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Counting the Cost of Drought Induced Productivity Losses in an Agro-Based Economy: The Case of Uganda

Nicholas Kilimani
University of Pretoria
Jan van Heerden
University of Pretoria
Heinrich Bohlmann
University of Pretoria
Louise Roos
Victoria University, Melbourne
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Department of Economics
University of Pretoria
0002, Pretoria
South Africa
Tel: +27 12 420 2413

Counting the cost of drought induced productivity losses in an agro-based economy: The case of Uganda

Nicholas Kilimani*, Jan van Heerden, Heinrich Bohlmann† and Louise Roos‡

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Abstract

Climate variability can affect economies directly through its impact on agricultural output, and indirectly, through its effect on the activities of down-stream industries and household welfare. This paper uses a Computable General Equilibrium model with a disaggregated agricultural sector to analyse the impact of a drought on the Ugandan economy. The losses were assessed with respect to GDP, agricultural output, employment, the trade balance and household consumption. The drought effects were shown to vary by sector. The fall in employment within the agricultural industries was less compared to the output losses. At a macro level, exports declined, while at a household level, the terms of trade gains mitigated part of the potential welfare losses thereby reducing consumption, but to a lesser degree. The findings indicate that a drought can cause substantial losses to the economy. The need for targeted interventions to mitigate such drought impacts is therefore critical.

JEL Classification code: D58, Q25, Q54

Keywords: computable general equlibrium modelling, drought, economic activity, Uganda

1 Introduction

NEMA (2010) notes that the severe droughts registered in recent years have had significant negative effects on water resources, agricultural sector performance and the overall economy of Uganda.[1] Moreover, climate models predict that extreme weather events will become more frequent in the 21^{st} Century (see

*Corresponding author: nick.kilimani@up.ac.za, Tel: +27718334525.

†Department of Economics, University of Pretoria, Private Bag X20, Hatfield 0028, Pretoria, South Africa.

‡Centre for Policy Studies, Victoria University, P.O. Box 14428, Melbourne, VIC 8001, Australia

[1] The El Niño and La Niña phenomena are thought to have been the principal causes.

e.g., Hertel et al., 2010). This paper seeks to investigate the economy-wide impacts of a typical drought on the Ugandan economy with the view to highlight some policy interventions to cushion the economy against the associated effects. This is critical given the fact that most of the existing policies to deal with droughts are largely focused on short-term responsive actions such as food aid, rather than proactive planning and mitigation strategies. Whereas responsive actions are critical for smoothing short-term disturbances, they are incapable of providing long-term social-economic resilience to future drought impacts (Ding et al., 2011). There is a general consensus that mitigation and preparedness are fundamental for mitigating future drought risks. However, public policy managers seldom allocate resources to mitigation because of limited information on the costs and benefits of drought mitigation programs.

The adverse effects of a drought pose the risk of exacerbating future water scarcity in addition to other stressors such as population growth, rapid urbanisation, and economic activity. The impact of droughts is most likely to be bigger on the developing countries than the developed. In Sub-Saharan Africa for example, the agricultural sector employs approximately 70-80 percent of the population and contributes nearly 30 percent of GDP, with not less than 40 percent in export composition (Commission for Africa, 2005). However, drought occurrences coupled with the low investment in water supply infrastructure, i.e., irrigation systems, limits the economic performance of, especially the agro-based economies (Faurès and Santini, 2008). Approximately 97 percent of total cropland in Sub-Saharan Africa is dependent on rain-fed subsistence agriculture. This has adverse implications for agricultural production whenever there are episodes of high seasonal rainfall variability (Calzadilla et al., 2013).

An analysis of the effects of droughts on the agricultural sector in Uganda shows that during periods of drought, all crops in the nine farming systems experience a moisture deficit ranging from $128m^3$ to $251m^3$ for perennial crops and $128?242m^3$ for non-perennial crops (DWRM, 2011). Therefore, changes in rainfall and temperature directly affect crop production. Rainfall as the primary source of all fresh water resources determines the recharge of both surface and ground water sources as well as the level of soil moisture, which is central to crop growth. Furthermore, rainfall is also the primary contributor to crop yield variability since it exhibits more volatility than potential crop evapo-transpiration— a key determinant of crop water requirements (Calzadilla et al., 2014). For instance in the United States, the period 2009-2011 saw swaths of west Texas and neighbouring states go through a severe drought. Another prolonged drought which started in 2012 is currently being experienced in the same region and California. The consequence of which has been a depletion of water storage reservoirs hence affecting all forms of social-economic activity in the region (see Galbraith, 2012).

Horridge et al. (2005) used a multi-regional Computable General Equilibrium (CGE) model and found that the severity of the 2002-03 drought cost 1.6 percent of Australia's GDP. Similarly, an econometric analysis on the US agriculture by Reilly et al. (2003) found that higher levels of rainfall were associated with reduced variability in crop yield. This implies that episodes of higher rainfall intensity reduce the yield gap between rain-fed and irrigated agriculture. Hence, the absence of irrigation systems amidst droughts can adversely affect the performance of the agricultural sector.

Whereas the cost of setting up irrigation infrastructure has generally been on the decline, coupled with improvements in the performance of such infrastructure, sub-Saharan Africa has not benefited in this regard for the most part (see Inocencio et al., 2007; Calzadilla et al., 2013). The region still faces higher costs for developing irrigation infrastructure compared to other regions of the world. As a consequence, approximately only 6 percent of the cultivated land area is equipped for irrigation compared to 33.6 percent in Asia and 17.7 percent for the world. In Uganda, less than 1 percent of potential arable land is under irrigation (Svendsen, et al., 2009). The state of irrigation infrastructure has therefore contributed to the region's inability to mitigate the adverse effects of climatic shocks. From a household welfare perspective, rural poverty accounts for 90 percent of total poverty in Sub-Saharan Africa. This is equally the case with Uganda where previous reductions in poverty rates arising from over two decades of sustained economic growth face a likelihood of reversal. The increased prevalence of droughts is posing a threat to the welfare of especially the rural households. Studies by Dorosh et al. (2002; 2003) to analyze the impact of agricultural productivity shocks in Uganda found that broader increases in agricultural productivity have the potential to raise household incomes, with the largest gains going to regions where household consumption is the lowest.

> *"Because agriculture accounts for a large share of incomes for these households, policies and external shocks that affect agriculture, including shifts in world prices, changes in agricultural productivity, and reductions in marketing costs, may have significant effects on rural poverty"* (Dorosh et al., 2003).

Miguel et al. (2004) found that variability in rainfall seasons is highly correlated with household income shocks in Uganda.[2] This implies that droughts impede production and income at a household level which in turn, affects aggregate output and welfare (see Asiimwe and Mpuga, 2007). In fact, Ligon and Sadoulet (2007) show that a percentage point increase in agricultural growth in developing countries, has been associated with a four to six percentage points increase in consumption by the poorest third of the population.

Moula (2008) in a study of the impact of climate change in Cameroon used rainfall and temperature data and found that a 1 percent standard deviation in rainfall and temperature had a negative effect on output. Similarly, Björkman-Nyqvist (2013) showed that rainfall deviations from their historical mean were linked to deviations in agricultural output in Uganda. The agricultural sector in Uganda is a key foreign exchange earner and supplier of inputs to other sectors

[2] Note that Miguel et al. (2004) found a close relationship between rainfall and GDP at a cross-country level. Similarly, Levine and Yang (2006) found that deviations in rainfall from the district level mean were positively associated with agricultural output in Indonesia in the 1990s.

of the economy. In addition, it is a vital source of livelihood since over 76 percent of household income is related to agricultural production. More importantly, 42 percent of households report agriculture as vital source of income while 26 percent cite it as the only source of income (MFPED, 2014). Therefore, any disruptions in agricultural activity can lead to economic instability at a micro and macro-level (see OPM, 2012).

Within the foregoing context, the key objective of this study is to analyse the susceptibility of agricultural output to drought, and the extent to which these effects are propagated within the economy. In this paper, a drought is analysed from the perspective of a short-term climate anomaly. Specifically, the study seeks to: analyse the cost of a drought on the key sectors and macroeconomic variables; suggest possible measures to mitigate these adverse impacts; and highlight key policy options arising from the analysis.

1.1 Contribution

This study differs from most of those in the literature on drought impacts in four ways. First, we use a general equilibrium framework in which data from climate and economic models are used for evaluating the social-economic impacts of a drought. Most studies employ partial equilibrium analysis to estimate the effects of drought on agricultural productivity on specific sectors or crops within a limited geographical area (see Schlenker and Lobell, 2010; Jones and Thornton, 2003). However, partial equilibrium models investigate the effects of drought on specific regions or sectors, holding the potential effects on other sectors constant. The preference for general equilibrium model analysis is in their ability to investigate the economy-wide impacts of shocks. Within a general equilibrium framework, it is possible to trace the consequence on other sectors of an expansion or contraction in any given sector.

Second, even for studies that employ a general equilibrium framework, many use global or multi-regional models e.g., the GTAP-W (see Hertel, 1997; Burniaux and Truong, 2002; Calzadilla et al., 2011; Calzadilla et al., 2014; Berrittella et al., 2007); TERM-H2O (Wittwer, 2012; Horridge and Wittwer, 2008), IMPACT (Rosegrant et al., 2008; Zhu et al., 2008) and IMPLAN (Giesecke, 2011). Given the aggregation and assumptions which are made when developing such models, their accuracy may be reduced. This is because the use of global models quite often dictates that analysis is based on regional averages. In effect, differences between countries in the same region are not accounted for, as local effects are averaged out.

Third, most of these studies have been undertaken in different contexts and for different motivations. For instance, most studies have been undertaken for developed or upper-middle income countries (see e.g., Calzadilla et al., 2014; Calzadilla et al., 2011; for South Africa; Reilly et al., 2003, for the USA, Falloon and Betts, 2009 for Europe). Some studies focus on virtual water trade in specific sectors (Hoekstra and Hung, 2005); while others focus on specific crops within the agricultural sector (see Pauw, et al., 2011; Hertel et al., 2010; Skjeflo, 2013). Even for studies that employ single-country general equilibrium models to analyze the impacts of droughts beyond agriculture i.e., the inclusion of other downstream sectors like manufacturing, some tend to limit their analysis to specific components of the agricultural sector. In addition, the shocks which are imposed on the productivity of primary factors are not informed by actual estimates derived from climate, and econometric models on yield productivity losses (see e.g., Horridge et al., 2005). Therefore, the resulting analysis may present a less than accurate picture of the potential economy-wide effects of drought.

Fourth, isolating drought effects can be analytically challenging especially in instances where data are incomplete or unavailable. Consequently, it may not always be possible to analyze the direct and indirect effects of a drought. Cognisant of such challenges, empirical studies have favoured the use of CGE models in undertaking disaster impact assessments (see, Horridge et al., 2005; Al-Riffai and Breisinger, 2012). Within the CGE literature, most studies have either adopted an ex ante approach to assess the impacts of hypothetical events (see Boyd and Ibarraran, 2009; Skjeflo, 2013), or ex post approaches, in order to evaluate the impacts of historical events (Horridge et al., 2005; Al-Riffai and Breisinger, 2012).

This paper uses a specially developed water-CGE model which has been modified from the official Uganda Applied General Equilibrium (UgAGE) model to analyze the impact of drought on the economy in the short-run. In this paper, the methodology used allows the focus of analysis to highlight the costs of a drought using actual productivity losses from the literature on crop yields. This approach is informed by the fact that the benefits of any intervention can easily be approximated using the estimated costs that would otherwise be avoided by drought mitigation programs. Therefore, in order to establish the benefits of drought mitigation programs, a quantification of the economic impacts of drought needs to be available (Ding et al., 2011). In spite of the importance of accessing the economic impacts of a drought, most studies tend to mix production losses, indemnity payments, and relief costs. In addition, studies focus on agricultural losses only and do not capture the broad range of impacts resulting from drought.

In this paper a highly disaggregated agricultural sector is used to assess the primary effects of a typical drought on the economy. Furthermore, we trace the resultant effects on the economy via the downstream industries, by modelling the drought effects on the agro-processing component of the manufacturing sector. In addition, unlike most studies whose analysis is based on simulating 'what if' scenarios, the modelling procedure in this paper is based on analysis of the impact of productivity losses which have already been measured using rigorous econometric and crop yield models under different climate shock scenarios. As such, the magnitude of productivity losses used in the model is not hypothetical, and can therefore approximate the true would be economy-wide effects of a typical drought within the model limitations. This modelling approach is therefore aimed at providing lessons not only for Uganda, but other developing countries. This is vital because developing countries tend to have similar social-economic structures. As a result, a drought is bound to present somewhat similar challenges.

The rest of the paper is organised as follows: Section 2 highlights Uganda's socioeconomic situation and the prevalence of climate related shocks, a brief synthesis of the literature on the issues under investigation is presented in Section 3, while Section 4 describes the UgAGE model and the modelling framework. Section 5 focuses on the analysis and discussion of the results, while the conclusion and emerging policy issues are presented in Section 6.

2 Situational analysis of drought prevalence in Uganda

Understanding the impact of climatic shocks depends both on the biophysical and socioeconomic factors, with the latter being the key determinants for a community or household's ability to cope with the shock (Akerlof et al., 2013). In this section, we highlight the prevalence of climatic shocks, and their impact on socioeconomic activity in the different regions of the country. The impacts of climate variability create challenges and impose severe losses and hardships especially on the poorest communities. This is largely the case because their livelihoods are often very sensitive to adverse climate change. Mubiru (2010) notes that the most dominant and widespread climate related disasters are due to drought, whose frequency has been observed to be on the increase over the past two decades (GOU et al., 2007). These changes in rainfall patterns and increasing temperatures are swiftly translating into yield reductions in many crops (Glantz et al., 2009).

Drought affects the recharge of ground and surface water sources, as well as soil moisture which is vital for crop production. The impacts of drought are further exacerbated by the fact that although the country is endowed with water resources, their distribution is uneven. For example, the semi-arid areas of the country stretching from Southwest through Central to the Northeast regions of the country (the 'cattle corridor') experience chronic water stress. As a consequence, prolonged droughts always cause severe water shortage, leading to loss of livestock, decline in milk production, food insecurity, increased food prices, and a negative effect on the overall micro and macroeconomy.

Historically, changes in weather patterns have generally had major spillover effects on the rest of the economy due to their effects on the agricultural sector. A number of empirical studies have shown that the agricultural sector is a key sector of the economy in most developing countries (Kalpana et al., 2012). In the case of most developing countries like Uganda, agriculture contributes substantially to the economy's aggregate output. Rainfall across the country is increasingly becoming unreliable and highly variable with respect to its onset, cessation, volume and distribution. The end result has been, either low crop yields or total crop failure (Mubiru et al., 2009). In addition, poor crop husbandry practices and a lack of precise information on rainfall onset, duration, amount and cessation have made smallholder farming, on which the agricultural sector stands, a risky undertaking.

Conventionally, farmers mostly start tilling land after the onset of rainfall. As such, valuable moisture is lost before they finally plant. Consequently, potential crop productivity is never attained as a result of a mismatch between the timing of optimum moisture conditions and the crop's peak water requirements. Essentially, farming has therefore become prone to risks because of the seasonal distribution and variable nature of rainfall in space and time, coupled with its unpredictability (Mubiru et al., 2012). Because of the different rainfall patterns between the South and the North of the country (above latitude 3°N), the cropping systems and dominant crops also differ (Phillips & McIntyre, 2000). The northern region with its unimodal rainfall pattern has a presence of annual crops such as millet, sorghum, groundnuts and sesame. In the South, the rainfall pattern is bimodal, with perennial crops such as banana and coffee. These crops are ordinarily affected by long periods of drought such as those experienced in the North. The cropping systems, including the choice of crop and planting time, are fundamentally dictated by rainfall distribution (see Phillips & McIntyre, 2000).

In a study on climate trends in Uganda, FEWSNET (2012) shows that for the period 1975-2009, the country witnessed an increase in temperature and a reduction in rainfall, with recent record temperatures of more than 0.8 degrees Celsius (°C) for both rain seasons (March–June and June–September). The study notes that given that the standard deviation of annual air temperatures in the mostly affected regions is low (approximately 0.3°C), the reported increases in temperature represent a major change (2+ standard deviations) from the historical climatic set up (see Figure 1). In fact, the study highlights the fact that both spring and summer rains have decreased over the past two and a half decades. A trend analysis of air temperature data equally shows that the degree of recent warming is vast and unprecedented within the past 110 years.

The 1900–2009 rainfall time series data obtained for the crop growing regions in Uganda indicates that rainfall has been approximately 8% lower on average than for the period 1920-1969. Unlike the June–September rainfall which appears to have been declining over a longer time horizon, the decline for the March–June season had only started to occur in recent years.[3] The March-June season, normally registers rainfall totals of more than 500mm, which is adequate for crops and livestock. The FEWSNET (2012) study therefore projects that if the current rainfall trends continue, by 2025, the drying impacts will likely lead to a further contraction of areas that receive adequate rainfall for agricultural activity. Current data shows that most of the areas in the north of the country are likely to be affected by the earlier than usual end of the June-September rain season. Projections for these rainfall reductions span the period 2010–2039, assuming persistence in the observed trends as depicted in Figure 1.

Given the increasing prevalence in the climatic trends, FEWSNET (2012) and Osbahr et al. (2011) indicate that farmers have actually realised these

[3] See FEWSNET (2012) for a mapping in of the contraction in the regions receiving adequate rainfall for viable agricultural activity.

changes in both rainfall and temperature. They note that although farmers perceive changes in climate based only on temperature and not in seasonality, rainfall distribution, amount and intensity, they report to have experienced the fact that the first rainy season (March-May) has become both more variable and less reliable than the second season (September-November). Those findings are in line with the study by Mubiru et al. (2012) which indicated that the first season rains were delayed for as many as 30 days (only starting in mid-April). They however note that the end of the rainy season had more or less stayed the same, irrespective of when it started. The implication of this trend is that the crop growing season has become shorter. Specifically, monthly data indicates a seemingly decreasing trend in the number of rainy days during the months which are crucial for crop growth during the first season. This makes rain-fed agricultural activity to be susceptible to the effects of this increasingly unreliable rainfall pattern.

In Uganda, the variability in rainfall patterns has become a major development policy challenge for the economy. For example, agriculture, a major victim of these changes, contributes approximately 22.7% of GDP (BoU, 2016), and employs over half of the country's labour force. The unpredictable patterns in rainfall have resulted in agricultural activity being undermined considerably and in some cases; entire livelihoods have been adversely affected. As a consequence, these adverse effects are being reflected in rising food prices[4], agricultural input prices used by other sectors like agro-processing; famine, unemployment and reduced agricultural export growth.

Droughts have become frequent and severe thereby posing a threat to prospects for stable long term economic performance. The spatial pattern of warming corresponds largely to the areas associated with reduced rainfall. Temperatures are reported to have increased by up to 1.5°C across much of the country, with typical rates of warming of approximately 0.2°C per decade. This trend is envisaged to continue as well as the expansion of warm aread in the meduim to long term, as the earth's temperature continues to rise. The western and north-western regions of the country are cited as the most affected by these changes. The increasing temperatures pose a threat to coffee prodcution, a key cash crop for the economy. Therefore, the effects of a warmer climate are likely to exacerbate the impact of decreasing rainfall and periodic droughts. Generally, the FEWSNET (2012) findings show that the country is becoming drier and hotter.

Drought is being experienced in the coffee growing areas which is likely to jeopardise the economic viability of such a vital commodity. Uganda's coffee production accounts for approximately 2.5% of global coffee production, and it is Africa's largest producer of Robusta coffee (World Bank, 2011). The coffee sector is extremely important for the economy in terms of employment and foreign exchange earnings. However, the current trend in climatic patterns is bound to put the sector's resilience in serious jeopardy if there are no measures to proactively manage these potential risks, going forward. A case in point was the lack of timely measures to stem the outbreak of the Coffee Wilt Disease

[4] Headline inflation reached double digit from early 2011 (MFPED, 2011).

which is estimated to have caused losses to the sector of approximately US$800 million over the past decade in lost export earnings (World Bank, 2011).

Previous studies have indicated that climatic change will have an adverse impact on the coffee growing regions of Uganda (AFCA, 2012). As a leading export generating approximately 20 percent of the foreign exchange earnings, a reduction in coffee output will result in a negative impact on the economy (UCDA, 2012). Note that coffee accounts for more than 60 percent of cash crop earnings (see Figure 3) and fetches over US $300 million (40 percent) of export revenue for the economy (MFPED, 2011, p.17). In addition, the coffee sub-sector, directly and indirectly employs over 3.5 million households (UCDA, 2012). It is worth noting however that coffee production relies on farmers on small land holdings. These small holder farmers according to Morton (2007) are cited as the most vulnerable to changes in climatic conditions. As such, any disruption in the performance of strategic commodities such as coffee has implications for escalating poverty levels and unemployment in the economy.

Läderach et al. (2011) assert that climatic change is likely to make some areas to become more suitable for coffee production while others will experience diminished suitability. According to the study, most of the coffee growing areas will become unsuitable. They further note that the areas which will become more suitable for coffee will have to compete with other crops.

3 Literature review

The increasing volatility in climate trends with its associated effects has raised the attention of researchers and policy makers especially in the developing countries (Dong et al., 2015). This attention is largely being driven by the fact that empirical evidence cites developing countries as the most susceptible to these changes in climate. Their susceptibility is attributed to their inability to cope with frequent and severe droughts, floods, as well as shifts in temperature and rainfall patterns (IPCC, 2007; Hepworth and Goulden, 2008). In fact, IPCC (2007) in its fourth assessment report warns that by 2100, parts of sub-Saharan Africa are likely to emerge as the most vulnerable, with likely agricultural losses of between 2 and 7 percent of GDP per annum at a national level. These impacts have been projected to occur along with a high population growth which is estimated to reach approximately 2 billion in the region by 2050 (UNDP, 2007). This is will present a strain on the resources of many countries in the region.

Current trends in climate are severe in most regions of the developing world, coupled with the fact that technological change has been dismal. For instance, the Eastern and Southern Africa regions are characterised mainly by semi-arid and sub-humid climates with long dry seasons (Shiferaw et al., 2014). This is in contrast with West Africa where the variability in precipitation is concentrated on relatively short annual timescales and it is directly influenced by the El Niño and La Niña-Southern Oscillation (ENSO) (Nicholson, 2001).[5] ENSO events

[5] El Niño and La Niña, respectively refer to the warming and cooling of surface temperatures (SST) in the equatorial Pacific Ocean. These influence atmospheric circulation and hence

have a strong bearing on the inter-tropical convergence zone (ITCZ), regional monsoon wind circulation, and patterns of rainfall anomalies over many parts of sub-Saharan Africa (see Jury, 2000; Singh, 2006). These climatic changes present a major risk to agriculture which the majority of the world's population especially those in developing countries, highly depend upon (World Bank, 2007; Lobell and Field, 2007; Seo et al., 2009). Bhavnani et al. (2008) note that in sub-Saharan Africa, droughts and floods account for approximately 70-80 percent of losses caused by climate related shocks. Frequent droughts have been observed to reduce the economic growth of many African countries and threaten their long term development prospects (see Jury, 2000; World Bank, 2005; Hellmuth et al., 2007; Brown et al., 2011).

Kurukulasuriya and Rosenthal (2003) argue that the social-economic impact of climate shocks is influenced by a given economy's ability to respond to such shocks. Therefore, the low adaptation capacity in many developing countries implies that households, especially those which depend on agriculture risk being stuck in the vicious cycle of poverty. The consequences of such shocks usually manifest in significant reductions in consumption, and asset depletion (Macours, 2013). It can also hamper household productivity and upward mobility, with inter-generational consequences. For instance, Hoddinott (2006) in their study of climate shocks and their consequences in Zimbabwe shows that women's Body Mass Index (BMI) fell as a result of drought. This has implications for their reproductive health. In addition, households with fewer opportunities for engaging in non-agricultural activity were found to have been severely affected by the drought as there was little scope for mitigation through engagement in other income generating activities.

As studies on susceptibility to climate shocks continue to emerge, it is vital to take stock of the key findings on the impacts of such shocks on economies in regions which have been cited as the most vulnerable. The outcomes from such investigations can serve as lessons for current and future assessments with respect to vulnerability. These investigations provide essential insights into the processes and actions needed to be taken in order to enhance our understanding of the links between climate shocks and social-economic activity especially in the developing world. For agro-based economies like Uganda, temperature and rainfall are the climate variables that directly affect the economy through their primary effects on agricultural production (see Ziervogel et al., 2006). Empirical evidence suggests that an increase in average temperatures can shift the duration of a growing season, thereby affecting crop growth in regions where heat already limits production.

A number of studies have investigated the extent of economic losses induced by droughts. These studies vary both in scope and methodology. The scope differs with respect to the determination of liability, assessment, comparison of different drought mitigation strategies, or exploring the vulnerability and re-

rainfall and temperature in specific regions around the globe. Since the changes in the Pacific Ocean (El Niño and La Niña) and changes in the atmosphere (Southern Oscillation) are inseparable, the acronym ENSO is used to describe the resulting atmospheric changes (Singh, 2006).

silience to a drought. Similarly, the methodologies range from linear programming models, surveys, econometric models, input-output (I-O) models, CGE models, through to hybrid models (see Cochrane, 1997). The I-O and CGE models have been favoured as most suitable for macroeconomic assessments of drought losses. However, the former does not account for behavioural changes and input substitutions. Thus, their results tend to yield upper bound estimates of the losses. Static CGE models on the other hand assume perfect adjustment to equilibrium which may over-estimate the resilience of the responses towards the shock (Rose, 2004; Rose and Liao, 2005).

To ensure robustness, CGE models have got several validation mechanisms for their results. Validity is a key issue in that it ensures that the modelling process: (i) is computationally sound, (ii) uses accurate up-to-date data, (iii) adequately captures behavioral and institutional characteristics of the relevant parts of the economy, (iv) is consistent with history and (v) is based on a model that has forecasting credentials. Among the most favoured validation mechanisms is the back-of-the-envelope (BOTE) technique used to explain results from a particular application of a full-scale model (see Dixon and Rimmer, 2013). Since CGE models are large scale in nature, a BOTE construction provides a mechanism for demonstrating that the computations have been performed correctly, i.e., that the results do in fact follow from the theoretical structure and model database. In addition, BOTE computations help CGE modellers to ensure that the model: is "understood"; isolates those assumptions which "drive" particular results; and can be used to assess the plausibility of particular results by seeing which real world phenomena have been considered, and which ones have been ignored. Finally, by modifying and extending the BOTE calculations, the reader is able to obtain a reasonably accurate idea of how some of the projections would respond to various changes in the underlying assumptions and data (Dixon et al., 1977, pp.194-195). Therefore, their limitations notwithstanding, CGE models are better at investigating issues that require an economy-wide scope.

Finally, the impacts of drought can be both direct and indirect. Identifying an adequate definition for direct and indirect impacts is crucial for economic impact assessments because the bounds set by such definitions dictate the scope of impacts that may or may not be included (Ding et al., 2011). However, consistent classification of the two types of impacts is often lacking. Van der Veen (2004) reviews the different cost concepts used in the economic literature on climate related disasters. For instance, Shiferaw et al. (2014) define the direct impacts as mostly on production, health, livelihoods, household assets, and infrastructure. The indirect impacts cause backward and forward multiplier effects in the economy resulting in a decline in household welfare through their impact on commodity prices (Zimmerman and Carter, 2003; Holden and Shiferaw, 2004). In this paper, the effects of a drought e.g., on output across industries are categorized as the direct economic impacts of drought; while indirect economic impacts stem from the interactions and transactions among industries and sectors. A detailed description of the methodology employed follows in the next section.

4 Methodology

4.1 UgAGE theory and database

We use the Uganda Applied General Equilibrium Model (UgAGE) to simulate and measure the potential effects of a typical drought on the Ugandan economy. The UgAGE model is an ORANI-style CGE model (Dixon et al., 1982; Horridge, 2001) built on a database for Uganda that distinguishes 37 industries and commodities; including 25 within the broader agriculture sector (see Roos et al., 2014). UgAGE also features theory and data linked to the demand and supply of taxable water in the economy, similar to that used in the UPGEM[6] model (Blignaut and Van Heerden, 2009). The detailed agricultural sector in the model, in combination with the model's treatment of water, allows for more accurate analysis of affected industries and commodities due to a drought.

The model's core theoretical structure is typical of most comparative-static CGE models and consists of blocks of equations that describe: i) industry demand for produced inputs and primary factors; ii) industry supply of goods and services; iii) investor demand for inputs to capital formation; iv) household demand; v) export demand; vi) government demand; vii) the composition of final purchasers prices that detail the relationship between basic costs, trade and transport margin costs and taxes; viii) market clearing conditions for commodities and primary factors; and ix) numerous other macro-economic variables and price indices.

The neoclassical assumptions drive the behavior of all private agents in the model. Each industry minimizes cost subject to given input prices and constant returns to scale production function. Zero pure profits are assumed for all industries. Optimising equations determining the commodity composition of industry output are derived subject to a CET function, while functions determining industry inputs are determined by a series of nests. At the top level of this nesting structure intermediate commodity composites and a primary-factor composite are combined using a Leontief production function. Each commodity composite is a CES function of a domestic good and its imported equivalent, incorporating Armington's assumption of imperfect substitutability for goods by place of production (Armington, 1969). The primary-factor composite is a CES aggregate of composite labour, capital and, in the case of primary sector industries, land. Household demand is modelled as a linear expenditure system that differentiates between necessities and luxury goods, while also incorporating the Armington CES nest for choices between imported and domestic versions of each commodity.

The UgAGE database is based on the 2009 Social Accounting Matrix (SAM) for Uganda published by the Uganda Bureau of Statistics (UBOS). From the SAM, the data is transformed to be compatible with the detail and structure of the UgAGE model. This is then aggregated into 37 industries and commodities and a single representative household. The model is implemented and solved using the GEMPACK suite of software programs. GEMPACK eliminates lin-

[6] University of Pretoria General Equilibrium Model.

earisation errors that may occur in ORANI-style models by implementing shocks in a series of small steps and updating the database between steps.[7] Simulation results are reported as percentage change deviations away from an unperturbed baseline represented by the structure of the base year data (Harrison and Pearson, 1996).

4.2 Model closure

In simulating the impact of a typical drought on Uganda, we set up the UgAGE model's policy closure to reflect a short-run time horizon. This choice of closure is a modified version of the standard Dixon-Parmenter-Sutton-Vincent (DPSV) closure (see Dixon et al., 1982 Chp. 19) as it is designed to reflect our interest in the near term impacts of a drought given that such an event is typically restricted to only a couple of years. In line with typical short-run economic theory, the assumptions of our short run policy closure restricts any change in capital stock levels and real wages, but allow endogenous movements in employment, and the rate of return on capital by industry relative to the baseline.

On the expenditure side, we set aggregate real investment to be exogenous while the investment slack variable is endogenous in order to shift the supply curve for capital. Keeping investment as exogenous is informed by the expectation that a typical drought does not drag on long enough to alter aggregate investment decisions over a short-run period. Aggregate real consumption and trade balance (in real terms) are endogenous while the ratio of household consumption to GDP is exogenous. In this regard, aggregate real consumption can hence be interpreted as the aggregate index of welfare. In addition, all tax rates, preference variables and technical change variables are held exogenous in the policy closure, that is, we do not allow them to change relative to their baseline projections as a result of the particular shock under investigation. The nominal exchange rate is set as the numeraire.

4.3 Simulation design

CGE modelling simulations typically analyze the impact of a particular exogenous shock or policy change on the economy, relative to a business-as-usual baseline picture of the economy. In this paper, we impose exogenous shocks on the Ugandan economy that are representative of the direct impacts of a typical drought. The literature identifies two main types of exogenous shocks associated with a drought scenario: the first is a reduction in primary factor productivity of agricultural industries dependent on rainfall, and the second is a partial and temporary closure of downstream manufacturing industries, such as agro-processing.

In calibrating the size of the exogenous shocks on the Ugandan economy, we use a 'quasi sequential' modelling process (see Figure 4). The model is calibrated

[7] In this particular application, we use Euler's multi-step solution technique to eliminate linearisation errors.

first, to obtain the primary factor productivity shocks from the agriculture industries' output data. The benchmark losses in output are based on a summary of crop productivity scenarios derived from a synthesis of studies from different regions of the world, using a variety of models (see Hertel et al., 2010, p.584). The process is quasi because we circumvent the process of having to estimate a profit model for Uganda's agricultural output which would have yielded the primary factor productivity shocks to be used. The approach we use has the potential to yield more robust results (Burke et al., 2011).

Second, we use the results from stage one which have been transformed into technological shocks for the primary factors in the agricultural sector's production function as shocks for our CGE model. Note that the primary factor productivity change has been calibrated for each agricultural industry. As such, we avoid the common approach used in many studies of imposing uniform shocks across all industries. This is vital as each industry is affected differently by a drought. Furthermore, productivity losses in the agricultural sector cause supply constraints to the other sectors of the economy. In our model, the sector of interest is the agro-processing component of the manufacturing sector. In this study, the impact of the productivity shocks is conveyed through factor returns, employment and commodity prices, among other critical macroeconomic variables. Regarding the issue of household welfare, although the model has no micro simulation component, we can still provide some intuitive answers with respect to how it might be affected based on what is known about the nature of households that directly derive their livelihood from the agricultural sector.

The drought shocks are implemented in the UgAGE model by:

1. Reducing primary-factor productivity for each agriculture industry by an appropriate amount to reflect the impact of a typical drought. In general, this implies that more primary factors in the form of capital, labour or land would be required to produce the same amount of output as before the drought, thereby raising input costs and ultimately reducing output. The sizes of the productivity shocks are calibrated and reverse-engineered for each agricultural industry. Specifically, a 10% reduction in output is based on a climate model based study on the impact of different levels of drought severity on crop yield for a number of crops (see Hertel et al., 2010). Since output is endogenous in a CGE model, we used the 'quasi-sequential' modelling procedure to determine the degree of productivity loss which would result in a 10 percent reduction in output for the selected agricultural industries. It is these productivity losses that were finally used in the CGE model as a proxy for the drought impact on the economy.

2. Reducing operational capital stock in the downstream manufacturing sector, specifically agro-processing, by an appropriately weighted amount to reflect the impact of a typical drought. This shock recognizes that a large-scale reduction in the inputs to the agro-processing sector will temporarily cause a shutdown of unused capital. The size of the shock is calibrated and weighted to reflect a temporary shutdown of 10 per cent of the capital

stock in the agro-processing industry, within the broader manufacturing industry. This shock also carries the benefit of mitigating any unrealistic benefits which the industry might receive through a terms of trade change, following the losses in the agricultural sector.

5 Simulation Results

5.1 Macro results

Table 4 presents results for the macroeconomic effects of a drought simulated using the UgAGE model. As noted earlier, the intensity of the drought being simulated can be considered as 'typical'. The results of the simulation reported here may then be used as a benchmark to evaluate the economy-wide effects of more or less severe droughts.

As expected, the drought causes GDP to decline. The exogenous shocks imposed due to the drought directly lower productivity across various agriculture industries, thereby reducing the level of agricultural output leading to the temporary shut-down of capital in the downstream manufacturing industries. We find that with the relatively 'typical' severity level of the drought simulated via the imposed exogenous shocks, GDP declines by 5 percent in the short-run relative to a business-as-usual baseline. As a comparison, OPM (2012, p.10) in a study of impact of the 2010/2011 drought in Uganda reported losses of 7.5 percent of GDP, equivalent to US$1.2 billion. With sticky real wages and fixed capital stocks (outside of the exogenous temporary closure of some capital in the manufacturing industry) assumed in the short-run, the loss in GDP from the supply side stems from reduced employment, lower effective capital stock weighted for the shock to the manufacturing industry and the deterioration in primary factor productivity as a result of the drought. Aggregate employment weighted by the wage bill declines by 5.1 percent. Given the relatively low wages which characterise employment in many sectors, such a decline in employment implies higher job losses induced by the simulated agricultural sector productivity losses.

Real household consumption recorded a decline of 4.6 percent, underscoring the welfare impact of a typical drought on household welfare. The decline in household consumption is slightly less than that of real GDP because the potential decline in household consumption was ameliorated by the gains in the terms of trade of 2.7 percent. The terms of trade improved on account of domestic price increases, resulting in a decline in exports by 5.2 percent.

Ultimately, the lesser decline in household consumption compared to that of real GDP is because of the ability for households to substitute between the now expensive domestically produced output with the relatively cheaper imported versions of the same. The interaction of this income and substitution effect is highlighted by the result for aggregate import volumes, which declines by only 0.24 percent relative to the baseline. In the absence of any other information, with real GDP and consumption falling by between 5 percent and 4.6 percent respectively, our first guess may have been that imports should also fall by approximately that amount in order to reflect the impact of the drought in dampening domestic demand.

However, the net result of imports falling by only 0.24 percent is mainly due to household and industry demands switching away from expensive domestic goods to relatively cheaper imported versions, as predicted by the Armington nests in the theoretical structure of industry and household demand.[8] Among the key export commodities, Maize registered the largest decline in output of 11.9 percent followed by Beans (11.5%). Output in the manufacturing sector as a whole declined by 13.2 percent, on account of the partial shutdown of capital in the industry in the model and the resulting rise in input costs due to the drought. Not surprisingly, imports of tradedables such as Beans and Manufactured goods increased relative to the baseline following the Armington substitution effect, thereby registering increases of 11.2 percent and 1.3 percent, respectively.

5.2 Losses in industry output

In Table 5, we present results for the impact of a drought on output for the selected industries. Outputs for the agricultural industries decline dramatically with Coffee being the worst affected. The negative down-stream effects are seen in the manufacturing sector via the decline in agro-processing activities within the sector.

It is worth noting that the large negative effects on output are not matched with similar reductions in employment except for Coffee farming which registered a decline in labour input of 17 percent. Indeed employment, especially in the agriculture industries declined due to the drought but not to the same degree as the decline in output. This is due to the fact that a considerable proportion of the decline in output emanates from reduced productivity of both inputs. With fixed capital, as per the short-run closure rules, the loss in employment defined by effective labour input is minimal.

Horridge et al. (2005) in their study of drought in Australia similarly found minimal declines in employment defined by physical labour units. This was attributed to the fact that the agricultural sector in Australia is characterized by owner-operators. In Uganda, changes in employment have a direct impact on household welfare via its effect on households' earning potential. The effect of a drought on household welfare can also be linked to changes in the consumer price index. Indeed, as the results in Table 4 indicate, household consumption is compromised, the fact that employment is relatively less affected, notwithstanding. This can be attributed to the low earnings associated with agricultural sector employment. As such, the rise in prices has implications for household welfare as most agricultural households often have lower incomes, with equally lower possibilities of compensating through non-farm income generating activities.

[8] See Armington (1969) for a thorough exposition.

Finally, it is fascinating to note that the impact of a typical drought on industry output is driven mainly by the direct effect of a drought on the productivity losses than the short-run elasticity. For example, a commodity like Groundnuts with a higher short-run supply elasticity of 0.32 registered a lower decline in output of 8.1 percent compared to Maize with a lower short-run elasticity of 0.25, but with output losses of 11.9 percent. This is due to the capital-labour ratio requirements for each of these industries. Results show that industries with higher capital-labour ratios were more severely affected by this productivity shock than those with lower ratios. The sectoral impact of a shock depends on the extent to which industries can substitute their inputs. In particular, the impact of a shock on a given industry hinges on the capital-labour intensity and how elastically each industry can substitute between its inputs and also vary their quantities. For instance, capital is fixed in the short-run. In this instance, a drought shock alters the relative prices of each good which causes each industry's input cost share to vary. In addition, studies on crop yields showed different crops are affected differently by drought even when it is of the same magnitude (see Hertel et al., 2010). These differences were accounted for in the implementation of the shock as described in sub-section 4.3 and also partly explain the observed differences.

5.3 Decomposition analysis of the changes in industry output

Table 6 presents results of the Fan decomposition[9] analysis of the results of the impact of a drought on industry output. If we take Maize for example, we see that the predicted changes in domestic output are derived from three effects:

i) The local market effect. i.e., changes in domestic demand for maize, whether domestically-produced or imported;

ii) The domestic share effect. i.e., a shift in local usage of maize, from the imported to the domestically produced; or

iii) The export effect. i.e., an increase in the export demand for maize.

In most cases, these effects tend to work in different directions. However, the results show that the effects of a drought adversely affect output thereby reducing all the components of the decomposition. The essence of the Fan decomposition is to show the relative magnitudes of these three contributions to output change. Table 6 gives a breakdown of the changes in shares in total industry output for some selected industries.

In Table 6, we select a few strategic industries for our analysis. For the selected industries, the local market contribution largely explains the reduction in overall output for all the industries. This highlights the effect of a drought in depressing overall demand for agricultural related commodities. This is largely driven by the effect of drought on output prices. Among the key export commodities, Beans registered the largest decline in export demand of 16.9 percent,

[9] Named after Fan Ming-Tai of the Academy of Social Sciences, Beijing Institute of Quantitative and Technical Economics.

contributing 6.6 percent to the fall in overall industry output of 11.3 percent. Similarly, Maize had a drop in export demand of 9.5 percent, contributing 4.9 percent to its overall drop in industry output of 11.9 percent.

In terms of a shift from the usage of local output from domestic to imported, we see that a drought induces a decline in the usage of relatively expensive local output, thereby increasing the amount of imported versions of the good, except for Wheat. This could be explained by the fact that domestic Wheat production is limited coupled with a slight decline in aggregate imports which were not bolstered by the terms of trade gains. The demand for locally produced output declined, with the largest decline being for manufactured output. This is explained by the cost of the intermediate agro-inputs as well as output declines which the manufacturing sector has to contend with, in the production of its final outputs. In this case, the drought only compounds the constraints to the performance of the manufacturing industry. An outstanding feature of the results is the fact that the drought causes a reduction in demand for staple commodities, with Matoke, registering the highest decline (10.8%), followed by Potatoes (7.1%), Cassava (6.9%), Maize (5.2%). Millet registered the lowest decline of 5.1%. The results underscore the adverse effects of a drought on the domestic and external sectors of the economy. Domestically, and at a micro level, it is clear that household welfare gets compromised from output decline and the rising prices, especially of staple commodities. At a macro level, higher prices hamper exports which affect foreign exchange earnings. This is critical, given the fact that the bulk of Uganda's exports are agro-based.

In the foregoing analysis, it is also important to be mindful of the model limitations. Specifically, the UgAGE model assumes that producers are profit maximising price takers and that households have access to well-functioning markets. The reality in Uganda, as is indeed in most developing countries, is that there are high transaction costs in the agricultural sector, and limited access to credit markets. In practice, these are factors which can compound the impact of a drought on the economy. Such factors in turn curtail the adaptive capacity of an economy at a micro level. In instances where multiple markets for goods which are produced and consumed by especially the agricultural households fail, production decisions become intertwined with consumption decisions (see De Janvry et al., 1991; Skjeflo, 2013). Cognisant of this reality, Löfgren and Robinson (1999) and Holden et al. (1999) have attempted to account for this inter-linkage in computable general equilibrium models of developing countries.[10]

Given the increasing frequency and severity of drought, future studies should account for market imperfections, and risk within a dynamic framework. This is critical given the fact that microeconometric studies on adaptation to climate anomalies in sub-Saharan Africa have found that farmers are already using a wide range of coping strategies to deal with such shocks. Coping mechanisms include the use of drought resistant crop varieties, livestock, tree planting; soil

[10] These studies add a micro-simulation component which captures detailed welfare measures in their CGE models.

conservation methods and diversification of their economic activities (see Below et al., 2010). However, empirical evidence still shows that adaptation is still constrained by certain factors, such as access to credit, property rights with respect to land, and irrigation (Deressa et al., 2009). In Uganda, less than 1 percent of the arable land is under irrigation.

Critical issues such as household adaptation through adjusting to changes in market prices are considered endogenous in computable general equilibrium modelling. Similarly, adaptation strategies such as adoption of drought resistant crop varieties, improved infrastructure and investment in irrigation, are not included in our model. A number of institutional and social structures which are critical to highlighting the true cost of a drought are not easily modelled using economy-wide techniques. Adger (2006) therefore suggests that quantitative assessments such as the ones employed in this study can be combined with qualitative studies that take into account much more complex social and institutional contexts in order to have a more comprehensive picture that more closely captures the actual cost of such shocks.

6 Conclusion

The UgAGE model used allows for the disaggregation of the impacts of drought through agricultural sector productivity losses. In this article, we focused on the short-run economy-wide costs of a typical drought. However, it is possible that the costs of a drought can easily persist into the medium to long term. In fact, as current climate trends suggest, the frequency and severity of drought is on the increase (IPCC, 2007). This implies that whereas a single drought episode might be short-lived, the increasing frequency can result in the effects of individual drought episodes overlapping, thereby presenting costs to the economy are both persistent and amplified. There is already evidence of how these changes in seasonality are affecting crop production in Uganda (see Mubiru et al., 2012).

The results from this study present critical lessons especially for developing countries that are dependent on agriculture as a source of food security, and export earnings, and still consider it as a base for industrialisation through agro-processing. As the findings indicate, this sector is sensitive to climate variability. Furthermore, as it is always the case, demand for staple crops is often inelastic, and agriculture still contributes to a large share of household income both directly and indirectly. In Uganda, a survey by the Uganda Bureau of Statistics (see MFPED, 2014) shows that 42 percent of the population derives part of their income from agriculture related activities, while 26 percent depend on agriculture as the only source of income. Our results are a further confirmation of the importance of this link.

Given the fact that the agriculture sector in Uganda is heavily dependent on smallholder rain-fed agriculture, it is vital to explore avenues for tapping into alternative sources of water for production. However, it is critical to note that the majority of households which heavily depend on agriculture are mostly poor. Therefore, interventions such as irrigation could focus on areas that are highly drought prone. In such areas, efficient water use practices such as small-scale irrigation can have a high potential to alleviate the cost of a drought both at a micro and macro level.

In addition, irrigation should be adopted together with other land management practices that promote soil moisture conservation. This will help in converting more evaporation into transpiration thereby greatly increasing agricultural output without necessarily placing additional pressure on the existing water sources. The rural economy - the backbone of the agricultural sector needs further adaptation mechanisms in the face of more volatile climatic trends.

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References

[1] ACF (2012). Seventh (7th) African Scientific Workshop, Addis Ababa, Ethiopia, African Coffee Scientific Conference. http://www.eafca.org/events/scientificconference.asp.

[2] Adger, W. N. (2006). Vulnerability. *Global Environmental Change,* 16, 268-281.

[3] Akerlof, K., Maibach, E. W., Fitzgerald, D., Cedeno, A. Y., & Neuman, A. (2013). Do people "personally experience" global warming, and if so how, and does it matter? *Global Environmental Change,* 23, 81-91.

[4] Al-Riffai, P., & Breisinger, C. (2012). Drought in Syria: An assessment of impacts and options for improving the resilience of the poor. *Quarterly Journal of International Agriculture,* 51(1), 21-49.

[5] Armington, P. S. (1969). *A theory of demand for products distinguished by place of production.* IMF Staff Papers, 16, 159-78.

[6] Asiimwe, J. B., & Mpuga, P. (2007). *Implications of rainfall shocks for household income and consumption in Uganda.* African Economic Research Consortium (AERC) Research Paper 168.

[7] Bekele, S., Tesfaye, K., Kassie, M., & Abate, T. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes,* 3, 67-79.

[8] Below, T., Artner, A., Siebert, R., & Sieber, S. (2010). *Micro-level practices to adapt to climate change for African small-scale farmers.* IFPRI

Discussion Papers. International Food Policy Research Institute, Washington D.C.

[9] Berrittella, M., Hoekstra, A. Y., Rehdanz, K., Roson, R., & Tol, R. S. J. (2007). The economic impact of restricted water supply: A computable general equilibrium analysis. *Water Research,* 41, 1799-1813.

[10] Bhavnani, R., Vorzorgebe, S., Owor, M., & Bousquet, F. (2008). *Report on the status of disaster risk reduction in the sub-Saharan Africa region.* Commission of the African Union, United Nations and the World Bank. Available from: http://www.unisdr.org/files/2229DRRinSubSaharanAfricaRegion.pdf.

[11] Björkman-Nyqvist, M. (2013). Income shocks and gender gaps in education: Evidence from Uganda. *Journal of Development Economics,* 105, 237-253.

[12] Blignaut, J., Van Heerden, J. H., & Horridge, M. (2008). Integrated water and economic modelling of the impacts of water market instruments on the South African economy." *Ecological Economics,* 66(1), 105-116.

[13] BoU (2016). Annual Report for 2014/15 Financial year, Bank of Uganda, Kampala-Uganda.

[14] Boyd, R., & Ibarraran, M. E. (2009). Extreme climate events and adaptation: An exploratory analysis of drought in Mexico. *Environment and Development economics,* 14(3), 371-395.

[15] Brown, C., Meeks, R., Hunu, K., & Yu, W. (2011). Hydro climate risk to economic growth in sub Saharan Africa. *Climate Change*, 106, 621-647.

[16] Burke, M., Dykema, J., Lobell, D., Miguel, E., & Satyanath, S. (2011). *Incorporating climate uncertainty into estimates of climate change impacts, with applications to US and African agriculture.* National Bureau of Economic, Research.

[17] Burniaux, J. M., & Truong, T. P. (2002). *GTAP-E: An energy environmental version of the GTAP model.* GTAP Technical Paper No.16.

[18] Calzadilla, A., Rehdanz, K., & Tol, R. S. J. (2011). Water scarcity and the impact of improved irrigation management: A computable general equilibrium analysis. *Agricultural Economics,* 42, 305-323.

[19] Calzadilla, A., Zhu, T., Rehdanz, K, Tol, R. S. J., & Ringler, C. (2013). Economy-wide impacts of climate change on agriculture in Sub-Saharan Africa. *Ecological Economics,* 93, 150-165.

[20] Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S. J., & Ringler, C. (2014). Climate change and agriculture: Impacts and adaptation options in South Africa. *Water Resources and Economics,* 5, 24-48.

[21] Cochrane, H. (1997). *Economic impacts of a Midwestern earthquake.* In: NCEER Bulletin, 11(1), 1-5.

[22] Commission for Africa (2005). *Our common interest:* Report of the Commission for Africa. Commission for Africa, London.

[23] De Janvry, A., Fafchamps, M., & Sadoulet, E. (1991). Peasant household behaviour with missing markets: some paradoxes explained. *Economic Journal,* 101, 1400-1417.

[24] Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19, 248-255.

[25] Ding, Y., Hayes, M. J., & Widhalm, M. (2011). Measuring economic impacts of drought: A review and discussion", Disaster Prevention and Management: *An International Journal,* 20 (4), 434-446.

[26] Dixon, P. B., Parmenter, B. R., Sutton, J., & Vincent, D. P. (1982). *ORANI: A multi-sectoral model of the Australian Economy.* North-Holland, Amsterdam.

[27] Dixon, P. B., Parmenter, B. R., Ryland, G. J., & Sutton, J. (1977). *ORANI, a general equilibrium model of the Australian Economy: Current specification and illustrations of use for policy analysis.* Volume 2 of the First Progress Report of the IMPACT Project. Australian Government Publishing Service, Canberra.

[28] Dixon, P. B. & Rimmer, M. T. (2013). *"Validation in computable general equilibrium modelling".* Handbook of Computable General Equilibrium Modelling, Elsevier.

[29] Dong, Z., Pana, Z., Ana, P., Wanga, L., Zhanga, J., He, D., Hana, H., & Pana, X. (2015). A novel method for quantitatively evaluating agricultural vulnerability to climate change. *Ecological Indicators,* 48, 49-54.

[30] Dorosh, P., El-Said, M., & Lofgren, H. (2002). *Welfare and production effects of technical change, market incentives and rural incomes: A CGE analysis of Uganda's agriculture. Washington.* The International Food Policy Research Institute.

[31] Dorosh, P., El-Said, M., & Lofgren, H. (2003). *Technical change, market incentives and rural incomes: A CGE analysis of Uganda's agriculture.* Paper presented at the 25^{th} International conference of agricultural economics, Durban, South Africa.

[32] DWRM (2011). National water resources assessment draft report. Directorate of Water Resources Management, Ministry of Water and Environment- Government of Uganda.

[33] Esikuri, E. E. (2005). *Mitigating drought-long term planning to reduce vulnerability.* Environment Strategy Notes, No.13, The World Bank, Washington D.C.

[34] Falloon, P. D., & Betts, R. A. (2009). Climate impacts on European agriculture and water management in the context of adaptation and mitigation- the importance of an integrated approach. *Science of the Total Environment,* 408, 5667-5687.

[35] Faurès, J. M., & Santini, G. (Eds.), (2008). *Water and the rural poor: Interventions for improving livelihoods in Sub-Saharan Africa.* Food and Agricultural Organization of the United Nations, Rome.

[36] FEWSNET (2012). A climate trend analysis of Uganda. Famine Early Warning Systems Network. Available from: http://pubs.usgs.gov/fs/2012/3062/FS2012-3062.pdf. [Accessed: 25th April 2013 at 21:49 CET].

[37] Galbraith, K. (2012). Texas drought sparked water worries for industry. Updated February 2012. Available from: http://www.texastribune.org/texas-environmental-news/water-supply/texas-drought-sparked-water-worries-industry/.

[38] Giesecke, J. A. (2011). "Development of a large-scale single US region CGE model using IMPLAN Data: A Los Angeles county example with a productivity shock application". *Spatial Economic Analysis*,6(3), 331-350.

[39] Glantz, M. H., Gommes, R., & Ramasamy, S. (2009). Coping with a Changing Climate: considerations for adaptation and Mitigation in Agriculture. Food and Agriculture Organization of the United Nations Rome.

[40] GOU, GEF, UNEP (2007). *Climate change: Uganda National Adaptation Programmes of Action.* Government of Uganda, Environmental Alert, Global Environment Facility and United Nations Environmental Programme- Kampala-Uganda.

[41] Haddad, E. A., Porsse A. A., & Pereda, P. C. (2012). *Territorial economic impacts of climate anomalies in Brazil.* Working Paper No. 2012-20, Department of Economics, University of São Paulo (FEA-USP). Available from: http://www.fea.usp.br/feaecon/RePEc/documentos/HaddadPorssePereda20WP.pdf.

[42] Harrison, W. J., & Pearson, K. R. (1996). Computing solutions for large general equilibrium models using GEMPACK*. Computational Economics,* 9, 83-127.

[43] Hellmuth, M. E., Moorhead, A., Thomson, M. C., & Williams, J. (2007). *Climate risk management in Africa. Learning from practice.* International Research Institute for Climate and Society (IRI), Columbia University New York, USA.

[44] Hepworth, N., & Goulden, M. (2008). *Climate change in Uganda: Understanding the implications and appraising the response.* LTS International, Edinburgh. Unpublished.

[45] Hertel, T. W. (1997). *Global trade analysis: Modelling and application.* Cambridge University Press, Cambridge.

[46] Hertel, T. W., Burke, M. B., & Lobell, D. B. (2010). The poverty implications of climate-induced crop yield changes by 2030. *Global Environmental Change,* 20, 577-585. DOI: http://dx.doi.org/10.1016/j.gloenvcha.2010.07.001.

[47] Hoddinott, J. (2006). Shocks and their consequences across and within households in rural Zimbabwe. *The Journal of Development Studies,* 42, 2, 301-321. DOI: 10.1080/00220380500405501.

[48] Hoekstra, A. Y., & Hung, P. Q. (2005). Globalization of water resources: International virtual water flows in relation to crop trade. *Global Environmental Change*, 15, 45-56.

[49] Holden, S. T., & Shiferaw, B. (2004). Land degradation, drought and food security in a less favoured area in the Ethiopian highlands: A Bio-economic model with market imperfections. *Agricultural Economics,* 30, 31-49. DOI: http://dx.doi.org/10.1016/j.wace.2014.04.004.

[50] Holden, S. T., Taylor, J. E., & Hampton, S. (1999). Structural adjustment and market imperfections: A stylized village economy-wide model with non-separable farm households. *Environmental and Development Economics*, 4, 69-87.

[51] Horridge, J. M. (2001). *ORANI-G: A generic single-country computable general equilibrium model.* Practical GE Modelling course 18-22:2001. Centre of Policy Studies, Monash University.

[52] Horridge, M., Madden, J., & Wittwer, G. (2005). The impact of the 2002-2003 drought on Australia. *Journal of Policy Modelling,* 27(3), 285-308, DOI: http://dx.doi.org/10.1016/j.jpolmod.2005.01.008.

[53] Horridge, M., & Wittwer, G. (2008). Sino-TERM, a multi-regional CGE model for China. *China Economic Review,* 29, 628-634. Available from: http://info.worldbank.org/etools/docs/library/236067/Singh_DroughtRiskAfrica.pdf. (Accessed 25^{th} April 2015).

[54] Inocencio, A., Kikuchi, M., Tonosaki, M., Maruyama, A., Merrey, D., Sally, H., & De Jong, I. (2007). *Costs and performance of irrigation projects: A comparison of sub-Saharan Africa and other developing regions.* International Water Management Institute Research Report 109. International Water Management Institute, Colombo, Sri Lanka.

[55] IPCC (2007). *Technical summary.* In: Parry, M.L., Canziani, O.F., Palutikof, J.P., et al.(Eds.), Climate Change 2007: Impacts, adaptation, vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

[56] Jones, P. G., & Thornton, P. K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change,* 13, 51-59.

[57] Jury, M. R. (2000). Economic impacts of climate variability in South Africa and development of resource prediction models. *Journal of Applied Meteorology,* 41, 46-55.

[58] Kalpana, S., & Narayan, S. (2012). Investigating the Impact of Agriculture and Industrial Sector on Economic Growth of India. OIDA International Journal of Sustainable Development, Vol. 5, No. 5, pp. 11-21, 2012.

[59] Kurukulasuriya, P., & Rosenthal, S. (2003). *Climate change and agriculture: A review of impacts and adaptations.* Climate Change Series Paper 91, World Bank, Washington D.C.

[60] Läderach, P., M, Lundy, A, Jarvis, J, Ramirez., E, Prez-Portilla., K, Schepp, & Eitzinger, A. (2011). Predicted impact of climate change on coffee supply chains. The Economic, Social and Political Elements of Climate Change. Part 4, 703–723. [Online] Available from: http://agrilife.org/borlaug3/files/2011/07/Impact-of-climate-change-on-coffee-supply-chains.pdf.

[61] Levine, D. I., & Yang, D. (2006). *"A note on the impact of local rainfall on rice output in Indonesian districts."* Mimeo, University of California, Berkeley and University of Michigan.

[62] Ligon, E., & Sadoulet, E. (2007). *Estimating the effects of aggregate agricultural growth on the distribution of expenditure.* Background paper prepared for the World Development Report 2008, World Bank, Washington D.C.

[63] Lobell, D. B., & Field, C. B. (2007). Global scale climate-crop yield relationships and the impacts of recent warming. *Environmental Research,* 2, 1-7.

[64] Löfgren, H., & Robinson, S. (1999). Non-separable farm household decisions in a computable general equilibrium model. *American Journal of Agricultural Economics,* 81, 663-670.

[65] Macours, K. (2013). Volatility, agricultural risk, and household poverty: micro-evidence from randomized control trials. *Agricultural Economics,* 44, Supplement 79-84.

[66] MFPED (2011). Background to the Budget for the 2011/12 Fiscal Year. Ministry of Finance Planning and Economic Development-Government of Uganda, Kampala-Uganda.

[67] MFPED (2014). Poverty status report 2014. Ministry of Finance Planning and Economic Development, Government of Uganda-Kampala. Available from: *http://www.finance.go.ug*. (Accessed: 20^{th} April 2014).

[68] Miguel, E., Satyanath, S., & Sergenti, E. (2004). Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy,* 112(4), 725-753.

[69] Moula, E. L. (2009). An Empirical assessment of the impact of climate change on smallholder agriculture in Cameroon. *Global and Planetary Change,* 67, 205-208. Available from: http://dx.doi.org/10.1016/j.gloplacha.2009.02.006.

[70] Morton, J. F. (2009). The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences, U.S.A., 104 (2007), pp. 19680–19685.

[71] Mubiru, D. N. (2010). *Climate change and adaptation options in Karamoja.* Available from: http://www.fao.org/fileadmin/user_upload/drought/docs/Karamoja%20Climate%20Change%20and%20Adaptation%20Options.pdf. (Accessed: 13^{th} April 2015).

[72] Mubiru, D. N., Agona, A., & Komutunga, E. (2009). Micro-level analysis of seasonal trends, farmers' perception of climate change and adaptation strategies in eastern Uganda. Paper presented at: International Conference on Seasonality; 2009 Jul 08–10; Brighton, UK. Brighton: Institute of Development Studies, University of Sussex; 2009. Available from: http://www.event.future-agricultures.org.

[73] Mubiru, D. N, Komutunga E, Agona A, Apok A, & Ngara T. (2012). Characterising agro-meteorological climate risks and uncertainties: Crop production in Uganda. S Afr J Sci. 2012; 108(3/4), Art. #470, 11 pages. Available from: http://dx.doi.org/10.4102/sajs.v108i3/4.470.

[74] NEMA (2010). *State of the environment report for Uganda 2010.* National Environmental Management Authority (NEMA), Kampala-Uganda. Available from: http://www.nemaug.org.

[75] Nicholson, S. E. (2001). Climatic and environmental change in Africa during the last two Centuries. *Climate Research,* 17, 123-144.

[76] OPM (2012). *The 2010-2011 integrated rainfall variability impacts, needs assessment and drought risk management strategy.* Department of Disaster Management-Office of the Prime Minister, Government of Uganda.

[77] Osbahr, H., Dorward, P., R, Sterns, & Cooper S. (2011). Supporting Agricultural Innovation in Uganda to Respond to Climate Risk: Linking Climate Change and Variability with Farmer Perceptions. Experimental Agriculture 47, 293–316.

[78] Pauw, K., Thurlow, J., Bachu, M., & Van Seventer, D. E. (2011). The economic costs of extreme weather events: A hydro-meteorological CGE analysis for Malawi. *Environment and Development Economics,* 16(2), 177-198. DOI: http://dx.doi.org/10.1017/S1355770X10000471.

[79] Phillips, J., & McIntyre, B. (2000). ENSO and inter-annual rainfall variability in Uganda: Implications for agricultural management. International Journal of Climatology, 2000;20:171–182. http://dx.doi.org/10.1002/(SICI)1097-0088(200002)20:2<171::AID-JOC471>3.0.CO;2-O.

[80] Reilly, J., Tubiello, F., McCarl, B., Abler, D., Darwin, R., Fuglie, K., Hollinger, S., Izaurralde, C., Jagtap, S., Jones, J., Learns, L., Ojima, D., Paul, E., Paustian, K., Riha, S., Rosenberg, N., & Rosenzweig, C. (2003). U.S agriculture and climate change: New results. *Climate Change,* 57, 43-69.

[81] Roos, E. L., Adams, P. D., & van Heerden, J. H. (2014). Construction a CGE database using GEMPACK for an African country. *Computational Economics.* DOI: 10.1007/s10614-014-9468-1.

[82] Rose, A. (2004). *"Economic principles, issues, and research priorities in hazard loss Estimation".* In: Modeling spatial and economic impacts of disasters, Y. Okuyama and S. E. Chang, eds. New York, Springer, 13-36.

[83] Rose A., & Liao S. Y. (2005). Modelling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. *Journal of Regional Science,* 45(1), 75-112.

[84] Rosegrant, M. W., Ringler, C., Msangi, S., Sulser, T. B., Zhu, T., & Cline, S. A. (2008). *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description.* Washington, D.C.: International Food Policy Research Institute (IFPRI) 42 pages. http://www.ifpri.org/sites/default/files/IMPACTwater.pdf.

[85] Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters,* 5 014010 (8pp). DOI:10.1088/1748-9326/5/1/014010.

[86] Seo, N., Mendelsohn, R., Dinar, A., Hassan, R., & Kurukulasuriya, P. (2009). A Ricardian analysis of the distribution of climate change impacts on agriculture across agro-ecological zones in Africa. *Environmental Resource Economics,* 43, 313-332. DOI: 10.1007/s10640-009-9270-z.

[87] Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B. M., & Menkir, A. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes,* 3, 67-79.

[88] Singh, M. (2006). *Identifying and assessing drought hazard and risk in Africa.* Regional conference on insurance and reinsurance for natural catastrophe risk in Africa, Casablanca, Morocco, November 12–14, 2006.

[89] Skjeflo, S. (2013). “Measuring vulnerability to climate change -Why markets matter”. *Global Environmental Change,* 23, 1694-1701.

[90] Svendsen, M., Ewing, M., & Msangi, S. (2009). *Measuring irrigation performance in Africa,* IFPRI Discussion Paper 00894. Available from: http://www.ifpri.org/sites/default/files/publications/ifpridp00894.pdf. (Accessed: 10.10.2014)

[91] UBOS (2012). *Statistical abstract,* Uganda Bureau of Statistics. Kampala: The Republic of Uganda.

[92] UBOS (2015). Statistical abstract, Uganda Bureau of Statistics, Kampala-Uganda.

[93] UCDA (2012). Monthly Reports. Uganda Coffee Development Authority. [Online] Available from: http://www.ugandacoffee.org/.

[94] UNDP (2007). *Human development report 2007/2008. Fighting climate change: Human solidarity in a divided world.* http://hdr.undp.org/sites/default/files/hdr_20072008_summary_english.pdf.

[95] Van der Veen, A. (2004). “Disasters and economic damage: Macro, meso and micro approaches.” *Disaster Prevention and Management*, 13(4), 274-279.

[96] Wittwer, G. (2012). *Economic modelling of water: The Austrian CGE experience.* Global Issues in Water Policy 3. DOI: 10.1007/978-94-007-2876-9_5.

[97] World Bank (2005). *Managing water resources to maximize sustainable growth: A country water resources assistance strategy for Ethiopia.* The World Bank, Washington D.C.

[98] World Bank (2007). *World development report 2008: Agriculture for development.* Washington D.C: The World Bank.

[99] World Bank (2011). Ugandan Coffee Supply Chain Risk assessment. A Report by the Agricultural Risk Management Team of the Agricultural and Rural Development department of the World Bank.

[100] Zhu, T., Ringler, C., & Rosegrant, M. W. (2008). *Development and validation of a global hydrology model for climate change impact assessment.* Working paper. International Food Policy Research Institute, Washington, D.C.

[101] Ziervogel, G., Bharwani, S., & Downing, T. E. (2006). Adapting to climate variability: Pumpkins, people and policy. *Natural Resources Forum,* 30(4), 1477-8947. DOI: 10.1111/j.1477-8947.2006.00121.x.

[102] Zimmerman, F. J., & Carter, M. R. (2003). Asset smoothing, consumption smoothing and reproduction of inequality under risk and subsistence constraints. *Journal of Development Economics,* 71, 233-260.

Table 4: Results of main macro variables (Percentage change deviation)

Variable description	Percentage change
Contribution of the Balance of Trade to GDP	-1.14
Aggregate employment	-5.13
Ratio, consumption/GDP	0
Average nominal wage	1.31
GDP price index	1.83
Terms of trade	2.67
Aggregate investment price index	0.24
Aggregate capital stock	-0.96
Consumer price index	1.31
Exports price index	2.67
Export volume index	-5.20
Import volume index	-0.24
Real GDP	-5.01
Aggregate primary factor use	-2.86
Real household consumption	-4.61
Aggregate real government expenditure	-4.61

Source: Author's computations.

Table 5: Results at sectoral level (Percentage changes)

		Category		
Commodity	Percentage change	Export	Staple	Agro-processing
Maize	-11.90	*	*	*
Millet	-11.88		*	
Beans	-11.35	*	*	
Wheat	-7.04			*
Matoke	-10.62		*	
Simsim	-10.35	*	*	*
Sorghum	-6.93		*	
Cassava	-6.93		*	
Potato	-7.07		*	
Groundnuts	-8.08		*	*
Coffee	-13.25	*		*
Manufacturing	-13.25			

Source: Author's computations.

Table 6: Effect of a drought on the shares of industry output

Industry	Local Market	Domestic share	Export	Total
Maize	-5.16	-1.83	-4.91	-11.90
Rice	-13.05	0.01	0*	-13.05
Wheat	-11.99	4.42	0.53*	-7.04
Cassava	-6.96	0	0.03*	-6.93
Potato	-7.07	-0.01	0.001*	-7.07
Tobacco farming	-0.16	-0.003	-0.03	-0.20
Groundnuts	-8.52	-0.05	0.48*	-8.08
Millet	-5.25	0	-6.64	-11.89
Sorghum	-3.00	-0.89	-3.05	-6.93
Beans	-4.75	-0.06	-6.55	-11.35
Coffee farming	-13.26	0.01	0*	-13.24
Tea farming	-2.25	-0.01	-5.05	-7.31
Vanilla	-0.004	0	-0.16	-0.16
Matoke	-10.80	0	0.18	-10.62
Forestry	-2.15	0.03	0.01*	-2.11
Manufacturing	-3.30	-6.65	-3.08	-13.03

Note: * Denotes industries whose output is classified as non-tradable in the model.

Source: Author's computations.

Figure 1: *Smoothed 1900-2009, March–June and June–September Rainfall and Air temperature time series for the crop-growing regions.*

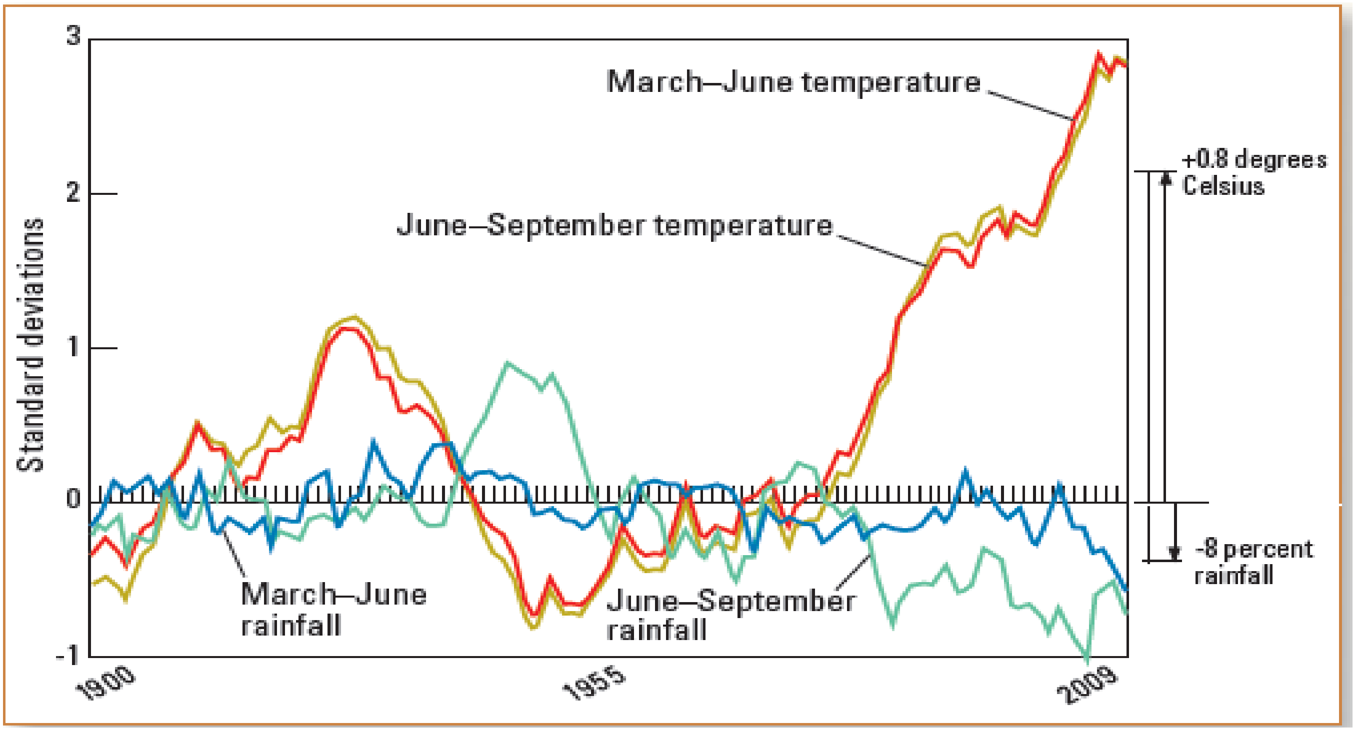
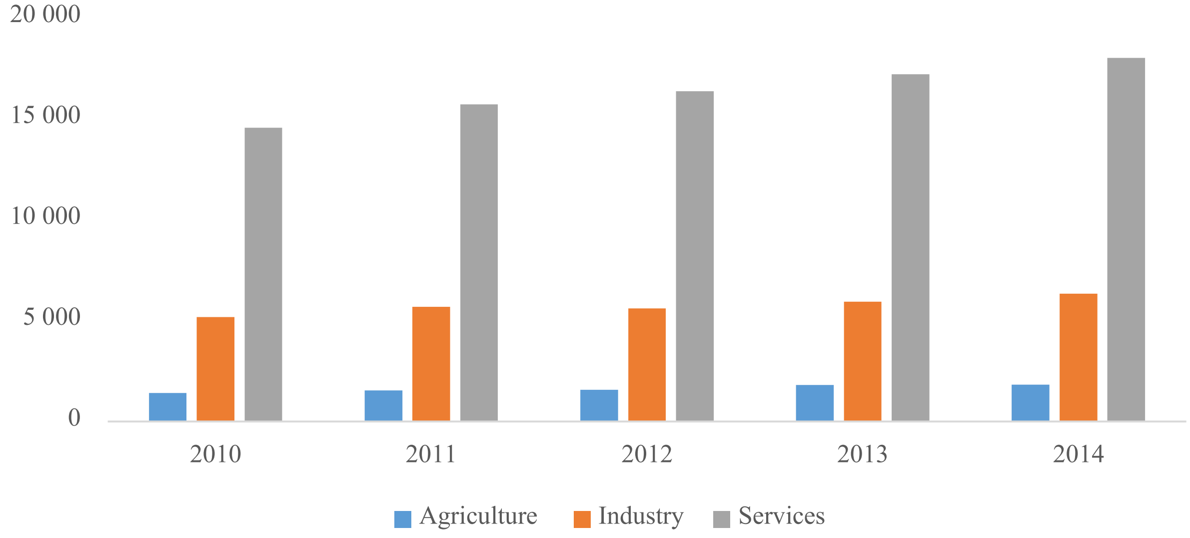


Figure 2: GDP by economic activity at Constant (2009/10) Prices (UGX billions)



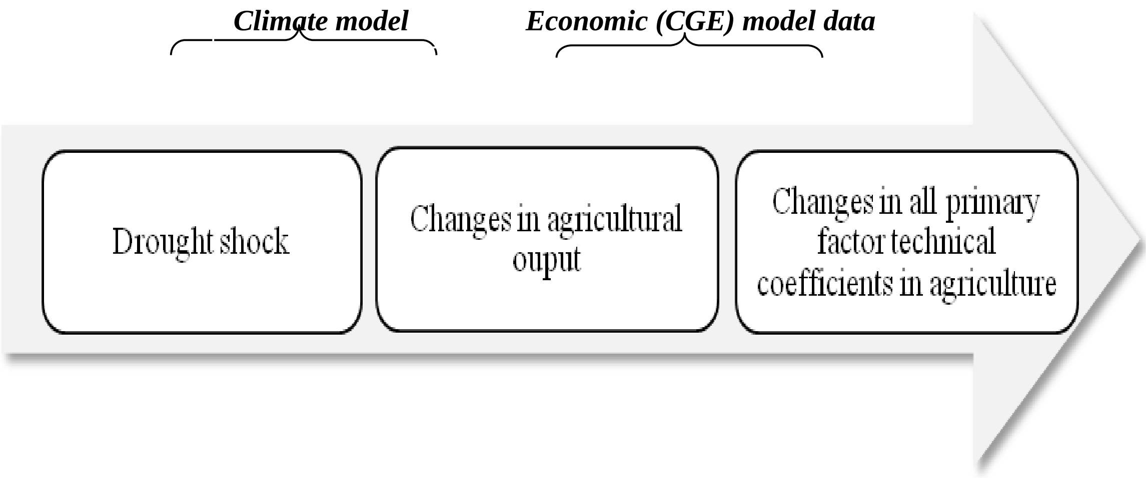
Source: Uganda Bureau of Statistics (2015).

Figure 3: *Composition of exports (US$ millions)*[1]

Source: Bank of Uganda (2012).

[1]ICBT refers to Informal Cross Boarder Exports.

Figure 4: Sequential modelling framework



Source: Adapted from Haddad et al. (2012).