if the F-calculated value falls within the F-Test critical region (i.e., $F - Calc \leq F - Critical\ value$), then we fail to reject the null hypothesis. (See appendix 8 and 9 for the F-Distribution table).

The F-Stat is given as:

$$F - Stat = \frac{S_1^2 \text{ (Larger Variance)}}{S_2^2 \text{ (Smaller Variance)}}$$

And the formula for Variance is given as:

$$S^2 = \frac{\sum(x_i - \bar{x})^2}{n - 1}$$

Whereby,

S^2 is the Sample Variance

x_i is the value of one observation in a dataset

\bar{x} is the mean (average) value of all observations within the dataset (i.e., country)

n is the number of observations.

Tables 12 and 13 below highlight the calculations for the values that are needed to calculate the variance of each country within the two groups.

Table 12: Variance Calculation Values (Group 1)

| Year | Togo (as X) | Sierra Leone (as Y) | X-X Mean | Y-Y mean | (X-X Mean) ^2 | (Y-Y mean) ^2 |
|------|-------------|---------------------|------------|--------------|------------------------|-------------------------|
| 2001 | \$1,261,844 | \$916,492 | -\$378,097 | -\$1,634,857 | \$142,957,057,836.39 | \$2,672,758,636,591.89 |
| 2002 | \$1,272,096 | \$1,075,121 | -\$367,845 | -\$1,476,228 | \$135,309,668,141.39 | \$2,179,250,215,155.14 |
| 2003 | \$1,286,863 | \$1,807,323 | -\$353,078 | -\$744,026 | \$124,663,809,275.64 | \$553,575,246,695.64 |
| 2004 | \$1,334,821 | \$1,984,212 | -\$305,120 | -\$567,137 | \$93,097,985,560.14 | \$321,644,802,121.89 |
| 2005 | \$1,398,661 | \$1,805,868 | -\$241,280 | -\$745,481 | \$58,215,857,440.14 | \$555,742,480,471.89 |
| 2006 | \$1,479,188 | \$2,207,102 | -\$160,753 | -\$344,247 | \$25,841,406,444.39 | \$118,506,255,194.39 |
| 2007 | \$1,519,481 | \$2,022,589 | -\$120,460 | -\$528,760 | \$14,510,521,255.14 | \$279,587,534,170.14 |
| 2008 | \$1,640,161 | \$2,159,182 | \$220 | -\$392,167 | \$48,565.14 | \$153,795,250,014.39 |
| 2009 | \$1,770,556 | \$2,757,400 | \$130,615 | \$206,051 | \$17,060,376,186.39 | \$42,456,860,062.89 |
| 2010 | \$1,795,057 | \$3,130,246 | \$155,116 | \$578,897 | \$24,061,089,793.14 | \$335,121,302,436.39 |
| 2011 | \$1,932,993 | \$3,327,801 | \$293,052 | \$776,452 | \$85,879,694,493.14 | \$602,877,125,965.14 |
| 2012 | \$1,881,093 | \$3,427,495 | \$241,152 | \$876,146 | \$58,154,467,968.14 | \$767,631,156,206.64 |
| 2013 | \$1,770,802 | \$3,614,290 | \$130,861 | \$1,062,941 | \$17,124,699,466.89 | \$1,129,842,772,275.39 |
| 2014 | \$1,965,136 | \$3,656,402 | \$325,195 | \$1,105,053 | \$105,752,031,921.39 | \$1,221,141,304,019.39 |
| 2015 | \$1,915,623 | \$3,585,060 | \$275,682 | \$1,033,711 | \$76,000,771,885.64 | \$1,068,557,656,237.89 |
| 2016 | \$2,014,675 | \$3,345,007 | \$374,734 | \$793,658 | \$140,425,851,806.64 | \$629,892,425,720.64 |
| | | | SUM | | \$1,119,055,338,039.75 | \$12,632,381,023,339.70 |

Table 13: Variance Calculation Values (Group 2)

| Year | Madagascar (as x) | Kenya (as y) | X-X Mean | Y-Y mean | (X-X Mean) ^2 | (Y-Y mean) ^2 |
|------|-------------------|--------------|------------|--------------|----------------------|-------------------------|
| 1981 | \$2,620,674 | \$4,676,849 | -\$846,329 | -\$3,781,028 | \$716,272,447,113.09 | \$14,296,173,787,069.60 |
| 1982 | \$2,620,311 | \$5,256,729 | -\$846,692 | -\$3,201,148 | \$716,887,013,594.93 | \$10,247,349,407,111.80 |
| 1983 | \$2,682,963 | \$5,400,354 | -\$784,040 | -\$3,057,523 | \$614,718,416,695.59 | \$9,348,447,744,840.96 |
| 1984 | \$2,777,938 | \$4,900,869 | -\$689,065 | -\$3,557,008 | \$474,810,306,255.32 | \$12,652,306,900,121.80 |
| 1985 | \$2,842,269 | \$5,697,650 | -\$624,734 | -\$2,760,227 | \$390,292,327,803.93 | \$7,618,853,858,258.74 |
| 1986 | \$2,958,192 | \$6,246,522 | -\$508,811 | -\$2,211,355 | \$258,888,435,850.09 | \$4,890,091,550,290.29 |
| 1987 | \$2,881,271 | \$6,188,694 | -\$585,732 | -\$2,269,183 | \$343,081,748,039.37 | \$5,149,192,117,817.63 |
| 1988 | \$2,983,068 | \$6,771,032 | -\$483,935 | -\$1,686,845 | \$234,192,896,028.09 | \$2,845,446,522,593.07 |
| 1989 | \$3,073,195 | \$7,047,115 | -\$393,808 | -\$1,410,762 | \$155,084,587,716.48 | \$1,990,249,812,522.35 |

| | | | | | | |
|------|-------------|--------------|-------------|--------------|--------------------------------|---------------------------------|
| 1990 | \$3,070,243 | \$6,823,645 | -\$396,760 | -\$1,634,232 | \$157,418,343,304.48 | \$2,670,714,683,777.35 |
| 1991 | \$3,112,145 | \$7,069,682 | -\$354,858 | -\$1,388,195 | \$125,924,062,163.70 | \$1,927,085,743,634.74 |
| 1992 | \$3,113,226 | \$7,133,443 | -\$353,777 | -\$1,324,434 | \$125,158,028,149.09 | \$1,754,125,788,254.35 |
| 1993 | \$3,227,036 | \$6,798,570 | -\$239,967 | -\$1,659,307 | \$57,584,067,768.54 | \$2,753,300,181,167.63 |
| 1994 | \$3,180,594 | \$7,187,487 | -\$286,409 | -\$1,270,390 | \$82,030,003,899.76 | \$1,613,891,104,986.13 |
| 1995 | \$3,253,063 | \$7,225,059 | -\$213,940 | -\$1,232,818 | \$45,770,240,401.15 | \$1,519,840,563,573.46 |
| 1996 | \$3,310,261 | \$6,812,113 | -\$156,742 | -\$1,645,764 | \$24,567,993,608.82 | \$2,708,539,600,852.68 |
| 1997 | \$3,368,756 | \$6,986,825 | -\$98,247 | -\$1,471,052 | \$9,652,434,801.87 | \$2,163,994,395,329.57 |
| 1998 | \$3,324,301 | \$7,230,456 | -\$142,702 | -\$1,227,421 | \$20,363,805,308.82 | \$1,506,562,652,191.29 |
| 1999 | \$3,372,630 | \$7,823,337 | -\$94,373 | -\$634,540 | \$8,906,226,428.43 | \$402,641,187,861.13 |
| 2000 | \$3,319,777 | \$7,396,995 | -\$147,226 | -\$1,060,882 | \$21,675,437,821.48 | \$1,125,470,912,613.46 |
| 2001 | \$3,270,499 | \$8,171,520 | -\$196,504 | -\$286,357 | \$38,613,745,597.82 | \$82,000,410,992.63 |
| 2002 | \$3,216,218 | \$8,382,327 | -\$250,785 | -\$75,550 | \$62,893,018,697.54 | \$5,707,823,486.13 |
| 2003 | \$3,288,670 | \$8,735,308 | -\$178,333 | \$277,431 | \$31,802,589,537.32 | \$76,967,882,696.85 |
| 2004 | \$3,397,380 | \$8,906,388 | -\$69,623 | \$448,511 | \$4,847,335,053.43 | \$201,161,992,534.63 |
| 2005 | \$3,756,924 | \$10,276,668 | \$289,921 | \$1,818,791 | \$84,054,298,988.09 | \$3,308,000,196,461.30 |
| 2006 | \$3,852,919 | \$10,651,209 | \$385,916 | \$2,193,332 | \$148,931,309,134.48 | \$4,810,704,652,965.13 |
| 2007 | \$3,907,452 | \$10,764,838 | \$440,449 | \$2,306,961 | \$193,995,492,886.76 | \$5,322,068,414,698.52 |
| 2008 | \$4,043,155 | \$10,873,141 | \$576,152 | \$2,415,264 | \$331,951,351,163.15 | \$5,833,499,518,789.36 |
| 2009 | \$4,275,992 | \$11,289,909 | \$808,989 | \$2,832,032 | \$654,463,516,727.87 | \$8,020,404,462,348.47 |
| 2010 | \$4,365,012 | \$12,099,842 | \$898,009 | \$3,641,965 | \$806,420,513,306.76 | \$13,263,908,049,568.10 |
| 2011 | \$4,385,354 | \$11,611,471 | \$918,351 | \$3,153,594 | \$843,368,916,337.54 | \$9,945,154,240,837.69 |
| 2012 | \$4,539,742 | \$12,271,072 | \$1,072,739 | \$3,813,195 | \$1,150,769,379,297.32 | \$14,540,455,048,804.20 |
| 2013 | \$4,277,324 | \$12,448,315 | \$810,321 | \$3,990,438 | \$656,620,438,165.87 | \$15,923,594,323,389.00 |
| 2014 | \$4,372,824 | \$12,240,150 | \$905,821 | \$3,782,273 | \$820,512,036,304.76 | \$14,305,587,995,897.60 |
| 2015 | \$4,346,493 | \$12,658,179 | \$879,490 | \$4,200,302 | \$773,503,002,123.93 | \$17,642,535,724,453.50 |
| 2016 | \$4,424,230 | \$12,429,814 | \$957,227 | \$3,971,937 | \$916,283,901,783.98 | \$15,776,282,428,653.20 |
| | | | | SUM | \$12,102,309,667,859.60 | \$218,242,311,681,444.00 |

The variance calculations for our four countries proceeds as follows:

Group 1:

$$(\text{Variance for Togo})S_x^2 = \frac{\sum(x_i - \bar{x})^2}{n - 1}$$

$$(\text{Variance for Togo})S_x^2 = \frac{1119055338039.75}{16 - 1}$$

$$(\text{Variance for Togo})S_x^2 = 74,603,689,202.65$$

$$(\text{Variance for Sierra Leone})S_y^2 = \frac{12,632,381,023,339.70}{16 - 1}$$

$$(\text{Variance for Sierra Leone})S_y^2 = \mathbf{842,158,734,889.32}$$

Group 2:

$$(\text{Variance for Madagascar})S_x^2 = \frac{12,102,309,667,859.60}{36 - 1}$$

$$(\text{Variance for Madagascar})S_x^2 = \mathbf{345,780,276,224.56}$$

$$(\text{Variance for Kenya})S_y^2 = \frac{218,242,311,681,444.0}{36 - 1}$$

$$(\text{Variance for Kenya})S_y^2 = \mathbf{6,235,494,619,469.84}$$

Therefore F-Stat is calculated as follows:

$$(\mathbf{Group\ 1})F - Stat = \frac{842,158,734,889.32}{74,603,689,202}$$

$$(\mathbf{Group\ 1})F - Stat = \mathbf{11.289}$$

$$(\mathbf{Group\ 2})F - Stat = \frac{6,235,494,619,469.84}{345,780,276,224.56}$$

$$(\mathbf{Group\ 2})F - Stat = \mathbf{18.03}$$

The F-Critical values for Group 1 from the F-Distribution table at a significance level of 0.05 and a Degree of Freedom of 15 is 4.81. On the other hand, the F-Critical value for Group 2 from the F-Distribution table at a significance level of 0.05 and a Degree of Freedom of 35 is 3.52.

Since the F-Stat for both groups – 11.29 for Group 1 and 18.03 for Group 2 – all fall outside the acceptance region for the null hypothesis at 4.81 and 3.52 respectively, there are sufficient evidence to reject the null hypothesis in favor of the alternative hypothesis. In other words, the variance among the two countries in each group are that of an unequal variance. (See Appendix

10 for a Microsoft Excel generated F-Stat descriptive statistic for the two groups) As a result, we can perform the T-test on the assumption that there is an unequal variance among the countries in each group.

T-Test Results

Having addressed the conformity of the paper's dataset to the normality and variance requirements for conducting a T-Test, we can proceed to perform our Two Sample Independent T-Test to see if the difference in the means of agricultural output among the two countries in each group is due to the positive agricultural R&D expenditure shock during the data period. The null hypothesis for the T-Test is given as follow:

$$H_0: \mu_x = \mu_y \text{ (Means of both countries are the same)}$$

$$H_1: \mu_x \neq \mu_y \text{ (Means of both countries are not the same)}$$

If the T-Stat is greater than the t-critical value, we reject the null hypothesis – meaning, the difference in the output means (average) of the countries in each group are due to the positive agricultural R&D shock. If not, we fail to reject the null hypothesis in favor of the alternative hypothesis.

T-Stat formula is given as:

$$\frac{\bar{x} - \bar{y}}{\sqrt{\left(\frac{S_x^2}{n_1} + \frac{S_y^2}{n_2}\right)}}$$

Whereby

\bar{x} is the mean of one of the sample dataset

\bar{y} is the mean of the second sample dataset.

S_x^2 is the variance of the first sample dataset x

S_y^2 is the variance of the second sample dataset y

And (n_1 & n_2) as the number of observations in sample x and sample y respectively.

We already have the variance values and total observations for all four countries from our earlier

F-Test calculation. The remaining values including the “mean” are all included in table 14.

Table 14: T-Stat Operation Values

| | Group 1 | | Group 2 | |
|-----------------|------------------|---------------------|-------------------|------------------|
| | <i>Togo</i> | <i>Sierra Leone</i> | <i>Madagascar</i> | <i>Kenya</i> |
| Mean | 1639940.625 | 2551349.375 | 3467002.8 | 8457877.14 |
| Variance | 74,603,689,202.7 | 842,158,734,889.3 | 345780276224.6 | 6235494619469.84 |
| n | 16 | 16 | 36 | 36 |

The T-Stat calculations thus proceeds as follows:

Group1(Togo and Sierra Leone):

$$\frac{1639941 - 2551349}{\sqrt{\left(\frac{74603689202.65}{16} + \frac{842158734889.32}{16}\right)}}$$

$$\frac{-911409}{\sqrt{(4662730575 + 52634920931)}}$$

$$\frac{-911409}{\sqrt{57297651506}}$$

$$\frac{-911409}{239369.28}$$

$$T - STAT = -3.81$$

GROUP 2 (Madagascar and Kenya):

$$\frac{3467003 - 8457877}{\sqrt{\left(\frac{345780276224.56}{36} + \frac{6235494619469.84}{36}\right)}}$$

$$\frac{-4990874}{\sqrt{(9605007672.90 + 173208183874.16)}}$$

$$\frac{-4990874}{\sqrt{182813191547.07}}$$

$$\frac{-4990874}{427566.59}$$

$$T - STAT = -11.67$$

In order to finalize our T-Test analysis, we need to test our T-Stat against the T-Critical value from the T-Distribution table at the alpha level and Degree of Freedom value. Since the F-Test has established the variance among the two countries in each group to be unequal, we can proceed to the Degree of Freedom approach that assumes unequal variance.

Thus, the Degree of Freedom is given as:

$$\text{Degree of Freedom (Unequal Variance)} = \frac{\left(\frac{S_x^2}{n1} + \frac{S_y^2}{n2}\right)^2}{\frac{\left(\frac{S_x^2}{n1}\right)^2}{n1-1} + \frac{\left(\frac{S_y^2}{n2}\right)^2}{n2-1}}$$

OR

$$\text{Degree of Freedom (Unequal Variance)} = \frac{\left(\frac{\text{Var 1}}{n1} + \frac{\text{Var 2}}{n2}\right)^2}{\frac{\left(\frac{\text{Var 1}}{n1}\right)^2}{n1-1} + \frac{\left(\frac{\text{Var 2}}{n2}\right)^2}{n2-1}}$$

GROUP 1 (Togo and Sierra Leone):

$$\text{Degree of Freedom (Unequal Variance)} = \frac{\left(\frac{74603689202.65}{16} + \frac{842158734889.32}{16}\right)^2}{\frac{\left(\frac{74603689202.65}{16}\right)^2}{16-1} + \frac{\left(\frac{842158734889.32}{16}\right)^2}{16-1}}$$

$$\frac{(4662730575 + 52634920931)^2}{\frac{(4662730575)^2}{15} + \frac{(52634920931)^2}{15}}$$

$$\frac{(57297651505.75)^2}{\frac{21741056416584400000}{15} + \frac{277043490136865000000}{15}}$$

$$\frac{328302086807414000000}{1449403761105620000 + 18469566009124300000}$$

$$\frac{3283020868074140000000}{186145063852349000000}$$

Degree of Freedom = 17.64 or 18

GROUP 2 (Madagascar and Kenya):

$$\text{Degree of Freedom(Unequal Variance)} = \frac{\left(\frac{345780276224.56}{36} + \frac{6235494619469.84}{36}\right)^2}{\frac{\left(\frac{345780276224.56}{36}\right)^2}{36-1} + \frac{\left(\frac{6235494619469.84}{36}\right)^2}{36-1}}$$

$$\frac{(9605007672.90 + 173208183874.16)^2}{\frac{(9605007672.90)^2}{35} + \frac{(173208183874.16)^2}{35}}$$

$$\frac{(182813191547.07)^2}{\frac{92256172396553800000}{35} + \frac{30001074960985600000000}{35}}$$

$$\frac{33420663003624500000000}{2635890639901540000 + 857173570313873000000}$$

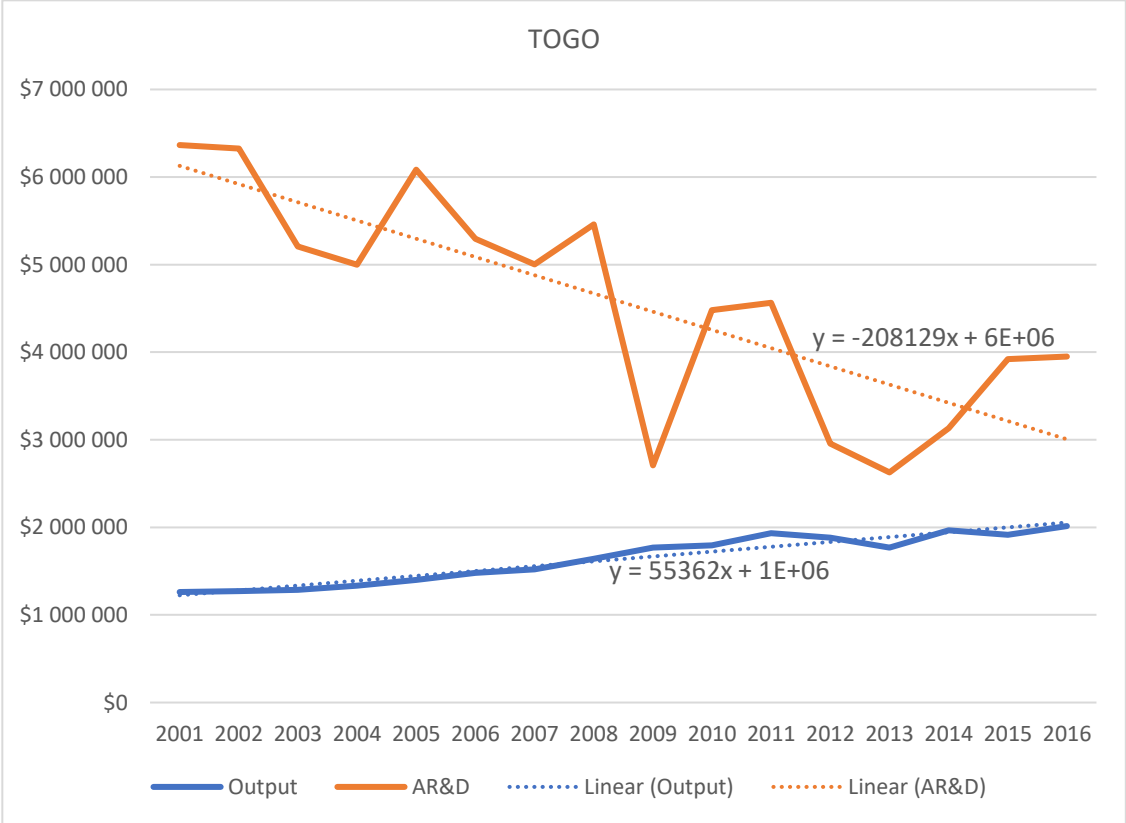
$$\frac{33420663003624500000000}{859809460953775000000}$$

Degree of Freedom = 38.87

Having the values for T-stat, the Degree of Freedom and the alpha level, we can now locate the T-critical value on the T-Distribution table to reject or accept the null hypothesis. (See Appendix 11 for the t-table). The T-Critical for Group 1 at a 0.05 significance level and a Degree of Freedom of 18 is 2.10, while the T-Critical for Group 2 at a 0.05 significance level and a Degree of Freedom of 39 is 2.02. (See Appendix 12 for a Microsoft Excel generated Descriptive Statistic for the T-Test). Since the T-statistic for Group 1 (-3.81) and Group 2 (-11.67) are all outside the acceptance region of the null hypothesis at a T-Critical values of (-)2.10 and (-)2.02, respectively, the null hypothesis that the means of the countries in each group are equal is rejected. In other words, the alternative hypothesis that there are indeed significant differences

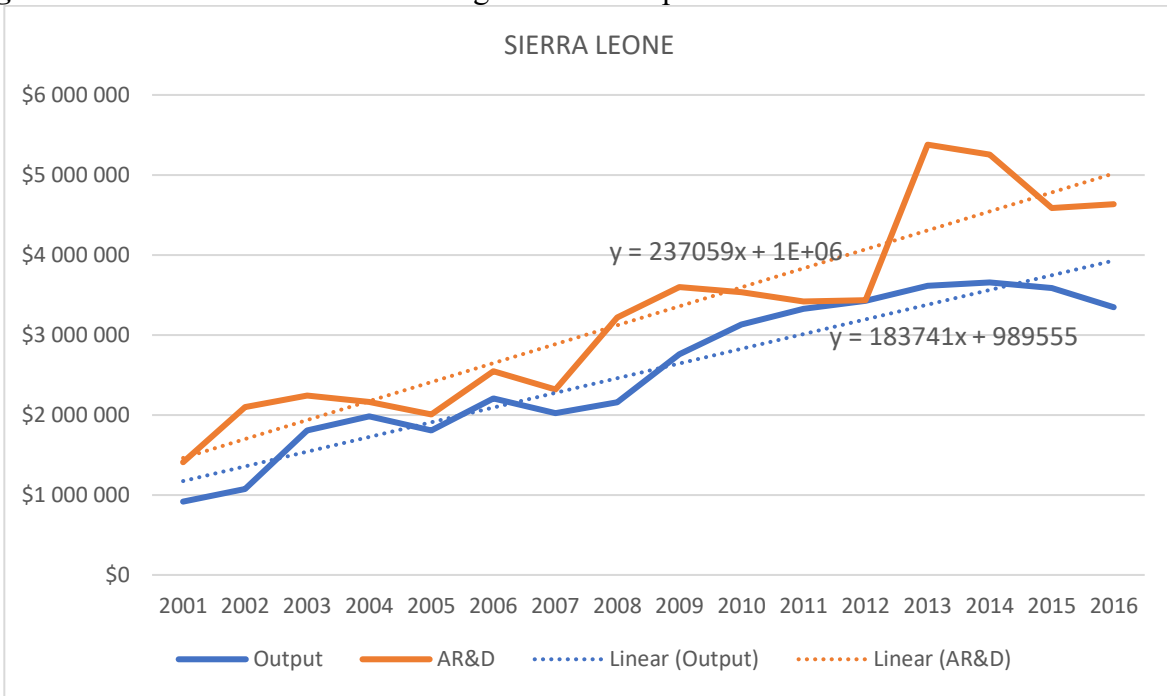
between the means of the two countries in each group is accepted. In the case of Group 1, it can be concluded that the difference in the agricultural output means of \$911,408.75 (in thousands) between Togo’s agricultural output (\$1,639,904.63[in thousands]) and Sierra Leone’s agricultural output (\$2,551,349.38[in thousands]) was due to the positive agricultural R&D expenditure shock by Sierra Leone when compared to Togo’s negative AR&D expenditure shock. Similar results were also observed for the countries in Group 2. The mean difference of \$4,990,874.33 (in thousands) in agricultural output between Kenya’s agricultural output of \$8,457,877.14 (in thousands) and Madagascar’s \$3,467,002.81 (in thousands) was also due to the positive agricultural R&D shock by Kenya, when compared to the negative AR&D shock by Madagascar in the study period. The findings of the Two Sample Independent T-Test are consistent with trends that can be discerned from figures 6, 7,8 &9.

Figure 6: Togo’s AR&D and Agricultural Output Trend



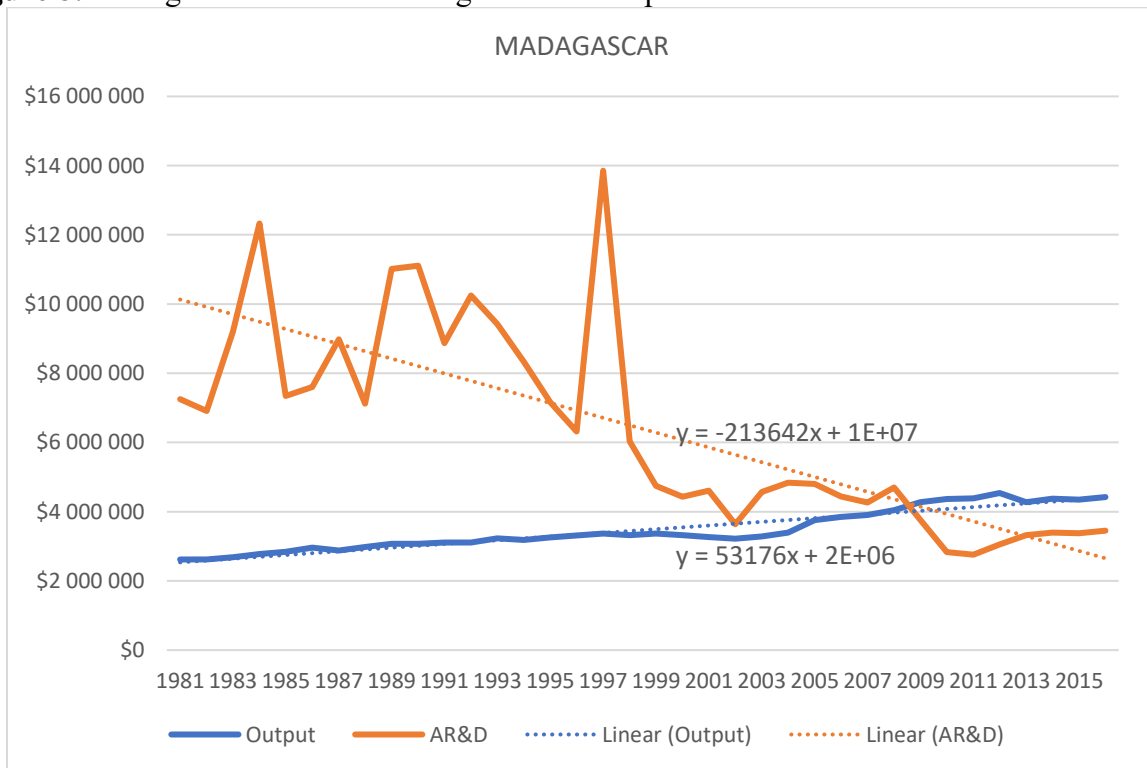
Source: Chart generated by author, and based on calculations from ASTI and FAOSTAT

Figure 7: Sierra Leone's AR&D and Agricultural Output Trend



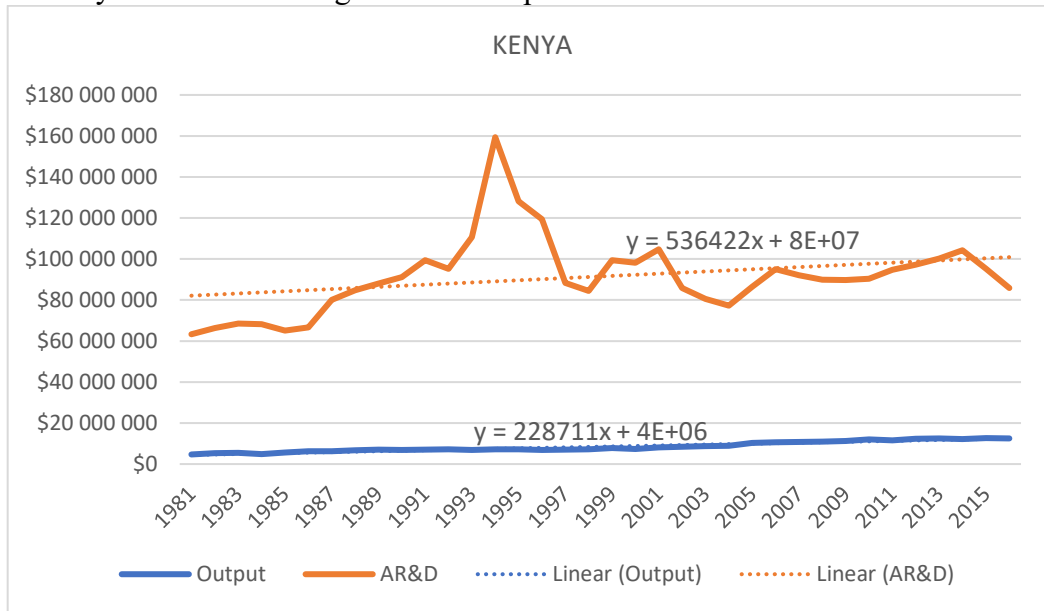
Source: Chart generated by author, and based on calculations from ASTI and FAOSTAT

Figure 8: Madagascar's AR&D and Agricultural Output Trend



Source: Chart generated by author, and based on calculations from ASTI and FAOSTAT

Figure 9: Kenya's AR&D and Agricultural Output Trend



Source: Chart generated by author, and based on calculations from ASTI and FAOSTAT

As can be observed from the agricultural output slopes of the four countries in figures 6,7,8, and 9, the countries with increasing agricultural R&D expenditure (i.e., Sierra Leone and Kenya) have larger agricultural output than the countries with a declining agricultural R&D (i.e., Togo and Madagascar). Sierra Leone's agricultural output slope is \$183,741 (in thousands), which is 3.2 times the agricultural output slope of Togo at \$55,362 (in thousands). This means during the study period, Sierra Leone's agricultural output as a result of positive agricultural R&D expenditure shock increased annually by USD \$183,741,000. Togo on the other hand without a positive AR&D expenditure shock only achieved an annual output of USD \$55,362,000. Similarly, Kenya's agricultural output slope is \$228,771 (in thousands), which is 4.3 times the agricultural output slope of Madagascar at \$53,176. Hence, during the study period, Kenya's agricultural output as a result of positive agricultural R&D expenditure shock increased annually by USD \$228,711,000, while Madagascar's agricultural output increased annually by only USD \$53,176,000.

SECTION 3

DISCUSSION AND POLICY OPTIONS FOR SUB-SAHARAN AFRICA

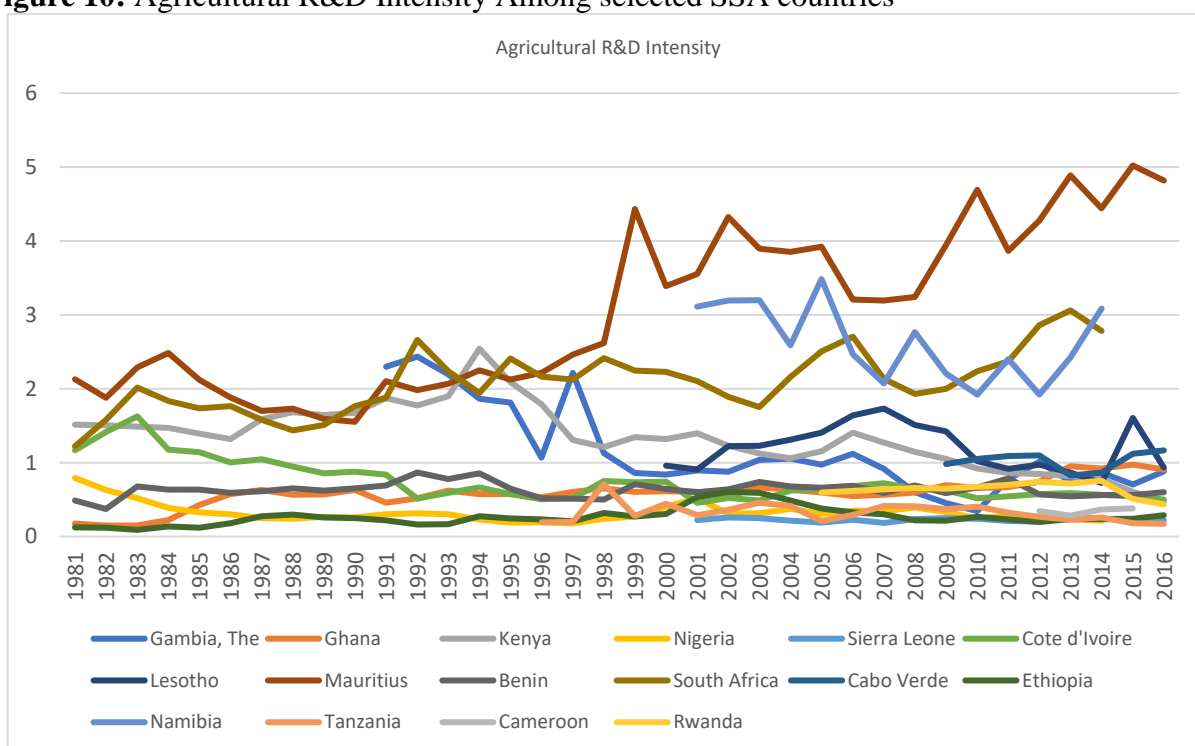
The empirical analysis has illustrated that investment in agricultural R&D through expenditure increases are crucial for facilitating growth within the agricultural sector in sub-Saharan Africa. However, what the empirical evidence does not prove is the efficient ways sub-Saharan African countries can spend their agricultural R&D expenditure. For instance, is the annual agricultural output mean value of USD \$183,741,000 and USD \$228,711,000 the maximum amount in value Sierra Leone and Kenya respectively could generate from their agricultural R&D investment? Or could they have generated more if they had spent their AR&D expenditure more efficiently? As a region that has historically been entrenched in incessant public debts, scarce financial resources, and in need of immediate and sustainable economic growth, these are important questions that warrants policy makers scrutiny. Two lessons for sub-Saharan African countries' agricultural-driven growth are articulated below.

Strategically Increase National Levels of Investment in Agricultural R&D:

The first lesson to be gained from the empirical analysis is simple and straightforward. If R&D within the agricultural sector is crucial for increasing agricultural output, then the most economically prudent choice of action is for Sub-Saharan African countries to prioritize at increasing their national aggregate of AR&D expenditure. The region's policy makers indeed agree with this recommendation since they have already collectively embraced and articulated an economic growth strategy that is consistent with the spirit of the proposition at the larger macro-economic level. (See appendix 13). More importantly, countries in the region in a multilateral effort under the African Union's 2003 *Maputo Declaration on Agriculture and Food Security*

agreed to invest a minimum of 1% of their agricultural GDP (AGDP) in R&D. (African Union, 2006). Unfortunately, the majority of the countries have not been able to fulfil this commitment, as the region's agricultural research investment continues to trail farther behind those in the developed world. Existing levels of AR&D investments among the countries have also declined due to decreasing government contributions, and the ending of foreign donor projects. (Pardey et., al, 2016). The top performers against the 1% benchmark, among whom include, Mauritius, Senegal, Namibia, and South Africa have all on average consistently exceeded the 1% benchmark; followed by the Gambia often slightly above or below the benchmark. (Pardey et., al, 2016). The success of these countries in achieving higher levels of agricultural R&D funding have been due to investments by alternative suppliers of agricultural R&D, including the active presence and participation of for-profit private sector. (Pardey et., al, 2016). South Africa has the most active for profit private agricultural R&D industry in the sub-continent with the domination of its seed industry, followed by sugarcane and citrus research, which are all performed by private R&D organizations and funded by the industries. (Chaminuka, 2019). The private sector's agricultural R&D activities in Senegal are also impressive with agricultural firms like Chemical Commercialization Company (SENCHEM), Suneor, and the Industrial & Agricultural Products Company (SPIA) all playing major innovators in the production and processing of the country's principal export crops (groundnuts and cotton), biofuels and sugar milling. (Gaye et al, 2014; Pray et. al, p.4, 2011). Recent privatization of corporations in these industries have also amplified the private sector's level of agricultural R&D activity in the country.

Figure 10: Agricultural R&D Intensity Among selected SSA countries



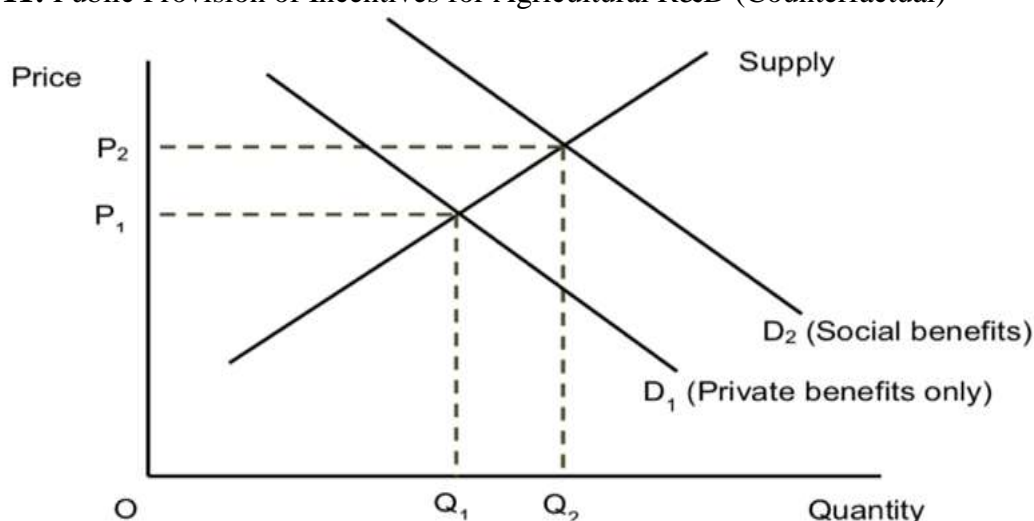
Source: Chat generated by author from ASTI dataset – “AR&D Intensity Key Trends,” ASTI-IFPRI, accessed December 24th, 2021, <https://www.asti.cgiar.org/ghana?country=GHA>.

It becomes self-evident that the antidote to most of sub-Saharan countries’ abysmal investment in agricultural R&D is to bring the private sector to the fold by incentivising new entrants or augmenting the R&D intensity of the few existing larger commercial exporting farms and private AR&D firms. Market failure, nevertheless, remains a barrier to achieving this objective. The domination of rural low-income smallholder farmers in the region’s agricultural sector in particular is one example. Approximately 60% of all farms in Ghana for example are less than 1.2 hectares in size; 25% are between 1.2 to 2.0 hectares, with only about 15% being above 2.0 hectares (The World Bank, 2021) – meaning, 85% of all farms in Ghana are smallholder farms. Over 60% of Sierra Leone’s populations are also engaged in smallholder agriculture. (Government of Sierra Leone, p.28, 2019). In Nigeria, 80% of Nigerian farmers are smallholder farmers, producing over 90% of domestic output. (Anderson et, al, p.1, 2017). Investing in

agricultural R&D, however, require interested private agents to have sufficient planning, technical, and financial capacity. Lacking a modicum of these capacities, sub-Saharan African countries' smallholder farmers are unable to conduct agricultural R&D on their own. Even with financial support from the government, including AR&D subsidies, these farmers may still be constrained in making the complementary investments required to reap the maximum benefits from the government's support. This leaves the burden of for-profit private innovation in agriculture to the few private sector R&D firms or large commercial farms that are involved in the export of the perennial commodities such as cocoa in Ghana, coffee and tobacco in Tanzania, and tea in Malawi. Positive externalities, non-rivalry of ideas and the imperfect credit markets, unfortunately also results in an unfavorable situation whereby the free market cannot be expected to produce the socially optimal amount of investment in agricultural R&D. As rational economic agents, the capable private firms and larger farms will invest in R&D to the extent that the investment only benefit the firm, rather than forgoing an extra marginal cost to achieve a socially optimal level. As represented in figure 11, these firms and farms will only supply up to Q_1 of R&D investment on their own at price P_1 where the marginal cost of the investment is equal to the marginal private benefit. The level at which the private investment falls below the economic optimum of Q_2 at P_2 represents an under-investment and can be attributed to "market failures". Hence, policy action including regulatory/legislative and/or fiscal policy (i.e., subsidies, grants, or tax incentives) are needed from the government to help bring social benefits of private agricultural R&D investment to its social optimum. For instance, in an agricultural R&D project by one of the largest commercial farms in Ghana – Green Gold Farms – in designing an efficient sowing and harvesting technology for corn production, the most economically wise decision by the government of Ghana will be to subsidize a reasonable portion of Green Gold Farm's R&D

expenditure for that specific project so the acquired knowledge or technology can easily and quickly spilled over to not only smallholder corn farmers, but also if possible, to smallholder farmers in rice, wheat, oats and other agricultural production.

Figure 11: Public Provision of Incentives for Agricultural R&D (Counterfactual)



Source: Graph is adopted from “Externality diagrams at AS Level and A-level: Guidance for Teachers,” AQA, accessed August 6th, 2021, p.6, <https://filestore.aqa.org.uk/resources/economics/AQA-7135-7136-TG1.pdf>.

The government’s efforts to step in with policy and /or incentives to address the market failure in this regard with the goal of increasing agricultural R&D to its optimum level also need to be done with caution to mitigate the impact of political failure. Political failure often emerges because a well-intentioned public policy to address market failures such as those of R&D investments fails to achieve their intended outcome, due to conflict between the general interest of society and the interest of politicians, interest groups, and bureaucrats within the public services (Keech and Munger, 2015). The tools that are needed to solve market failures in R&D investment are in particular, highly susceptible to political failures since they involve targeting the correct producer firms, the specific type of technology, and the appropriate agricultural sub-sector. At the same time, each agricultural sub-sector, whether deserving or not has incentives to use lobbying or other methods to increase their share of the agricultural R&D support from the

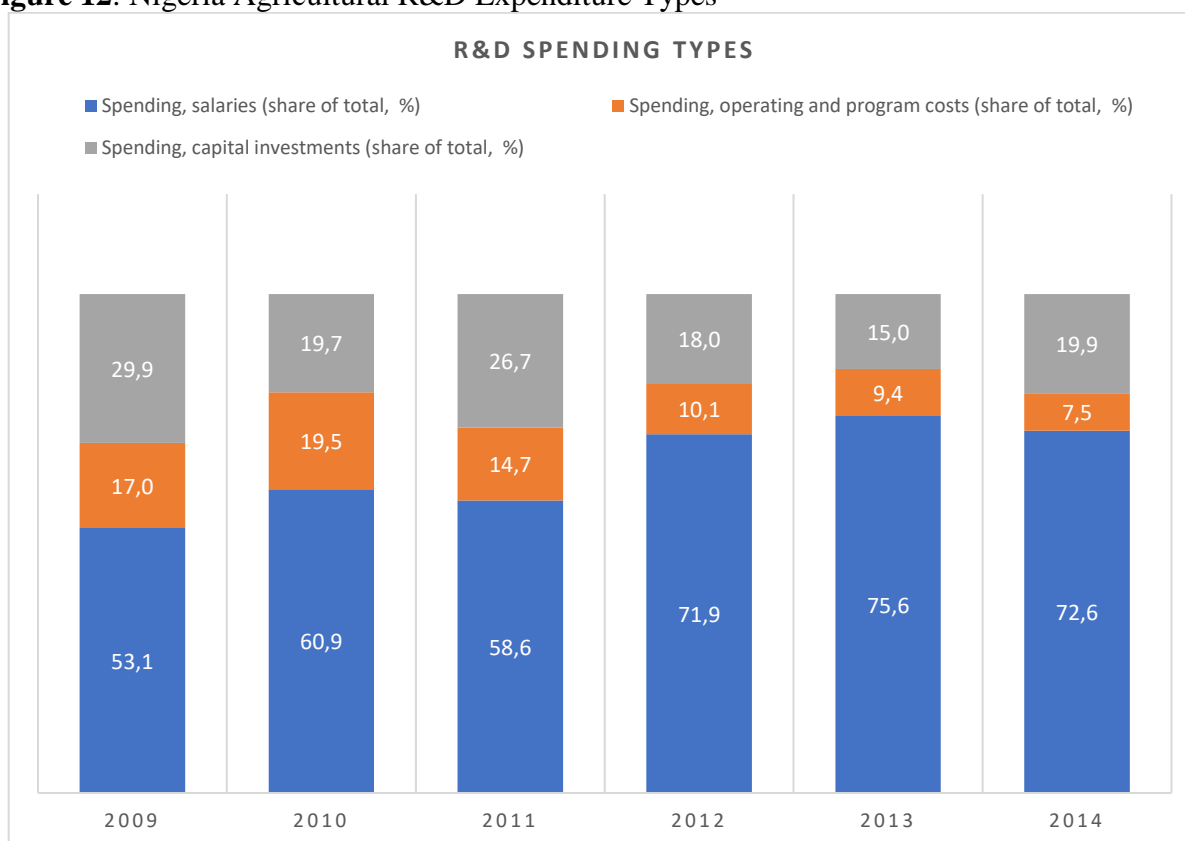
government. This is a typical recipe for rent seeking, whereby a well-defined group with superior information can ensure they receive more priority than what is optimal. While such non-market pressured-R&D investment policies could by coincidence, increase the optimal national level of investment in the right agricultural R&D sub-sector, there is a high likelihood of a “pork barrel spending”, resulting in wasteful spending. As a result, these risks must be understood and if possible, mitigated in the context of policymaking to raise the national aggregate of agricultural R&D investment successfully and effectively.

Improve Efficiency of R&D Expenditure within the Public R&D Sector:

Given the important role of government-funded public agricultural R&D institutes in driving agricultural innovation in the sub-continent, an analysis of the institutes’ expenditure efficiency with regards to management and capacity practices are also vital. As evident in figures 12, 13 and 14, sub-Saharan African countries like Nigeria, when compared to Ghana and Sierra Leone spend a greater proportion of their agricultural R&D expenditure on researchers’ salaries and capital investments at the neglect of expenditure on program or operational funding. In 2014 for instance, Nigeria spent 72.6% of its AR&D expenditure on salaries, 7.5% on program cost and 19.9% on capital investment. (See Figure 12). Ghana and Sierra Leone also spent a significant amount of their AR&D expenditure on researchers’ salaries (74.2% and 66.8% respectively), a moderate amount on program/operations cost (22.9% and 30.2% respectively), but an insignificant amount on capital investment (2.9% each). (See figures 13 & 14). All three expenditure types are equally important, but an optimal balance among them is of greater significance in maximizing the impact of AR&D investment on output. Program/operational cost, which encompasses things like the cost of lab materials and supplies, books, chemicals, expert consulting, prototypes, and many others are necessary to enable researchers to conduct

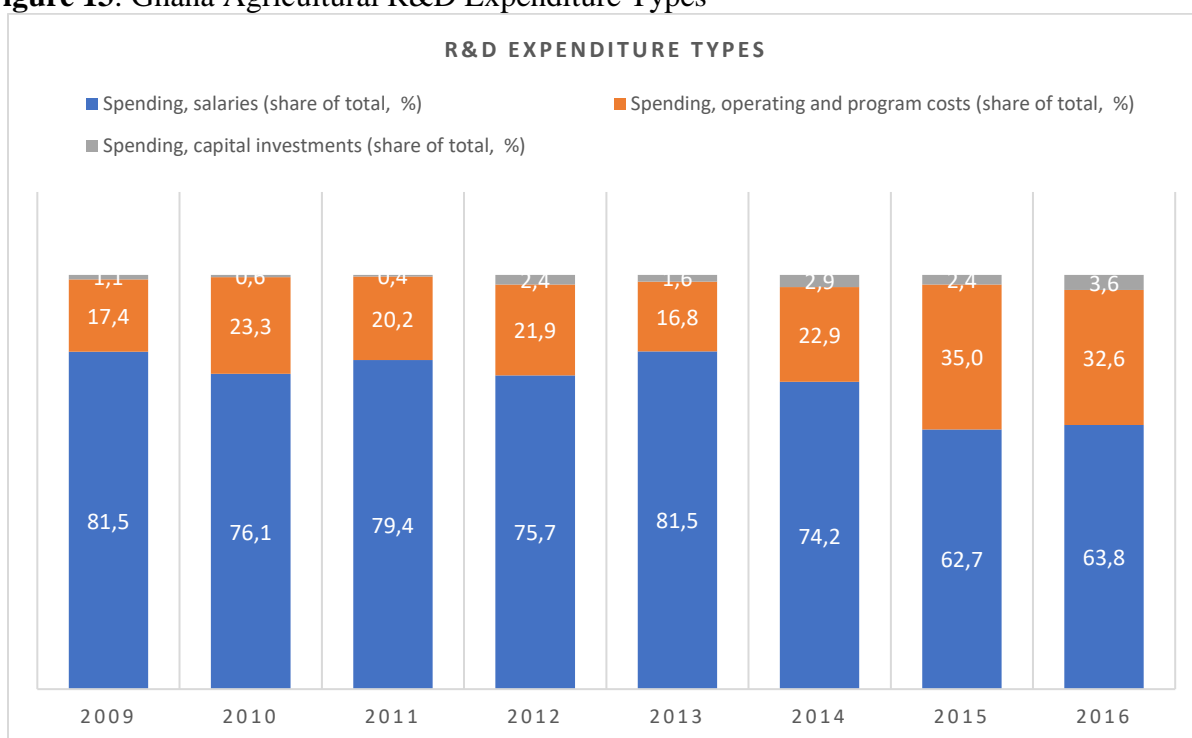
“actual” research. (See Appendix 14) Capital investment, which also includes the acquisition, upgrade, and maintenance of physical assets, such as property, buildings, and equipment is also important to create a professional environment that is conducive for the safe and efficient conduct of R&D. Similarly, expenditures on researchers’ salaries and competitive compensations are greatly important to enhance the recruitment of the best researchers, motivate the existing researchers to perform at the highest level, and consequently minimize researchers’ turnover rate. However, paying researchers competitive salaries without the necessary commensurate operational budget for actual research towards agricultural development is very much like asking researchers to accept payment for doing less work, or not giving them the means to do what they are supposed to be doing – namely, engage in R&D.

Figure 12: Nigeria Agricultural R&D Expenditure Types



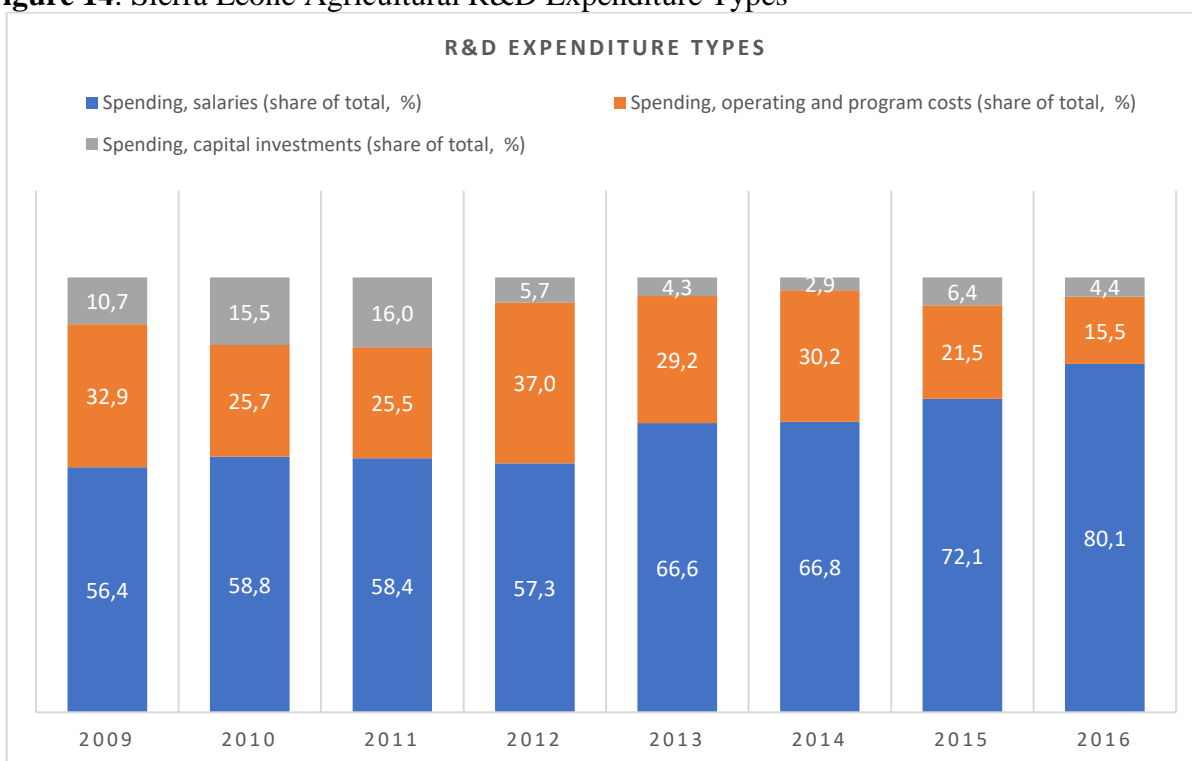
Source: Chart generated by author from ASTI dataset – “Nigeria Key Trends,” ASTI-IFPRI, accessed December 24th, 2021, <https://www.asti.cgiar.org/ghana?country=GHA>.

Figure 13: Ghana Agricultural R&D Expenditure Types



Source: Chat generated by author from ASTI dataset – “Ghana Key Trends,” ASTI-IFPRI, accessed December 24th, 2021, <https://www.asti.cgiar.org/ghana?country=GHA>.

Figure 14: Sierra Leone Agricultural R&D Expenditure Types



Source: Chat generated by author from ASTI dataset – “Sierra Leone Key Trends,” ASTI-IFPRI, accessed December 24th, 2021, <https://www.asti.cgiar.org/ghana?country=GHA>.

CONCLUSION

The paper has empirically demonstrated that agricultural R&D is an important instrument for agricultural growth, which in turn is a necessary step for sub-Saharan African countries' realization of an inclusive and sustainable economic growth. As a result, the countries need to wholly commit to this growth strategy in policymaking and implementation. The study's empirical findings are in line with the endogenous growth theory of Paul Romer, with particular emphasis on the role of government as a strategic and active participant in the development of a vibrant public and private agricultural R&D sector. The study has also established that while R&D expenditure increases are necessary, they are not sufficient to maximize the output gains from R&D investment. A strategic balance among the three R&D expenditure types (i.e., Salaries, Program/Operational cost, and Capital expenditure) is required to ensure optimum returns on investment. Meaning, every extra researcher hired within the agricultural R&D sector need to correspond to a proportionate financial allocation for programs/operations and capital investment to allow researchers to efficiently conduct research with the necessary tools, equipment, and support. Hence, the sub-region's governments should not be overambitious and simply stimulate AR&D expenditure increases. Instead, sub-Saharan African countries should prioritize their limited resources on specific agricultural (sub)-sectors that give the countries the best buck for their investment. This proposition does not call for Sub-Saharan African countries to be narrow-minded in their innovation investments. Rather, they should gradually and progressively expose the various (sub)-sectors of priority to R&D investment when optimal level of R&D funding has been efficiently allocated towards the most important economic (sub)-sectors. Commitment by the sub-region's countries to meeting the African Union's agreed upon 1% of AGDP investment in agricultural R&D will be a necessary first step.

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Appendix

Appendix 1: International Organization’ Documents with Reference to SSA Challenges

| Organization | Reference to SSA’s Challenges and Crisis |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>European Civil Protection and Humanitarian Aid Operations (ECHO)</p> <p>Source: “Evaluation of the European Union’s Humanitarian Assistance in the Central Africa Region, including Humanitarian Coordination, 2014 – 2018 – Final Report,” European Civil Protection and Humanitarian Aid Operations (ECHO), European Commission, 2019, (accessed August 18th, 2021), p.4.</p> | <p>Between 2014-2018, the Central Africa region suffered multiple humanitarian crisis, notably the Central African Republic’s conflict and refugee protection crisis, Cameroon’s complex and multi-layered crisis, and Chad’s food, nutrition, and refugee crisis, together leaving 7-10 million people in need of assistance.</p> |
| <p>United Nations Office for the Coordination of Humanitarian Affairs (OCHA)</p> <p>Source: “Humanitarian Outlook for the Horn of Africa and the Great Lakes Region,” United Nations, OCHA, Regional Humanitarian Outlook, October – December 2015, (accessed August 18th, 2021),p.17, https://reliefweb.int/report/world/global-humanitarian-overview-2021-enarfres.</p> | <p>African migrants continuous to undertake the often-perilous journeys from the Horn of Africa to Europe and South Africa. These mixed migration flows include refugees, asylum seekers, displaced persons, victims of exploitation and abuse, unaccompanied children, persons with health needs, environmental migrants, and migrant workers.</p> |
| <p>Government of the United Kingdom</p> <p>Source: “Africa Action Plan: UK Progress Report,” Government of the United Kingdom, accessed August 18th, 2021, p. 1.</p> | <p>Progress in Africa, and improvement in the lives of its people, has been undermined or destroyed by conflict and insecurity. Scarce resources needed to fight poverty have been wasted. Conflicts in one country have fueled insecurity and instability in neighbours. Without peace and security, Africa will not realise the goals.</p> |

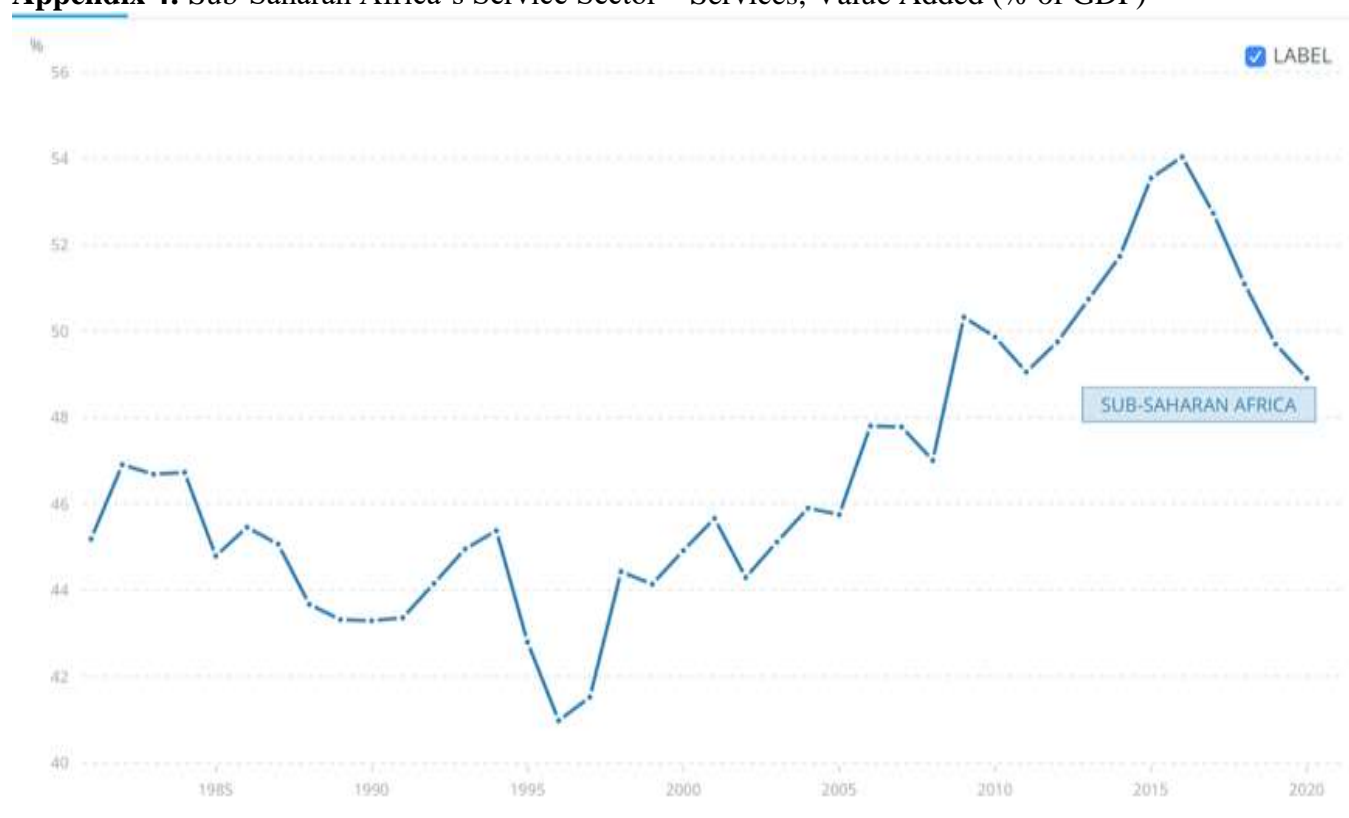
Appendix 2: The Economist’s “The Hopeless Continent” and “Africa Rising” cover pages



Appendix 3: Sub-Saharan Africa Regional Economic Communities Legal Framework

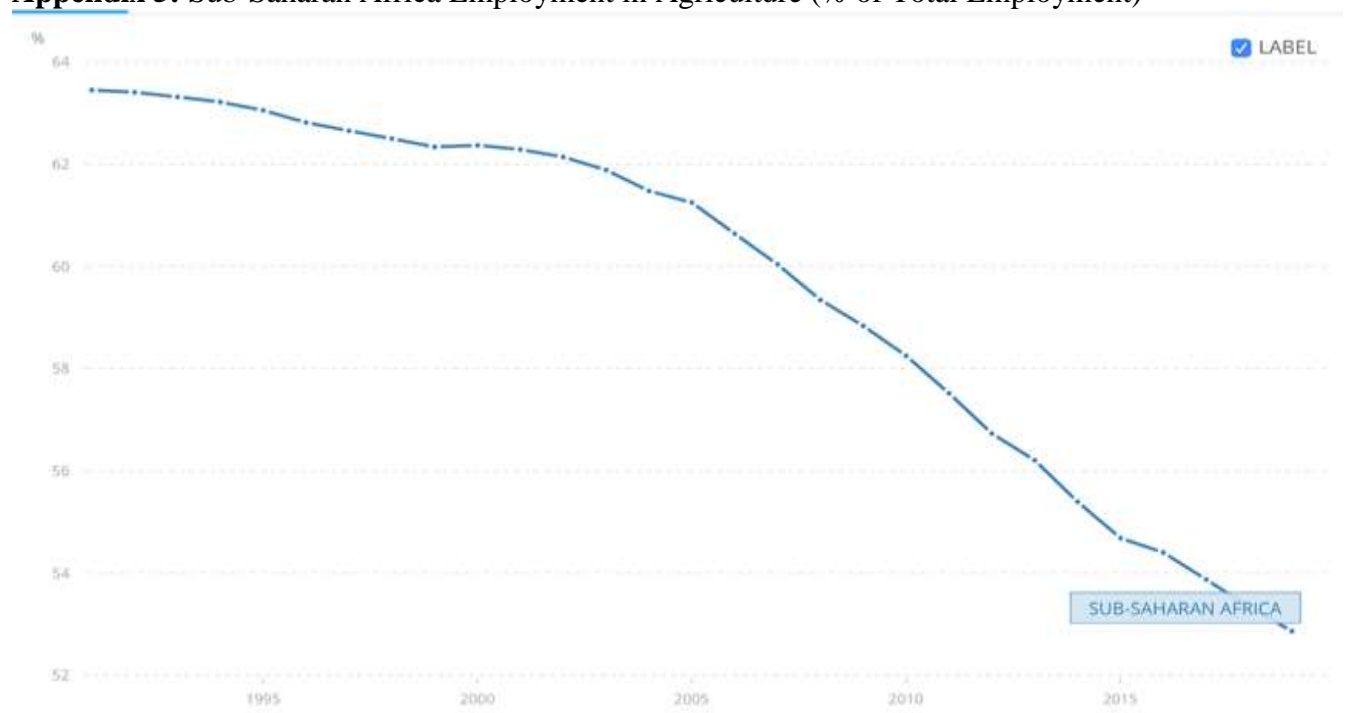
| Regional Economic Community | Member States | Provisions on Democracy in their governance framework |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>African Union</i> | All African States | <p><i>Article 4 of the Constitutive Act of the African Union:</i> respect for democratic principles, human rights, the rule of law and good governance; condemnation and rejection of unconstitutional changes in governments.</p> <p><i>The African Charter on Democracy, Elections, and Governance:</i> commitment by Parties to democracy, rule of law, human rights; as well as to constitutional transfer of power; sanctions in cases of unconstitutional changed of government.</p> |
| <i>ECOWAS</i> | Benin, Burkina Faso, Cabo Verde, Cote d'Ivoire, The Gambia, Ghana, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo | <p><i>Article 4 of the Treaty of Ecowas:</i> adherence to human rights and democratic governance.</p> <p><i>Declaration of Political Principles of the ECOWAS:</i> reaffirms the decision to achieve the respective aims.</p> <p><i>Protocol on Democracy and Good Governance:</i> envisages sanctions for breaches of democracy.</p> |
| <i>SADC</i> | Angola, Botswana, Comoros, Democratic Republic of the Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia, Zimbabwe | <p><i>Article 4 of the Treaty of the SADC:</i> affirms the principles of human rights, democracy, and rule of law.</p> <p>SADC Principles and Guidelines Governing Democratic Elections.</p> |
| <i>ECCAS</i> | Angola, Burundi, Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Republic of the Congo, Sao Tome and Principe | <p><i>Bata Declaration for the Promotion of Lasting Democracy, Peace and Development in Central Africa:</i> reaffirms the sovereign right of each nation to determine the nature and rate of its democratization.</p> |
| <i>EAC</i> | Burundi, Kenya, Rwanda, South Sudan, Tanzania, Uganda | <p><i>Article 3.3.b and 6.b of the EAC Treaty:</i> adherence to good governance, democracy, rule of law, human rights is a precondition for membership and an obligation of the Member States.</p> <p>EAC Principles for Election Observation and Evaluation.</p> |
| <i>IGAD</i> | Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, and Uganda | <p>Draft Protocol on Democracy, Governance and Elections.</p> <p>Guidelines for Election Observers and Code of Conduct for Election Observers.</p> |

Appendix 4: Sub-Saharan Africa's Service Sector – Services, Value Added (% of GDP)



Source: "Services, value added (% of GDP) – Sub-Saharan Africa," <https://data.worldbank.org/indicator/NV.SRV.TOTL.ZS?locations=ZG>.

Appendix 5: Sub-Saharan Africa Employment in Agriculture (% of Total Employment)



"Employment in Agriculture (% of total employment) (modeled ILO estimate) – Sub-Saharan Africa," The World Bank, World Development Indicators, accessed January 25th, 2021, <https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=ZG>.

Appendix 6: Exogenous Influence on Agricultural Output

| | |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Agricultural Land (sq/km)</p> | <p>Agricultural land simply refers to the share of the total land area that is arable (i.e., suitable for growing crops), under permanent crops, and under permanent pastures. Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or pasture, land under market or kitchen gardens, and land temporarily fallow. Permanent pasture is land used for five or more years of forage, including natural and cultivated crops. Land under permanent crops is land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee, and rubber.</p> <p>Source: The World Bank, “Metadata Glossary,” accessed December 27th, 2021, https://databank.worldbank.org/metadataglossary/world-development-indicators/series/AG.LND.AGRI.K2</p> |
| <p>Labor (per 1000 persons)</p> | <p>Persons of working age who were engaged in any activity to produce goods and provide services for pay or profit, whether at work during the reference period or not at work due to temporary absence from a job, or to working-time arrangement within agriculture, forestry, and fishing. Labor consists of each country’s unskilled labor population who work directly (i.e., farmers) or provide “for profit services” for the production of agricultural output. These could include individuals that provide services to farmers including weeding, preparing the soil, harvesting, irrigation services and many others.</p> <p>Source: Food and Agriculture Data (FAOSTAT)</p> |
| <p>Environment/Climate</p> | <p>Gives detailed information about a country’s environment and climate as well as their conduciveness to agricultural production including “climatology”, “trends & variability”, “climate projections”, “mean projections, vulnerability, and impacts.</p> <p>Source: The World Bank, “Climate Change Knowledge Portal,” accessed January 4th, 2021, https://climateknowledgeportal.worldbank.org/country-profiles.</p> |
| <p>Political/Social Stability</p> | <p>The BTI Transformation Index: Analyzes transformation processes toward democracy and a market economy in international comparison and identifies successful strategies for peaceful change.</p> <p>Source: “BTI Transformation Index, ”https://bti-project.org/en/?&cb=00000.</p> |
| <p>Historical Natural Disasters</p> | <p>Based on literature review and factual research.</p> |

Appendix 7: Kolmogorov-Smirnov Test Distribution Table

| Sample Size N | Level of Significance for $D = \text{Max} F^*(X) - S_N(X) $ | | | | |
|--------------------|--------------------------------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| | .20 | .15 | .10 | .05 | .01 |
| 4 | .300 | .319 | .352 | .381 | .417 |
| 5 | .285 | .299 | .315 | .337 | .405 |
| 6 | .265 | .277 | .294 | .319 | .364 |
| 7 | .247 | .258 | .276 | .300 | .348 |
| 8 | .233 | .244 | .261 | .285 | .331 |
| 9 | .223 | .233 | .249 | .271 | .311 |
| 10 | .215 | .224 | .239 | .258 | .294 |
| 11 | .206 | .217 | .230 | .249 | .284 |
| 12 | .199 | .212 | .223 | .242 | .275 |
| 13 | .190 | .202 | .214 | .234 | .268 |
| 14 | .183 | .194 | .207 | .227 | .261 |
| 15 | .177 | .187 | .201 | .220 | .257 |
| 16 | .173 | .182 | .195 | .213 | .250 |
| 17 | .169 | .177 | .189 | .206 | .245 |
| 18 | .166 | .173 | .184 | .200 | .239 |
| 19 | .163 | .169 | .179 | .195 | .235 |
| 20 | .160 | .166 | .174 | .190 | .231 |
| 25 | .149 | .153 | .165 | .180 | .203 |
| 30 | .131 | .136 | .144 | .161 | .187 |
| Over 30 | .736 | .768 | .805 | .886 | 1.031 |
| | $\frac{\quad}{\sqrt{N}}$ | $\frac{\quad}{\sqrt{N}}$ | $\frac{\quad}{\sqrt{N}}$ | $\frac{\quad}{\sqrt{N}}$ | $\frac{\quad}{\sqrt{N}}$ |

Source: Lilliefors, Hubert W. "On the Kolmogorov-Smirnov Test for Normality with Mean and Variance Unknown." *Journal of the American Statistical Association*, vol. 62, no. 318, Taylor & Francis Group, 1967, pp. 399–402, <https://doi.org/10.1080/01621459.1967.10482916>. (page 400)

Appendix 8: F-Test Table – 5% significance level below 22 (n-1)

F Distribution: Critical Values of F (5% significance level)

| v_1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 | 18 | 20 |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1 | 161.45 | 199.50 | 215.71 | 224.58 | 230.16 | 233.99 | 236.77 | 238.88 | 240.54 | 241.88 | 243.91 | 245.36 | 246.46 | 247.32 | 248.01 |
| 2 | 18.51 | 19.00 | 19.16 | 19.25 | 19.30 | 19.33 | 19.35 | 19.37 | 19.38 | 19.40 | 19.41 | 19.42 | 19.43 | 19.44 | 19.45 |
| 3 | 10.13 | 9.55 | 9.28 | 9.12 | 9.01 | 8.94 | 8.89 | 8.85 | 8.81 | 8.79 | 8.74 | 8.71 | 8.69 | 8.67 | 8.66 |
| 4 | 7.71 | 6.94 | 6.59 | 6.39 | 6.26 | 6.16 | 6.09 | 6.04 | 6.00 | 5.96 | 5.91 | 5.87 | 5.84 | 5.82 | 5.80 |
| 5 | 6.61 | 5.79 | 5.41 | 5.19 | 5.05 | 4.95 | 4.88 | 4.82 | 4.77 | 4.74 | 4.68 | 4.64 | 4.60 | 4.58 | 4.56 |
| 6 | 5.99 | 5.14 | 4.76 | 4.53 | 4.39 | 4.28 | 4.21 | 4.15 | 4.10 | 4.06 | 4.00 | 3.96 | 3.92 | 3.90 | 3.87 |
| 7 | 5.59 | 4.74 | 4.35 | 4.12 | 3.97 | 3.87 | 3.79 | 3.73 | 3.68 | 3.64 | 3.57 | 3.53 | 3.49 | 3.47 | 3.44 |
| 8 | 5.32 | 4.46 | 4.07 | 3.84 | 3.69 | 3.58 | 3.50 | 3.44 | 3.39 | 3.35 | 3.28 | 3.24 | 3.20 | 3.17 | 3.15 |
| 9 | 5.12 | 4.26 | 3.86 | 3.63 | 3.48 | 3.37 | 3.29 | 3.23 | 3.18 | 3.14 | 3.07 | 3.03 | 2.99 | 2.96 | 2.94 |
| 10 | 4.96 | 4.10 | 3.71 | 3.48 | 3.33 | 3.22 | 3.14 | 3.07 | 3.02 | 2.98 | 2.91 | 2.86 | 2.83 | 2.80 | 2.77 |
| 11 | 4.84 | 3.98 | 3.59 | 3.36 | 3.20 | 3.09 | 3.01 | 2.95 | 2.90 | 2.85 | 2.79 | 2.74 | 2.70 | 2.67 | 2.65 |
| 12 | 4.75 | 3.89 | 3.49 | 3.26 | 3.11 | 3.00 | 2.91 | 2.85 | 2.80 | 2.75 | 2.69 | 2.64 | 2.60 | 2.57 | 2.54 |
| 13 | 4.67 | 3.81 | 3.41 | 3.18 | 3.03 | 2.92 | 2.83 | 2.77 | 2.71 | 2.67 | 2.60 | 2.55 | 2.51 | 2.48 | 2.46 |
| 14 | 4.60 | 3.74 | 3.34 | 3.11 | 2.96 | 2.85 | 2.76 | 2.70 | 2.65 | 2.60 | 2.53 | 2.48 | 2.44 | 2.41 | 2.39 |
| 15 | 4.54 | 3.68 | 3.29 | 3.06 | 2.90 | 2.79 | 2.71 | 2.64 | 2.59 | 2.54 | 2.48 | 2.42 | 2.38 | 2.35 | 2.33 |
| 16 | 4.49 | 3.63 | 3.24 | 3.01 | 2.85 | 2.74 | 2.66 | 2.59 | 2.54 | 2.49 | 2.42 | 2.37 | 2.33 | 2.30 | 2.28 |
| 17 | 4.45 | 3.59 | 3.20 | 2.96 | 2.81 | 2.70 | 2.61 | 2.55 | 2.49 | 2.45 | 2.38 | 2.33 | 2.29 | 2.26 | 2.23 |
| 18 | 4.41 | 3.55 | 3.16 | 2.93 | 2.77 | 2.66 | 2.58 | 2.51 | 2.46 | 2.41 | 2.34 | 2.29 | 2.25 | 2.22 | 2.19 |
| 19 | 4.38 | 3.52 | 3.13 | 2.90 | 2.74 | 2.63 | 2.54 | 2.48 | 2.42 | 2.38 | 2.31 | 2.26 | 2.21 | 2.18 | 2.16 |
| 20 | 4.35 | 3.49 | 3.10 | 2.87 | 2.71 | 2.60 | 2.51 | 2.45 | 2.39 | 2.35 | 2.28 | 2.22 | 2.18 | 2.15 | 2.12 |
| 21 | 4.32 | 3.47 | 3.07 | 2.84 | 2.68 | 2.57 | 2.49 | 2.42 | 2.37 | 2.32 | 2.25 | 2.20 | 2.16 | 2.12 | 2.10 |
| 22 | 4.30 | 3.44 | 3.05 | 2.82 | 2.66 | 2.55 | 2.46 | 2.40 | 2.34 | 2.30 | 2.23 | 2.17 | 2.13 | 2.10 | 2.07 |
| 23 | 4.28 | 3.42 | 3.03 | 2.80 | 2.64 | 2.53 | 2.44 | 2.37 | 2.32 | 2.27 | 2.20 | 2.15 | 2.11 | 2.08 | 2.05 |
| 24 | 4.26 | 3.40 | 3.01 | 2.78 | 2.62 | 2.51 | 2.42 | 2.36 | 2.30 | 2.25 | 2.18 | 2.13 | 2.09 | 2.05 | 2.03 |
| 25 | 4.24 | 3.39 | 2.99 | 2.76 | 2.60 | 2.49 | 2.40 | 2.34 | 2.28 | 2.24 | 2.16 | 2.11 | 2.07 | 2.04 | 2.01 |
| 26 | 4.22 | 3.37 | 2.98 | 2.74 | 2.59 | 2.47 | 2.39 | 2.32 | 2.27 | 2.22 | 2.15 | 2.09 | 2.05 | 2.02 | 1.99 |
| 27 | 4.21 | 3.35 | 2.96 | 2.73 | 2.57 | 2.46 | 2.37 | 2.31 | 2.25 | 2.20 | 2.13 | 2.08 | 2.04 | 2.00 | 1.97 |
| 28 | 4.20 | 3.34 | 2.95 | 2.71 | 2.56 | 2.45 | 2.36 | 2.29 | 2.24 | 2.19 | 2.12 | 2.06 | 2.02 | 1.99 | 1.96 |
| 29 | 4.18 | 3.33 | 2.93 | 2.70 | 2.55 | 2.43 | 2.35 | 2.28 | 2.22 | 2.18 | 2.10 | 2.05 | 2.01 | 1.97 | 1.94 |
| 30 | 4.17 | 3.32 | 2.92 | 2.69 | 2.53 | 2.42 | 2.33 | 2.27 | 2.21 | 2.16 | 2.09 | 2.04 | 1.99 | 1.96 | 1.93 |
| 35 | 4.12 | 3.27 | 2.87 | 2.64 | 2.49 | 2.37 | 2.29 | 2.22 | 2.16 | 2.11 | 2.04 | 1.99 | 1.94 | 1.91 | 1.88 |
| 40 | 4.08 | 3.23 | 2.84 | 2.61 | 2.45 | 2.34 | 2.25 | 2.18 | 2.12 | 2.08 | 2.00 | 1.95 | 1.90 | 1.87 | 1.84 |
| 50 | 4.03 | 3.18 | 2.79 | 2.56 | 2.40 | 2.29 | 2.20 | 2.13 | 2.07 | 2.03 | 1.95 | 1.89 | 1.85 | 1.81 | 1.78 |
| 60 | 4.00 | 3.15 | 2.76 | 2.53 | 2.37 | 2.25 | 2.17 | 2.10 | 2.04 | 1.99 | 1.92 | 1.86 | 1.82 | 1.78 | 1.75 |
| 70 | 3.98 | 3.13 | 2.74 | 2.50 | 2.35 | 2.23 | 2.14 | 2.07 | 2.02 | 1.97 | 1.89 | 1.84 | 1.79 | 1.75 | 1.72 |
| 80 | 3.96 | 3.11 | 2.72 | 2.49 | 2.33 | 2.21 | 2.13 | 2.06 | 2.00 | 1.95 | 1.88 | 1.82 | 1.77 | 1.73 | 1.70 |
| 90 | 3.95 | 3.10 | 2.71 | 2.47 | 2.32 | 2.20 | 2.11 | 2.04 | 1.99 | 1.94 | 1.86 | 1.80 | 1.76 | 1.72 | 1.69 |
| 100 | 3.94 | 3.09 | 2.70 | 2.46 | 2.31 | 2.19 | 2.10 | 2.03 | 1.97 | 1.93 | 1.85 | 1.79 | 1.75 | 1.71 | 1.68 |
| 120 | 3.92 | 3.07 | 2.68 | 2.45 | 2.29 | 2.18 | 2.09 | 2.02 | 1.96 | 1.91 | 1.83 | 1.78 | 1.73 | 1.69 | 1.66 |
| 150 | 3.90 | 3.06 | 2.66 | 2.43 | 2.27 | 2.16 | 2.07 | 2.00 | 1.94 | 1.89 | 1.82 | 1.76 | 1.71 | 1.67 | 1.64 |
| 200 | 3.89 | 3.04 | 2.65 | 2.42 | 2.26 | 2.14 | 2.06 | 1.98 | 1.93 | 1.88 | 1.80 | 1.74 | 1.69 | 1.66 | 1.62 |
| 250 | 3.88 | 3.03 | 2.64 | 2.41 | 2.25 | 2.13 | 2.05 | 1.98 | 1.92 | 1.87 | 1.79 | 1.73 | 1.68 | 1.65 | 1.61 |
| 300 | 3.87 | 3.03 | 2.63 | 2.40 | 2.24 | 2.13 | 2.04 | 1.97 | 1.91 | 1.86 | 1.78 | 1.72 | 1.68 | 1.64 | 1.61 |
| 400 | 3.86 | 3.02 | 2.63 | 2.39 | 2.24 | 2.12 | 2.03 | 1.96 | 1.90 | 1.85 | 1.78 | 1.72 | 1.67 | 1.63 | 1.60 |
| 500 | 3.86 | 3.01 | 2.62 | 2.39 | 2.23 | 2.12 | 2.03 | 1.96 | 1.90 | 1.85 | 1.77 | 1.71 | 1.66 | 1.62 | 1.59 |
| 600 | 3.86 | 3.01 | 2.62 | 2.39 | 2.23 | 2.11 | 2.02 | 1.95 | 1.90 | 1.85 | 1.77 | 1.71 | 1.66 | 1.62 | 1.59 |
| 750 | 3.85 | 3.01 | 2.62 | 2.38 | 2.23 | 2.11 | 2.02 | 1.95 | 1.89 | 1.84 | 1.77 | 1.70 | 1.66 | 1.62 | 1.58 |
| 1000 | 3.85 | 3.00 | 2.61 | 2.38 | 2.22 | 2.11 | 2.02 | 1.95 | 1.89 | 1.84 | 1.76 | 1.70 | 1.65 | 1.61 | 1.58 |

Appendix 9: F-Test Distribution Table – 5% significance level above 22 (n-1)

F Distribution: Critical Values of F (5% significance level)

| v_1 | 25 | 30 | 35 | 40 | 50 | 60 | 75 | 100 | 150 | 200 |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1 | 249.26 | 250.10 | 250.69 | 251.14 | 251.77 | 252.20 | 252.62 | 253.04 | 253.46 | 253.68 |
| 2 | 19.46 | 19.46 | 19.47 | 19.47 | 19.48 | 19.48 | 19.48 | 19.49 | 19.49 | 19.49 |
| 3 | 8.63 | 8.62 | 8.60 | 8.59 | 8.58 | 8.57 | 8.56 | 8.55 | 8.54 | 8.54 |
| 4 | 5.77 | 5.75 | 5.73 | 5.72 | 5.70 | 5.69 | 5.68 | 5.66 | 5.65 | 5.65 |
| 5 | 4.52 | 4.50 | 4.48 | 4.46 | 4.44 | 4.43 | 4.42 | 4.41 | 4.39 | 4.39 |
| 6 | 3.83 | 3.81 | 3.79 | 3.77 | 3.75 | 3.74 | 3.73 | 3.71 | 3.70 | 3.69 |
| 7 | 3.40 | 3.38 | 3.36 | 3.34 | 3.32 | 3.30 | 3.29 | 3.27 | 3.26 | 3.25 |
| 8 | 3.11 | 3.08 | 3.06 | 3.04 | 3.02 | 3.01 | 2.99 | 2.97 | 2.96 | 2.95 |
| 9 | 2.89 | 2.86 | 2.84 | 2.83 | 2.80 | 2.79 | 2.77 | 2.76 | 2.74 | 2.73 |
| 10 | 2.73 | 2.70 | 2.68 | 2.66 | 2.64 | 2.62 | 2.60 | 2.59 | 2.57 | 2.56 |
| 11 | 2.60 | 2.57 | 2.55 | 2.53 | 2.51 | 2.49 | 2.47 | 2.46 | 2.44 | 2.43 |
| 12 | 2.50 | 2.47 | 2.44 | 2.43 | 2.40 | 2.38 | 2.37 | 2.35 | 2.33 | 2.32 |
| 13 | 2.41 | 2.38 | 2.36 | 2.34 | 2.31 | 2.30 | 2.28 | 2.26 | 2.24 | 2.23 |
| 14 | 2.34 | 2.31 | 2.28 | 2.27 | 2.24 | 2.22 | 2.21 | 2.19 | 2.17 | 2.16 |
| 15 | 2.28 | 2.25 | 2.22 | 2.20 | 2.18 | 2.16 | 2.14 | 2.12 | 2.10 | 2.10 |
| 16 | 2.23 | 2.19 | 2.17 | 2.15 | 2.12 | 2.11 | 2.09 | 2.07 | 2.05 | 2.04 |
| 17 | 2.18 | 2.15 | 2.12 | 2.10 | 2.08 | 2.06 | 2.04 | 2.02 | 2.00 | 1.99 |
| 18 | 2.14 | 2.11 | 2.08 | 2.06 | 2.04 | 2.02 | 2.00 | 1.98 | 1.96 | 1.95 |
| 19 | 2.11 | 2.07 | 2.05 | 2.03 | 2.00 | 1.98 | 1.96 | 1.94 | 1.92 | 1.91 |
| 20 | 2.07 | 2.04 | 2.01 | 1.99 | 1.97 | 1.95 | 1.93 | 1.91 | 1.89 | 1.88 |
| 21 | 2.05 | 2.01 | 1.98 | 1.96 | 1.94 | 1.92 | 1.90 | 1.88 | 1.86 | 1.84 |
| 22 | 2.02 | 1.98 | 1.96 | 1.94 | 1.91 | 1.89 | 1.87 | 1.85 | 1.83 | 1.82 |
| 23 | 2.00 | 1.96 | 1.93 | 1.91 | 1.88 | 1.86 | 1.84 | 1.82 | 1.80 | 1.79 |
| 24 | 1.97 | 1.94 | 1.91 | 1.89 | 1.86 | 1.84 | 1.82 | 1.80 | 1.78 | 1.77 |
| 25 | 1.96 | 1.92 | 1.89 | 1.87 | 1.84 | 1.82 | 1.80 | 1.78 | 1.76 | 1.75 |
| 26 | 1.94 | 1.90 | 1.87 | 1.85 | 1.82 | 1.80 | 1.78 | 1.76 | 1.74 | 1.73 |
| 27 | 1.92 | 1.88 | 1.86 | 1.84 | 1.81 | 1.79 | 1.76 | 1.74 | 1.72 | 1.71 |
| 28 | 1.91 | 1.87 | 1.84 | 1.82 | 1.79 | 1.77 | 1.75 | 1.73 | 1.70 | 1.69 |
| 29 | 1.89 | 1.85 | 1.83 | 1.81 | 1.77 | 1.75 | 1.73 | 1.71 | 1.69 | 1.67 |
| 30 | 1.88 | 1.84 | 1.81 | 1.79 | 1.76 | 1.74 | 1.72 | 1.70 | 1.67 | 1.66 |
| 35 | 1.82 | 1.79 | 1.76 | 1.74 | 1.70 | 1.68 | 1.66 | 1.63 | 1.61 | 1.60 |
| 40 | 1.78 | 1.74 | 1.72 | 1.69 | 1.66 | 1.64 | 1.61 | 1.59 | 1.56 | 1.55 |
| 50 | 1.73 | 1.69 | 1.66 | 1.63 | 1.60 | 1.58 | 1.55 | 1.52 | 1.50 | 1.48 |
| 60 | 1.69 | 1.65 | 1.62 | 1.59 | 1.56 | 1.53 | 1.51 | 1.48 | 1.45 | 1.44 |
| 70 | 1.66 | 1.62 | 1.59 | 1.57 | 1.53 | 1.50 | 1.48 | 1.45 | 1.42 | 1.40 |
| 80 | 1.64 | 1.60 | 1.57 | 1.54 | 1.51 | 1.48 | 1.45 | 1.43 | 1.39 | 1.38 |
| 90 | 1.63 | 1.59 | 1.55 | 1.53 | 1.49 | 1.46 | 1.44 | 1.41 | 1.38 | 1.36 |
| 100 | 1.62 | 1.57 | 1.54 | 1.52 | 1.48 | 1.45 | 1.42 | 1.39 | 1.36 | 1.34 |
| 120 | 1.60 | 1.55 | 1.52 | 1.50 | 1.46 | 1.43 | 1.40 | 1.37 | 1.33 | 1.32 |
| 150 | 1.58 | 1.54 | 1.50 | 1.48 | 1.44 | 1.41 | 1.38 | 1.34 | 1.31 | 1.29 |
| 200 | 1.56 | 1.52 | 1.48 | 1.46 | 1.41 | 1.39 | 1.35 | 1.32 | 1.28 | 1.26 |
| 250 | 1.55 | 1.50 | 1.47 | 1.44 | 1.40 | 1.37 | 1.34 | 1.31 | 1.27 | 1.25 |
| 300 | 1.54 | 1.50 | 1.46 | 1.43 | 1.39 | 1.36 | 1.33 | 1.30 | 1.26 | 1.23 |
| 400 | 1.53 | 1.49 | 1.45 | 1.42 | 1.38 | 1.35 | 1.32 | 1.28 | 1.24 | 1.22 |
| 500 | 1.53 | 1.48 | 1.45 | 1.42 | 1.38 | 1.35 | 1.31 | 1.28 | 1.23 | 1.21 |
| 600 | 1.52 | 1.48 | 1.44 | 1.41 | 1.37 | 1.34 | 1.31 | 1.27 | 1.23 | 1.20 |
| 750 | 1.52 | 1.47 | 1.44 | 1.41 | 1.37 | 1.34 | 1.30 | 1.26 | 1.22 | 1.20 |
| 1000 | 1.52 | 1.47 | 1.43 | 1.41 | 1.36 | 1.33 | 1.30 | 1.26 | 1.22 | 1.19 |

Appendix 10: F-Test Excel Generated Descriptive Statistics

| GROUP 1 | | |
|----------------------------------------|--------------------------|--------------------|
| F-Test Two-Sample for Variances | | |
| | <i>Sierra Leone</i> | <i>Togo</i> |
| Mean | 2551349.375 | 1639940.625 |
| Variance | 842,158,734,889.32 | 74,603,689,202.65 |
| Observations | 16 | 16 |
| Df | 15 | 15 |
| F | 11.28843284 | |
| P(F<=f) one-tail | 0.000014 | |
| F Critical one-tail | 2.403447071 | |
| P Two-tail | 0.000028 | |
| GROUP 2 | | |
| F-Test Two-Sample for Variances | | |
| | <i>Kenya</i> | <i>Madagascar</i> |
| Mean | 8,457,877.14 | 3,467,002.81 |
| Variance | 6,235,494,619,469.84 | 345,780,276,224.56 |
| Observations | 36 | 36 |
| Df | 35 | 35 |
| F | 18.03311249 | |
| P(F<=f) one-tail | 0.000000000000040 | |
| F Critical one-tail | 1.757139526 | |
| P Two-tail | 0.000000000000081 | |

Appendix 11: T-Test Distribution Table:

t Table

| cum. prob | $t_{.50}$ | $t_{.75}$ | $t_{.80}$ | $t_{.85}$ | $t_{.90}$ | $t_{.95}$ | $t_{.975}$ | $t_{.99}$ | $t_{.995}$ | $t_{.999}$ | $t_{.9995}$ |
|-----------|-------------------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|--------------|--------------|---------------|
| one-tail | 0.50 | 0.25 | 0.20 | 0.15 | 0.10 | 0.05 | 0.025 | 0.01 | 0.005 | 0.001 | 0.0005 |
| two-tails | 1.00 | 0.50 | 0.40 | 0.30 | 0.20 | 0.10 | 0.05 | 0.02 | 0.01 | 0.002 | 0.001 |
| df | | | | | | | | | | | |
| 1 | 0.000 | 1.000 | 1.376 | 1.963 | 3.078 | 6.314 | 12.71 | 31.82 | 63.66 | 318.31 | 636.62 |
| 2 | 0.000 | 0.816 | 1.061 | 1.386 | 1.886 | 2.920 | 4.303 | 6.965 | 9.925 | 22.327 | 31.599 |
| 3 | 0.000 | 0.765 | 0.978 | 1.250 | 1.638 | 2.353 | 3.182 | 4.541 | 5.841 | 10.215 | 12.924 |
| 4 | 0.000 | 0.741 | 0.941 | 1.190 | 1.533 | 2.132 | 2.776 | 3.747 | 4.604 | 7.173 | 8.610 |
| 5 | 0.000 | 0.727 | 0.920 | 1.156 | 1.476 | 2.015 | 2.571 | 3.365 | 4.032 | 5.893 | 6.869 |
| 6 | 0.000 | 0.718 | 0.906 | 1.134 | 1.440 | 1.943 | 2.447 | 3.143 | 3.707 | 5.208 | 5.959 |
| 7 | 0.000 | 0.711 | 0.896 | 1.119 | 1.415 | 1.895 | 2.365 | 2.998 | 3.499 | 4.785 | 5.408 |
| 8 | 0.000 | 0.706 | 0.889 | 1.108 | 1.397 | 1.860 | 2.306 | 2.896 | 3.355 | 4.501 | 5.041 |
| 9 | 0.000 | 0.703 | 0.883 | 1.100 | 1.383 | 1.833 | 2.262 | 2.821 | 3.250 | 4.297 | 4.781 |
| 10 | 0.000 | 0.700 | 0.879 | 1.093 | 1.372 | 1.812 | 2.228 | 2.764 | 3.169 | 4.144 | 4.587 |
| 11 | 0.000 | 0.697 | 0.876 | 1.088 | 1.363 | 1.796 | 2.201 | 2.718 | 3.106 | 4.025 | 4.437 |
| 12 | 0.000 | 0.695 | 0.873 | 1.083 | 1.356 | 1.782 | 2.179 | 2.681 | 3.055 | 3.930 | 4.318 |
| 13 | 0.000 | 0.694 | 0.870 | 1.079 | 1.350 | 1.771 | 2.160 | 2.650 | 3.012 | 3.852 | 4.221 |
| 14 | 0.000 | 0.692 | 0.868 | 1.076 | 1.345 | 1.761 | 2.145 | 2.624 | 2.977 | 3.787 | 4.140 |
| 15 | 0.000 | 0.691 | 0.866 | 1.074 | 1.341 | 1.753 | 2.131 | 2.602 | 2.947 | 3.733 | 4.073 |
| 16 | 0.000 | 0.690 | 0.865 | 1.071 | 1.337 | 1.746 | 2.120 | 2.583 | 2.921 | 3.686 | 4.015 |
| 17 | 0.000 | 0.689 | 0.863 | 1.069 | 1.333 | 1.740 | 2.110 | 2.567 | 2.898 | 3.646 | 3.965 |
| 18 | 0.000 | 0.688 | 0.862 | 1.067 | 1.330 | 1.734 | 2.101 | 2.552 | 2.878 | 3.610 | 3.922 |
| 19 | 0.000 | 0.688 | 0.861 | 1.066 | 1.328 | 1.729 | 2.093 | 2.539 | 2.861 | 3.579 | 3.883 |
| 20 | 0.000 | 0.687 | 0.860 | 1.064 | 1.325 | 1.725 | 2.086 | 2.528 | 2.845 | 3.552 | 3.850 |
| 21 | 0.000 | 0.686 | 0.859 | 1.063 | 1.323 | 1.721 | 2.080 | 2.518 | 2.831 | 3.527 | 3.819 |
| 22 | 0.000 | 0.686 | 0.858 | 1.061 | 1.321 | 1.717 | 2.074 | 2.508 | 2.819 | 3.505 | 3.792 |
| 23 | 0.000 | 0.685 | 0.858 | 1.060 | 1.319 | 1.714 | 2.069 | 2.500 | 2.807 | 3.485 | 3.768 |
| 24 | 0.000 | 0.685 | 0.857 | 1.059 | 1.318 | 1.711 | 2.064 | 2.492 | 2.797 | 3.467 | 3.745 |
| 25 | 0.000 | 0.684 | 0.856 | 1.058 | 1.316 | 1.708 | 2.060 | 2.485 | 2.787 | 3.450 | 3.725 |
| 26 | 0.000 | 0.684 | 0.856 | 1.058 | 1.315 | 1.706 | 2.056 | 2.479 | 2.779 | 3.435 | 3.707 |
| 27 | 0.000 | 0.684 | 0.855 | 1.057 | 1.314 | 1.703 | 2.052 | 2.473 | 2.771 | 3.421 | 3.690 |
| 28 | 0.000 | 0.683 | 0.855 | 1.056 | 1.313 | 1.701 | 2.048 | 2.467 | 2.763 | 3.408 | 3.674 |
| 29 | 0.000 | 0.683 | 0.854 | 1.055 | 1.311 | 1.699 | 2.045 | 2.462 | 2.756 | 3.396 | 3.659 |
| 30 | 0.000 | 0.683 | 0.854 | 1.055 | 1.310 | 1.697 | 2.042 | 2.457 | 2.750 | 3.385 | 3.646 |
| 40 | 0.000 | 0.681 | 0.851 | 1.050 | 1.303 | 1.684 | 2.021 | 2.423 | 2.704 | 3.307 | 3.551 |
| 60 | 0.000 | 0.679 | 0.848 | 1.045 | 1.296 | 1.671 | 2.000 | 2.390 | 2.660 | 3.232 | 3.460 |
| 80 | 0.000 | 0.678 | 0.846 | 1.043 | 1.292 | 1.664 | 1.990 | 2.374 | 2.639 | 3.195 | 3.416 |
| 100 | 0.000 | 0.677 | 0.845 | 1.042 | 1.290 | 1.660 | 1.984 | 2.364 | 2.626 | 3.174 | 3.390 |
| 1000 | 0.000 | 0.675 | 0.842 | 1.037 | 1.282 | 1.646 | 1.962 | 2.330 | 2.581 | 3.098 | 3.300 |
| Z | 0.000 | 0.674 | 0.842 | 1.036 | 1.282 | 1.645 | 1.960 | 2.326 | 2.576 | 3.090 | 3.291 |
| | 0% | 50% | 60% | 70% | 80% | 90% | 95% | 98% | 99% | 99.8% | 99.9% |
| | Confidence Level | | | | | | | | | | |

Appendix 12: T-Test Excel Generated Descriptive Statistics

| GROUP 1 | | |
|------------------------------------------------------|---------------------------|--------------------|
| t-Test: Two-Sample Assuming Unequal Variances | | |
| | <i>Sierra Leone</i> | <i>Togo</i> |
| Mean | 2551349.375 | 1639940.625 |
| Variance | 842,158,734,889.32 | 74,603,689,202.65 |
| Observations | 16 | 16 |
| Hypothesized Mean Difference | 0 | |
| df | 18 | |
| t Stat | 3.807542704 | |
| P(T<=t) one-tail | 0.000644766 | |
| t Critical one-tail | 1.734063607 | |
| P(T<=t) two-tail | 0.001289532 | |
| t Critical two-tail | 2.10092204 | |
| GROUP 2 | | |
| t-Test: Two-Sample Assuming Unequal Variances | | |
| | <i>Kenya</i> | <i>Madagascar</i> |
| Mean | 8457877.139 | 3467002.806 |
| Variance | 6,235,494,619,469.84 | 345,780,276,224.56 |
| Observations | 36 | 36 |
| Hypothesized Mean Difference | 0 | |
| df | 39 | |
| t Stat | 11.67274154 | |
| P(T<=t) one-tail | 0.0000000000000013 | |
| t Critical one-tail | 1.684875122 | |
| P(T<=t) two-tail | 0.0000000000000027 | |
| t Critical two-tail | 2.02269092 | |

Appendix 13: Sub-Saharan Africa’s Major Growth Targeted Innovation Policy Frameworks

| Policy Framework | Objectives | Source |
|----------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Science, Technology, and Innovation Strategy for Africa 2024</i> | Centered on AU Agenda 2063, and aims to foster social transformation and economic competitiveness of African countries through human capital development, innovation, value addition, industrialization, and entrepreneurship. | <i>Science, Technology and Innovation Strategy for Africa 2024 – STISA 2024</i> , The African Union, June 2020, (accessed August 16 th , 2021), https://au.int/en/documents/20200625/science-technology-and-innovation-strategy-africa-2024 . |
| <i>The 2007 Joint Africa-EU Strategy (JAES)</i> | The strategy recognizes the importance of innovation as an essential engine of socio-economic growth and sustainable development; hence, the need to cooperate in building knowledge-based societies. | <i>The Africa-EU Strategic Partnership: A joint Africa-EU Strategy</i> , The African Union, 2007, (accessed August 16 th , 2021), https://africa-eu-partnership.org/en/about-us/why-joint-strategy . |
| <i>The Second Decade of Education Action Plan 2006– 2015</i> | Provides a comprehensive articulation of the African Union’s policy on knowledge and multilateral partnership for Africa’s development. | <i>The Second Decade of Education Action Plan 2006– 2015 – Plan of Action</i> , 2006, (accessed August 17, 2021), https://www.edu-au.org/strategies/second-decade-of-education-for-africa . |
| <i>The African Development Bank’s 2008 Higher Education Science and Technology Strategy</i> | Aims to take steps to strengthening African countries’ tertiary institutions capacity to generate new productive knowledge. | <i>Strategy for Higher Education, Science and Technology</i> , The African Development Bank, February 2008, (accessed August 17 th , 2021), https://www.afdb.org/en/documents/document/strategy-for-higher-education-science-and-technology-11360 . |

Appendix 14: R&D Expenditure Types Description

| (FRASCETI MANUAL) | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|
| Capital Expenditure | Program Cost | Labor/Salaries |
| Expenditure on the acquisition of fixed assets that are used in the performance of R&D for more than one year including land and building (testing grounds, sites for laboratories and pilot plants), machinery, capitalized computer software, other intellectual property products. | Expenditure on actual conduct of R&D including non-capital purchases of materials, supplies, equipment and services to support R&D (water, fuel, gas and electricity, books, journals, reference materials, subscriptions, small prototypes or models made outside the specific R&D unit), materials for laboratories, royalties or licenses for the use of patents and other intellectual property rights, on site consultants who are not employed in statistical unit but provide direct services to the R&D unit, utilities, insurance and ancillary cost. | Expenditure on salaries spent on researchers. |