Area Yield Crop Insurance and Diversification in Ghana: An Agricultural Household Programming Model

by

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ABSTRACT

Although diversification and insurance are acknowledged as important in ameliorating risk, to our knowledge, no empirical study has investigated how the two approaches work in concert in developing countries. Given increasing climate variability and the risks it poses to rain-fed agriculture, this study uses the Expected Utility Framework to develop two non-separable household mathematical programming and simulation models to examine the relationship between crop-diversification and index-based (area-yield) insurance for a representative agricultural household. The representative household is constructed using the IMPACT Lite household survey on Ghana, collected by the Consultative Group on International Agricultural Research Program on Climate Change, Agriculture and Food Security. In the base model, the household manages risk by diversifying their activities and allocating resources among six crop activities without the option of insurance. In the second model, the household has the option of both diversification and area yield insurance. Also, we assess how insurance coverage level and premium subsidies influence household participation and overall welfare benefits from insurance using sensitivity analysis. The results point to a highly risk averse representative household with a coefficient of absolute risk aversion of 0.016. The level of diversification increases with risk aversion in both the base and insurance models. Although insurance does not completely substitute for crop diversification, it reduces the degree of diversification. The degree of diversification for low and very high risk averse households is 23% and 35% more in the base model than in the insurance model, respectively. At 70% insurance coverage, the representative household insures all of its available land, regardless of risk aversion and premium subsidies. However, it only insures part of its available land at 90% coverage, due to higher premiums, and the portion under insurance decreases as risk aversion rises. For the household to insure all of its available land at the 90% coverage level, 80% of its premiums must be subsidised. Regardless of risk aversion, coverage level or subsidy, the availability of insurance increases the household's expected value of consumption and thus increases welfare. Comparing welfare (as measured by the expected value of consumption) in the base and baseline insurance models (i.e., no subsidy and 70% coverage level), our results show that insurance increases welfare by approximate 45% and 55% for low and very high risk averse households, respectively. For policy makers, this study provides empirical evidence suggesting that even in the presence of diversification, introducing area yield insurance would help reduce the perceived riskiness of rain-fed agriculture and increase agricultural households' welfare.

DEDICATION

To my Dad, Anthony Nyamekye and my fiancée, Afiba.

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CHAPTER 1 INTRODUCTION

1.1 Context: Agriculture, Climate Variability and Risk Amelioration

Given its contribution to developing economies, agriculture is a cornerstone of most government policies (Singh, Squire and Strauss 1986; Anderson and Martin 2005). Agriculture is considered a risky venture due to its biological nature and reliance on variable rainfall. Agricultural households are thus constantly faced with risks and uncertainties (Dercon 2006; Yesuf and Bluffstone 2009) that include climate (Antle 1995; Ito and Kurosaki 2009; Maatman et al. 2002), production (Park 2006; Hazell and Norton 1986), income (Kazianga and Udry 2006), consumption (Shively 1997) and price (Yesuf and Bluffstone 2009).

Climate variability is seen as a prominent source of risk affecting rain-fed agricultural systems (Kurukulasuriya and Ajwad 2006; Magombeyi and Taigbenu 2008; Lotze-Campen and Schellnhuber 2009). Studies indicate that the climate is changing and its impact and potential consequences are large and numerous (Olesen and Bindi 2002; Olesen et al. 2011; Mendelsohn, Dinar and Dalfelt 2000; Hertel and Rosch 2010; Laux et al. 2010). Although climate variability and its accompanying challenges affect the globe as a whole, its negative impact is more prominent in developing countries as compared to their developed counterparts (Antle 1995; Cooper et al. 2008; Hassan 2010). It has been argued that the developing world contributes the least to the changing climate, yet, suffers the most consequences (Mendelsohn et al. 2000; Mendelsohn and Dinar 1999; Mendelsohn 2008; Antle 1995; Hassan 2010; Kurukulasuriya 2006; Laux et al. 2010; Hertel and Rosch 2010; Cooper et al. 2008). The rippling effects of climate risks are especially evident in agriculture, and aggravate production, income and price risks, and ultimately, poverty and food insecurity (Ito and Kurosaki 2009). Serious efforts have, therefore, been made to understand and help farmers in developing countries deal with these challenges (Adger et al. 2003; Smit and Skinner 2002; Seo and Mendelsohn 2008; Cooper et al. 2008; Tsuji, Hoogenboom and Thornton eds 1998; Ngewnya 2014; Paavola 2008).

Studies have highlighted a number of approaches that poor agricultural households employ to cope with risks (Berbel 1993; Maatman et al. 2002; Nyikal and Kosura 2005). Poor farmers attempt to reduce their risk exposure through several strategies, the most prominent being: growing their own necessities (Finkelshtain and Chalfant 1991; Fafchamps 1992), diversifying their activities (Walker and Ryan 1990; Anosike and Coughenour 1990; Bradshaw, Dolan and Smit 2004), savings (Dercon 2014), grain storage (Park 2006), raising livestock (Ajao and Ogunniyi 2011; Kazianga and Udry 2006), credit (Mishra 1994), social networks and gift giving (Fafchamps and Lund 2003; Molini et al. 2008), insurance (traditional and index-based) (Mishra 1994; Keyzer, Molini and Boom 2007; Sakurai and Reardon 1997) and adopting risk-reducing production inputs/factors (Just and Pope 1979).

In coping with climate variability in the developing world, two important risk management strategies are 1) diversification (Hassan and Nhemachena 2008; Deressa et al. 2009; Perz 2005; Cooper et al. 2008) and 2) insurance (Barnett, Barrett and Skees 2008; Kunreuther 1996; Linnerooth-bayer and Mechler 2007; Nnadi et al. 2013; Gine, Townsend and Vickery 2008). Diversification is a farmer-initiated, self-insuring activity that involves spreading livelihoods across numerous activities. It may be on-farm, where households grow more than one crop and/or livestock, and/or off-farm, where they supplement farming with other income-generating activities. In contrast, insurance is an externally offered means of risk amelioration where an outside organization offers a service for risk management.

The efficacy of diversification strategies can be difficult to interpret. Studies show that diversification might not occur as the result of a choice, but out of necessity (i.e. desperation-led diversification), due primarily to poverty (Barrett, Reardon and Webb 2001; Reardon et al. 2000; Little et al. 2001). In such cases, diversification is not a risk amelioration option but a "desperate struggle for survival" (Ellis 1998, pp2). A review of the literature by Dercon (2002) suggests that farmers are likely to give up significant income to lower risk when they diversify, but many times are not successful at smoothing risk. Moreover, the benefits of diversification usually come at a cost of reduced expected short-term net returns (Markowitz 1952; Chan, Karceski and Lakonishok 1999; Cooper et al. 2008). Nevertheless, diversification can be an effective risk reduction strategy since it minimizes income variability by relying on strategic complementarities between activities that are not perfectly, positively correlated; thus, it remains popular among agricultural households in developing countries (Sakho-Jimbira and Bignebat 2007).

Similarly, insurance is typically used to hedge against contingent losses. It is conventionally defined as "the equitable transfer of a risk of loss from one entity to another in exchange for a premium or a guaranteed and quantifiable small loss to prevent a large and possibly devastating loss" (Vetrivel and Yoga 2012, pp.2). Insurance is regarded as a potentially effective method for mitigating the perceived riskiness of agriculture (Kunreuther 1996; Barnett and Mahul 2007). Conventionally, agricultural insurance assesses the risk of the insured on an individual basis (Skees, 2008). Indemnity payments are made to compensate for actual individual losses (Linnerooth-Bayer et al. 2011; Ali 2013). But, this form of insurance has been troublesome in the developing world due to underdeveloped or non-existent insurance markets, poor contract enforcement, information asymmetry (moral hazard and adverse selection), high transaction costs, and high exposure to spatially covariate risks (Skees, Barnett and Ky 2006; Skees 2007; Collier, Skees and Barnett 2009; Skees, Hartell and Murphy 2007; Barnett and Mahul 2007; Skees, Barnett and Collier 2008; Linnerooth-Bayer et al. 2011). Index-based insurance has arisen as a newer form of agricultural insurance that assesses losses using measures such as area-wide yields, or weather, that cannot be influenced by the actions of the insured, but are correlated with yields as a proxy for individual losses (Binswanger-Mkhize 2012; Miranda and Farrin 2012). Indemnity payments are made based on deviations from the index and not on individual losses (Ali 2013). This form of insurance seems to address challenges of traditional insurance, present in developing economies, by reducing transaction costs and information asymmetry (Barnett et al. 2008; Barrett et al. 2007; Leblois et al. 2013).

Several developing countries have explored the potential of index-based insurance on a pilot basis, though there are few instances of large scale implementations of such programmes (Gine et al. 2008; Barrett et al. 2007; Chantarat et al. 2007; Hess, Richter and Stoppa 2001; Stoppa and Hess 2003; Keyzer et al. 2007; Skees, Hazell and Miranda 1999; Miranda and Farrin 2012; Sina 2012; Collier et al. 2009; Wang et al. 2013; Panda 2013; Panda et al. 2013; Binswanger-Mkhize 2012; Varadan and Kumar 2012; Kumar et al. 2011; Ali 2013; Barnett and Mahul 2007; Barnett et al. 2008). Some pilots have seen low demand and low willingness to pay (Hill, Hoddinott and Kumar 2011; Sarris, Karfakis and Christiaensen 2006; Gine et al. 2008). Debates on the effectiveness of index-based insurance programmes are thus complex and mixed, notably because of the challenge posed by the associated basis risk[1] (Vedenov and

[1]Basis risk arises as a result of an imperfect correlation between the insurance index and the yields of farmers (Barnett et al. 2008; Barnett and Mahul 2007). The consequence of this imperfect correlation might be that a farmer may experience yield loss but receive no insurance pay-out, or experience no loss but receive an insurance pay-out (Leblois et al. 2013).

Barnett 2004; Binswanger-Mkhize 2012). However, the lack of a better alternative makes it a promising insurance option in the developing world; therefore, designing index-based insurance products with lower basis risk has been central to several studies (Miranda and Farrin 2012; Barrett et al. 2007; Barnett et al. 2005; Stoppa and Hess 2003).

1.2 Problem Statement

Further to the discussion above, much of the attention given to ameliorating risk in the developing world's agriculture has focused on diversification or insurance. Although each of these means of ameliorating risk is acknowledged as being important, little research has investigated how the two approaches work in concert. Studies on the relationship between insurance and diversification have mostly focused on traditional crop insurance in developed countries (O'Donoghue, Key and Roberts 2005; Wu 1999; Wu and Adams 2001; Goodwin, Vandeveer and Deal 2004). To our knowledge, no comparable empirical studies have examined the relationship between crop insurance (traditional or index-based) and diversification in a developing world context. An assessment of the relationship between diversification and index-based insurance in the developing world would address this knowledge gap and thus improve our understanding of farmers' choices of risk mitigation options.

This study begins by assuming that farmers have the option of diversifying to varying degrees, and that traditional crop insurance is unavailable. We then ask, what role could index-based insurance play in agricultural households' overall risk management and decision-making? Does index-based insurance complement or crowd out diversification? Knowing the explicit relationship between the two strategies might help answer these questions, and inform policy and the design of insurance programmes to effectively attract more farmers.

1.3 Research Objective and Questions

The main objective of this study is to understand how diversification and index-based insurance work in concert under climate variability. Two broad questions guide this study.

I. Does index-based insurance complement or substitute for diversification?

Binswanger-Mkhize (2012) argues that wealthy farmers may already be self-insured through income diversification and their assets; thus, formal insurance may not be valuable to them. Poor farmers, on the other hand, cannot pay insurance premiums for crops that only pay out after harvest (Binswanger-Mkhize 2012). Given the possibility to diversify is insurance a better option? It has also been argued that risk management options are not mutually exclusive and are likely to complement each other (Barnett et al. 2008; Barrett et al. 2007). To what extent, therefore, is insurance complementary to or substitutable for diversification already employed by farmers? How do insurance premiums and coverage (i.e., the percentage of area yield below which a farmer gets insurance pay-out) affect this relationship?

II. To what extent can index-based insurance reduce yield risk and how does risk preference influence diversification and insurance behaviours?

Risk-averse farmers are thought to prefer low-risk and low-return investments to high-risk and high-return ones. This risk aversion is believed to be a major reason underpinning the poverty trap phenomenon in many developing economies (Moscardi and de Janvry 1977; Yesuf and Bluffstone 2009; Barrett et al. 2007; Paavola 2008; Barnett and Mahul 2007). If risk influences farmers' production and investment choices, to a large extent, then one would expect that any effort to reduce their risk exposure could change their production and investment patterns and, as a consequence, improve welfare. However, whether index-based insurance is effective at lowering the perceived riskiness of agriculture, in the context of climate variability where farmers have the option to diversify, seems to have been neglected empirically in the developing world. We thus examine the extent to which insurance reduces the perceived riskiness of agriculture and how it affects production decisions and overall welfare. We also investigate how farmers' risk preferences affect their diversification and insurance decisions.

1.4 General Approach

This study employs farm-level modelling to achieve its objectives. Rohm and Dabbert (2003) argue that farm-level models present a viable alternative to sectorial models, which are often too aggregated to capture the details that form the core of the agro-environmental analysis. Buysse (2010) iterates that " the farm is the actual centre of decision making in agriculture and, therefore, the interpretation of results of a farm-level approach is easier than for an aggregate approach" and a "good farm representation and farm process understanding also enhances the development of more aggregate models" (pp.3).

A mathematical programming approach is used to develop the farm-level models. Mathematical programming has become a widely used tool for agricultural analyses. Howitt (1995) identifies three major advantages to using mathematical programming. Firstly, it facilitates analysis in cases where time-series data are unavailable and/or cannot be used because of structural changes in a developing economy. Secondly, programming models are structured in a way that makes it easy to characterize resource, environmental, or policy constraints. Lastly, mathematical programming represents production technologies in such a way that intrinsically allows input determinism. Mills (2014) and Buysse (2010) stress that a key motivation for using programming models is making the best use of limited data. This motivation is a significant issue in the case of index-based insurance in developing countries, where experience and data are limited. As a basis for our empirical model, we employ data from the IMPACT Lite survey collected by CCAFS on production behaviour and diversification (Rufino et al. 2012). We then allow household the opportunity to add index-based insurance in policy simulations.

1.5 Organization of Study

This thesis is organized into seven chapters. Following this introductory chapter, Chapter 2 presents a review of relevant literature. Chapter 3 and Chapter 4 are respectively devoted to the theoretical considerations and empirical methods. Chapter 5 explains the data, study area and parameters used in the models. Chapter 6 presents the results and discussions of the research findings. Finally, Chapter 7 summarizes the results, presents conclusions, recommendations and suggests areas for further study.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview

This chapter provides a review of relevant literature for this study. Given the objectives of this thesis, three broad areas of literature, agricultural household models, diversification, and index-based insurance are reviewed. The main purpose of the review is to use previous research to provide background and to guide this study.

2.2 Agricultural Household Models

Agricultural household models combine the producer, consumer and labour-supply decisions of households into a single conceptual framework. These models can be adapted to households in widely different socio-economic environments (Singh et al. 1986; Huffman 1991). One extreme application of these models is pure subsistence farm households where only family labour and available land are used to produce all the goods consumed. In this case, households do not sell or purchase labour, consumption goods and farm inputs. Levels of production, leisure and consumption are determined simultaneously (Hazell 1982; Nakajima 1969). Hazell (1982) iterates that "such models are inherently difficult to apply" since "the parameters of the utility function cannot be estimated in direct or indirect form, and it is difficult to estimate production and consumption systems simultaneously when these are nonlinear and inadequately identified" (pp. 384). He also argues that such models cannot be easily adapted to account for risk. On the other extreme, commercial farm households use hired labour, purchase farm inputs and consumption goods and sell most of their output (Huffman 1991). In such cases, production, leisure and consumption decisions are completely independent. Barnum & Squire (1979) and Lau, Yotopoulos, Chou, & Lin (1981) note that when markets are perfectly competitive, the simultaneity between consumption, leisure, and production decisions completely breaks down.

Early applications of agricultural household models typically assumed separability between production and consumption. In this sense, production and consumption are treated recursively. These models have overly restrictive assumptions—all markets are complete, perfect and competitive; family and hired labour are perfect substitutes; on- and off-farm family employment are perfect substitutes; and there are no transaction and commuting costs (de Janvry 1991; Singh et al. 1986). de Janvry (1991) notes that if these assumptions hold, then, production and consumption decisions can be taken sequentially, since production outcomes determine consumption decisions but not conversely. The household equilibrium is derived from a two-stage process. Firstly, on the production side, households maximize income given that labour is valued at the market wage. Secondly, households' consumption is determined given income and market wage. Hazell (1982) notes that this formulation is practical since indirect utility functions can be derived in prices and income, and a farm's production function independently estimated. Barnum & Squire (1979) and Delforce (1994) argue that separation of production and consumption does not necessarily hold if risk and risk aversion are introduced.

In the developing country context, it is well-documented that farm households are exposed to numerous market imperfections and constraints, such as labour (Maatman et al. 2002; Ito and Kurosaki 2009; Fafchamps 1992), credit (Bhalotra and Heady 2003; Barnett et al. 2008; Holden, Shiferaw and Pender 2004; Ellis 1998; Mishra 1994; Dercon 2002; Clarke and Dercon 2009), food (Steven Were Omamo 1998; de Janvry et al. 1991) and insurance (Barnett et al. 2008; Shen and Odening 2013; Janvry and Sadoulet 1993; Rosenzweig 1988; Dercon 2002;

Korir 2011; Ito and Kurosaki 2009; Chantarat et al. 2013; Linnerooth-Bayer et al. 2011). Thorbecke (1993) contends that farm households' behaviour cannot be understood without reference to these imperfections. Coyle (1994), Kanbur et al. (1993) and Yotopoulos & Lau (1974) argue that in the presence of market failures and risk, agricultural households' production and consumption decisions are non-separable, and should therefore be modelled as such. Kanbur et al. (1993) describe a non-separable household model as one where "the household's decisions regarding production (use of inputs, choice of activities, desired production levels) are affected by its consumer characteristics (consumption preferences and demographic composition)" (pp.2).

Empirical research on non-separable models is limited. Omamo (1998) considered a non-separable model examining the impact of transport costs on smallholder farmers' cropping decisions in the Siaya District, western Kenya. As one would expect, the market imperfections cited earlier prevail in this part of Kenya, and in the region of Ghana studied in this thesis. Omamo (1998)'s results indicate that households diversify production partly to meet their own demand for diversity in consumption, and that proximity to markets and transport infrastructure increase the amount of land allocated to cash crops and decrease that allocated to food crops.

Non-separability in production and consumption leads to what Ahn & Squire (1981) term as semi-commercial household models, which lie between a wholly commercialized farm and a pure subsistence farm. The representative households simulated in Omamo (1998) fits into this semi-commercial category. In semi-commercial household models, two fundamental blocks of microeconomic analysis, the household and the firm, are integrated (Singh et al. 1986). Singh et al. (1986) contend that most agricultural households in developing economies produce partly for their own consumption and partly for sale. They purchase part of their inputs and provide some on their own. Non-separable household models, as used in this thesis, try to capture these interactions.

2.3 Diversification

Diversification is a common risk mitigation and income smoothing strategy among agricultural households (Sakho-Jimbira and Bignebat 2007), particularly in developing countries. A key reason for diversification is to “create a portfolio of livelihoods with different risk attributes” to manage risk exposure (Paavola 2008, pp. 644). Sing et al. (2009) parse diversification into two broad types: 1) horizontal or the addition of new activities (such as livestock, aquaculture or new crops, improved crop varieties and increased production for the market, income diversification through off-farm employment) and 2) vertical or value-added activities, e.g., processing, packaging and marketing (Kankwamba, Mapila and Pauw 2013). Kandulu et al. (2012) enumerate several benefits of diversification, including as a buffer against commodity prices and input fluctuations, and climate variability; insofar as the effects of variability differs among different agricultural enterprises, losses incurred from investing in one enterprise may be offset by gains from another enterprise. These benefits are underpinned by an imperfect correlation of net returns from various activities (Kandulu et al. 2012).

2.3.1 Measures of Diversification

Although there are various measures of agricultural diversification, the most common are the Herfindahl (HI), Transformed Herfindahl (Simpson) Index (THI) and Modified Entropy Index, each of which is derived as the proportion of total cropping area under the cultivation of different crops in a defined geographical area (Kumar and Sharma 2012; O’Donoghue, Key and Roberts 2005). While the ease of derivation and interpretation may differ among these indices, they provide comparable results. When applied to diversification, the THI[2] is derived by subtracting the HI from one as represented in Kankwamba et al. (2013):

$$\mathrm{THI} = 1 - \mathrm{HI} = 1 - \sum_{i=1}^{n} P_i^2$$
$$\text{where } P_i = \frac{A_i}{\sum_{i=1}^{n} A_i} \tag{2.1}$$

The HI is derived by summing the squares of each crop's share in the total amount of land cultivated, where P_i is the proportion of land allocated to the *i*th crop and A_i is the land allocated to the *i*th crop (Sichoongwe et al. 2014; Pal and Kar 2012; Kankwamba et al. 2013). Bound between 0 and 1, the THI values increase with diversification; THI is zero when there is complete specialization and tends to unity when there is complete diversification as *n* approaches infinity. An alternative index, with the same range and interpretation as the THI, is the Modified Entropy Index (MEI), defined as below (Kankwamba et al. 2013):

$$\mathrm{MEI} = \sum_{i=1}^{n} \mathrm{P_i} * \ln_n\left(\frac{1}{\mathrm{P_i}}\right) \tag{2.2}$$

where *n,* the number of crops, is also the base of the logarithm function.

Given its intuitive ease of interpretation and following Sichoongwe et al. (2014), the THI is used in this thesis.

[2] As noted in Kankwamba et al. (2013), the key advantage of the Transformed (Simpson) Herfindahl Index over the Herfindahl lies in the ease of interpreting diversification. Whereas high values (approaching unity) of the former imply increased diversification, low values (tending to 0) of the Herfindahl suggest the same.

2.3.2 Empirical Studies on Diversification as a Risk Management Strategy

The studies cited in this section use different empirical approaches and assess the importance of diversification as a risk management strategy in developing countries.

Ajao and Ogunniyi (2011) examined farmers' strategies for adapting to climate change conditions of reduced precipitation and high temperatures in the Oyo state of Nigeria. Ajao and Ogunniyi (2011) used a multinomial logit model to determine the adaptation strategies farmers chose based on a number of climate attributes and socioeconomic characteristics. Their findings indicate that farmers adapt to climate variability by growing new crops, adapting drought tolerant/resistance crop varieties, diversifying from crops to livestock production and using new land management practices. A major limitation of this study is that it does not identify which combination of these strategies is most effective in dealing with climate variability.

Similarly, Hassan and Nhemachena (2008) used a multinomial logit model to analyze the determinants of farm-level climate adaptation measures among farms in eleven African countries, including Ghana. Given perceptions of warming temperatures, decreased precipitation and frequent droughts, Hassan and Nhemachena (2008) found that farmers used various measures in combinations, the most prominent being emphasizing livestock over crops, switching from dryland to irrigation and diversifying into mulitiple crops and mixed crop-livestock systems. Their results indicate that 52% of the African farms surveyed relied on a combination of multiple cropping and livestock rearing in dryland conditions.

Other diversification research stresses the importance of supplementing farm employment activities with off-farm activities to attenuate risks. Paavola (2008) studied how farmers modified their livelihood strategies under climate variability in Morogoro, Tanzania. They found that while livelihood diversification was the primary adaptive mechanism for agricultural households in Morogoro, farmers also switched between crops (e.g., changing from maize to sorghum if there was a threat of a drought) to smooth their consumption. Reardon, Delgado and Matlon (1992) also examined the effects and determinants of agricultural household income diversification in Burkina Faso. They defined income diversification as combining full-time off-farm employment with farming. Their results show that a harvest reduction promoted income diversification, which, in turn, was associated with greater incomes and consumption over time.

In sum, although the foregoing studies on diversification do not examine it within the context of index-based insurance in developing countries,—indeed, we found no literature, to the best of our knowledge for even developed countries—all point to the significance of diversification to agricultural households seeking to ameliorate their production and income risks, and to adapt to climate variability.

2.4 Index-Based Insurance

The original idea of insurance using indices is attributed to Halcrow (1949) with renewed attention in the 1990s (Hardaker et al. 2004). The basic feature of this type of insurance is that contracts are written and sold for specific events (e.g., drought or area yield loss) in standard monetary units, with a certificate for each unit bought called a Standard Unit Contract (SUC) (Skees et al. 1999). Pay-outs are not based on individual losses but on a third-party measure defined at a regional level (e.g., historical area yields or weather variables recorded at a local weather station) with the aim of overcoming the challenges of traditional insurance (primarily, information asymmetry and high transaction costs) (Skees et al. 2006; Skees 2007; Collier et al. 2009; Skees, Hartell, et al. 2007; Barnett and Mahul 2007; Skees et al. 2008; Linnerooth-Bayer et al. 2011). Farmers who buy the same contracts in a given region pay the same premium rate for a SUC and receive the same pay-out per SUC if the insured event occurs (Skees et al. 1999).

A major challenge of index-based insurance is its associated basis risk, where an insured may experience a loss but receive no pay-out or, experience no loss but receive pay-out (Binswanger-Mkhize 2012; Vedenov & Barnett 2004). Though several studies have explored ways to design index schemes to reduce basis risk by using index variables that are highly correlated with actual yields, it still remains a big challenge of index-based insurance (Collier et al., 2009; Sina 2012; J. Skees et al. 1999; Barnett, Black, Hu, & Skees, 2005; Barrett et al., 2007; Miranda & Farrin, 2012; Stoppa & Hess, 2003). Vedenov & Barnett (2004) argue that to completely eliminate basis risk, separate contracts would have to be written on indices measured at the various locations where the contract is to be used, which would be costly and defeat one of the most attractive properties of index-based insurance (i.e., low transaction costs).

Other challenges of index-based insurance include its crop-specific nature. Many index insurance products are designed for specific crops and thus, farmers who practice intercropping may be excluded or not fully benefit from them (Sina 2012). Amidst its challenges, index-based insurance is deemed to be a promising insurance option as compared to traditional insurance, especially for developing economies where transactions costs tend to be high (Barnett et al. 2008; Barrett et al. 2007; Leblois et al. 2013).

The development of insurance programmes based on weather indices is more recent as compared to those pertaining to area-yields. Although it has been used less in empirical studies than area-yield, research (Sina 2012; Skees et al. 1999) acknowledges the potential of weather-based indices, especially in developing economies, where yield data is unreliable. Governments and non-governmental international organizations have piloted index insurance schemes in various developing countries, including Brazil, India, Malawi, Mongolia, Kenya and Ethiopia, though most have been weather-based (Carter et al. 2014; Miranda and Farrin 2012). Skees et al. (1999) notes that although area-yield index is likely to produce better contracts since they are more correlated to individual yields, "rainfall insurance contracts may be technically more feasible for most countries because of the existence of long data series at regional weather stations". Weather-based indices are likely to capture climate variability more than area-yields due to the direct relation between the weather variables used and climate. Nevertheless, for reasons further discussed in Section 5.5.4, we are unable to use weather-based indices in this study; consequently, we concentrate on area-yield index-based insurance.

Area-yields insurance (AYI) was first implemented in Sweden in the 1950s. Area-yields insurance contracts are designed based on the long-term average yield of a region (e.g. district, community or county), and payments are made to farmers who purchase the contract when the area-yield of the region falls below a pre-determined limit (e.g., 70% percent of the long-term average) (Skees et al. 1999; Barnett et al. 2005; Olivier Mahul 1999; Oliver Mahul 1999; Miranda and Farrin 2012). Contracts require long and reliable historical area-yield data to be feasible and accurate.

In general, an insurance contract specifies a premium paid by the policyholder and an indemnity schedule of the insurer that specifies the pay-out in case the policyholder faces a loss (Huberman, Mayers and Smith 1983). The following sections review how AYIs are designed and priced in terms of indemnity and premiums, as well as the effect of premium subsidies on insurance uptake.

2.4.1 Indemnity Schedule

Miranda (1991) developed a theoretical framework and indemnity function for area yield index insurance. Since then, several AYI studies (Barnett et al. 2005; Smith, Chouinard and Baquet 1994; Olivier Mahul 1999; Vercammen 2000) have used—with some modifications—the indemnity function as formally proposed by Miranda (1991):

$$\tilde{n} = \max(y_c - \tilde{y}, 0) * scale, \quad \text{and}$$
$$y_c = \mu * coverage \tag{2.3}$$

where $\tilde{n}$ represents the indemnity unit of production per acre or, dollar value per acre, representing the pay-out policyholders receives when they experience losses ; y_c refers to the critical or trigger yield (i.e., the yield below which the insured receives a pay-out); $\tilde{y}$ denotes the stochastic area yield; μ is the predicted area yield; $coverage$ is the percentage of the predicted area yield chosen by policyholders which determines their critical yields; and $scale$ is a choice variable, in monetary units per acre, that the insured varies per acre to align expected indemnities with expected farm-level losses (Barnett et al. 2005). The general assumption is that there exists a constant price, determined when the contract begins, that acts as a scaling factor to convert the units of production per acre into monetary units per acre. Typically, either estimated average market or futures prices, or a combination of the two, are used to indemnify yield losses (Wang et al. 1998; Barnett et al. 2005). An alternative indemnity function, also based on Miranda (1991)'s model, is that used by the U.S. Department of Agriculture for its area yield insurance scheme, the Group Risk Plan (GRP)[3]:

$$\tilde{n} = \max\left[\left(\frac{y_c - \tilde{y}}{y_c}\right) * yfcast * scale, 0\right] \text{ and}$$
$$y_c = yfcast * coverage \tag{2.4}$$

where *yfcast* represents the forecasted per acre county yield, $coverage$ is as defined in equation (2.3) and ranges from 70% to 90% of expected area yields in 5% increments, and $scale$ (i.e., a choice variable that determines the monetary value of losses and estimated as a percentage of a pre-determine amount) ranges from 90% to 150% (Skees, Black and Barnett 1997). Under the GRP, policyholders receive indemnity payments depending on the percentage differences between actual area yields and forecasted yields and the dollar value of protection selected (Skees, Black and Barnett 1997; Barnett et al. 2005).

Using Miranda (1991)'s function, Smith et al. (1994) argued that an "almost ideal" area yield insurance scheme would allow the insured to select the level of coverage, conditional on scale being 100% and coverage any non-negative value. Smith et al. (1994) compared the net yield variances in the "almost ideal" case (i.e., scale =100%, and coverage>0%), the GRP case (i.e., scale = 90% to 150%, and coverage = 70% to 90%) and, when coverage was constrained at 75% and 90%. Their findings indicate that the almost ideal case lowered net yield variability the most (65%), while the 75% coverage lowered it the least (46.6%).

[3] The GRP was replaced by a similar area yield insurance scheme, the Area Risk Protection Insurance Plan, in 2014.

2.4.2 Pricing (Premium) and Subsidies

Accurate pricing of an insurance contract is crucial to the success of insurance programmes. In area-yield insurance, transaction costs and adverse selection problems tend to be less, relative to conventional insurance (which makes it cheaper to administer), and thus contracts are normally assumed to be actuarially fair where premiums paid are equal to expected indemnities (Wang et al. 1998; Barnett et al. 2005; Smith et al. 1994). An actuarially fair premium is derived from the expected indemnity as:

$$\pi_{ij} = E\tilde{\pi}_{ij} \ \forall i, j \tag{2.5}$$

where π_{ij} is per acre premium for farm i and insurance contract j, and $\tilde{\pi}_{ij}$ is per acre indemnity. Premiums are determined for the insurer to also cover expected loss (i.e., expected indemnification) and administrative costs and to possibly make a profit (Brockett, 2015). Accordingly, insurers typically incorporate a proportional load factor, $(1 + \lambda)$ to account for administrative expenditures and profits (Briys 1985). As Coble and Barnett (2013) note, given the possibility of extreme catastrophic events, "…a private insurer would add to the expected loss cost a load which reflects ambiguity regarding the extent to which the available historical data adequately reflect the probability and magnitude of catastrophic events" (pp. 500).

Berg, Quirion, & Sultan (2009), in investigating the feasibility and farmers' interests for weather index-based insurance in Burkina Faso, presented a premium, p, as:

$$p = 1.1 * Mean[Indemnity_i] \tag{2.6}$$

Berg, Quirion, & Sultan (2009) assumed that the farmer pays an additional 10% margin, the load factor, of the average indemnity in annual premiums as the cost of transferring risk. They adopt this margin for simplicity, as they acknowledge that index-based contracts do not clearly indicate how insurers derive their margins. Since a mark-up of 10% seems reasonable, we adopt their assumption for this study.

Governments typically subsidize premiums to encourage participation in crop insurance schemes, as is the case in the US (e.g., O'donoghue, Roberts and Key (2009); Goodwin and Smith (2013)). However, the effects of subsidies on uptake remain inconclusive at best. In an econometric analysis of the effects of subsidized crop insurance in the U.S., Goodwin and Smith (2013) note that subsidizing risk fosters various distortions in farmers' decisions. For instance, the insured may assume more risks than they might have otherwise by altering their production patterns and practices, i.e., changing the quantity of acreage allocated to crops, and cultivating riskier crops on riskier land. Using OLS regression, county-level data on planted acreage and five-year historical subsidy rates and subsidy-adjusted loss ratios from 2000-2010 for corn, cotton, wheat and soybean, they estimated the extent to which acreage responds to changes in crop insurance subsidies. Goodwin and Smith (2013)'s results shows increased acreage allocation in response to high subsidies. In a different vein, Du et al. (2014) used a mixed logit model to analyse coverage choices and the determinants of those choices (premiums, subsidies and soil quality at the county-level) for corn and soybean growers. Their results indicate that farmers' actual crop insurance decisions are not consistent with the expected utility maximization framework (i.e., that given actuarially fair premiums, one would select high coverage levels or coverage levels with high subsidies).

2.4.3 Empirical Studies on the Performance of Area Yield Insurance

Wang et al. (1998) assessed the performance of individual farm and area yield crop insurance programmes for a representative southwest Iowa corn farmer who uses combinations of options, futures and different crop insurance schemes using stochastic simulation. They assumed area yield crop insurance to be actuarially fair and then defined the individual yield crop insurance at initially 35% above the fair premium to capture transactions costs from providing individual crop insurance. Their findings indicate that performance (i.e., farmer participation in an insurance scheme and welfare or willingness to pay) for different crop insurance schemes was primarily affected by the correlation between individual farm-yields and area yields as well as limits on the coverage.

Barnett et al. (2005) also compared the performance of multiple peril crop insurance and area yield insurance contracts to determine how much each lowered variances in net yields. They used the U.S. Department of Agriculture's actual indemnity function for GRP explained earlier. Their results suggest that area yield insurance performed better relative to multiple peril crop insurance in states where there were high correlations between farm-level and area yields. Similarly, Clover and Nieuwoudt (2003) used the indemnity function and premium schedule used in Barnett et al. (2005), as well as linear regression, to assess the viability of a government-subsidized area yield insurance programme in KwaZulu-Natal, South Africa. Their analysis suggests that such a scheme in South Africa would require high levels of subsidization, which would be costly.

In a different vein, in an econometric analysis of the effects of index-based insurance on irrigated rice smallholder producers' welfare and loan repayment in northern Peru, Carter, Galarza and Boucher (2007) assessed two types of actuarially fair alternative schemes: one based on directly measured average area yields and another estimated using weather information. They found that directly measured area-yield insurance was better for lenders and borrowers than weather-index insurance, and both insurance schemes could crowd-in the supply and demand of credit.

2.5 Conclusion

Overall, the foregoing literature review provides context for this study in several aspects. The first pertains to the importance of using a non-separable agricultural household model, given the market imperfections and constraints in our study area. The second is the use of the THI to assess the extent of diversification as an important risk management strategy because of its intuitive interpretation and the complexity of the relationship between diversification and area-yield insurance. Finally, following Miranda (1991)'s framework for deriving an indemnity schedule, premium, and the related attributes of coverage and scale, which inform how most studies calculate these variables, our study assumes actuarially fair premiums and a 10% load factor.

CHAPTER 3 THEORETICAL APPROACH

3.1 Overview

This chapter provides the theoretical background for this study. Farmers' behaviour under risk has been studied primarily through an extension of the theory of consumer behaviour-expected utility theory. Presented in the following sections are reviews of expected utility theory in a household decision-making and households' risk preference.

3.2 Expected Utility Theory and Household Models

For several decades, expected utility theory has provided the main theoretical basis for studies of choice under uncertainty. The theory maintains that if a decision maker's behaviour satisfies the completeness, transitivity and independence axioms as postulated by von Neumann and Morgenstern (1947), then a utility function exists such that the decision maker acts in a manner that maximizes his/her expected utility (Fishburn 1982).

The expected utility theory is based on an ordinal ranking of utility derived from different goods and services (Hazell 1982). It presents decision-making as a choice between risky alternatives under various states of nature. Assuming that the expected utility of consumption is being maximized, and that there are *n* different states of nature, the expected utility from a risky situation or action, a_j, can be represented as in Barry (1984), as:

$$E(U_j) = \sum_{i=1}^{n} p(\theta_i) * U\left[\mathrm{C}(\theta_i, a_j)\right] \tag{3.1}$$

where $\mathrm{C}(\theta_i, a_j)$ is the level of consumption for the *ith* state of nature (θ_i) that may correspond to, for example, prices and yields and the *jth* action (a_j), e.g., a specific farming activity; $U[C(\theta_i, a_j)]$ is the corresponding utility function; and $p(\theta_i)$ refers to the probability of the occurrence of the *ith* alternative state of nature.

In a household decision-making framework, the expected utility theory is applied to instances where households are assumed to maximize expected utility subject to specified constraints. The type of model under consideration determines the constraints needed. In typical production models, the constraints usually considered are land, labour, capital and production technology (Bardsley and Harris 1987; Singh et al. 1986). In addition, a household model would consider budget and household time related constraints (Singh et al. 1986). Presented below is a generic constrained optimization model assuming EU maximization.

$$Max\ E(U) = pU(x) \quad (3.2)$$

subject to:

$$Ax \leq d \quad (3.3)$$

$$x \geq 0 \quad (3.4)$$

where $E(U)$ is expected utility, x is a vector of non-negative activity levels, p is a vector of state probabilities which incorporates risk into the model, and $U(x)$ is a vector of utility values for various activities in different states of nature. A is a matrix of technical coefficients and d is a vector of resource stocks.

Expected utility theory has been criticized based on evidence against the empirical validity of its axioms, especially the independence axiom (Allais and Hagen 1979; Dreze 1974; Machina 1981; Kahneman and Tversky 1979; Tversky and Kahneman 1992). Alternative approaches such as the safety first theory (Roy 1952) and prospect theory (Kahneman and Tversky 1979) have accumulated experimental evidence, raising doubts about the expected utility theory as a sound behavioural theory. Bar-shira, Just and Zilberman (1997) and Richter, Schiller and Schlesinger (2014) argue that most of the violations of the expected utility hypothesis are from carefully planned experiments. Consequently, they question the validity of abandoning the use of the expected utility hypothesis based on such experiments when studying real-world decision-making.

Other supporters of expected utility theory point to the lack of viable alternatives with comparable predictive power and versatility (Machina 1983). Moschini and Hennessy (2001) argue that expected utility models are intended to capture the notion of risk aversion, which is the main characteristic of choice under uncertainty. Therefore, the expected utility theory is deemed acceptable and is used in numerous risk-related empirical studies (Bhende and Venkataram 1994; Heidelbach 2006; Saha 1994).

Several studies have incorporated expected utility theory into agricultural household models. The generalized non-separable agricultural household model typically ignores risk. It is assumed that an agricultural household is a price-taker in both the goods and factor markets, and has a monotonically increasing and strictly concave utility function. Following Barnum and Squire (1979), Ahn and Squire (1981) and Saha (1994), a risk-free household model is presented below where the household maximizes its utility of consumption subject to production, resource and income constraints within a single agricultural cycle planning horizon:

$$\text{Max } U = U(C) \qquad \text{with } u_i > 0, u_{ii} < 0, \;\; i = c \tag{3.5}$$

subject to:

$$F = F\left(D, d_j, A\right) \qquad j = 1, \dots, \tag{3.6}$$

$$T = H + l + D \tag{3.7}$$

$$P'C = wH + R + p_c F - \sum p_j d_j, \tag{3.8}$$

where C is a $(h * 1)$ vector of items consumed (own-consumption and purchased), including leisure; F is the total output of own-consumption goods; D is the total labour input (both family and hired) used in F production; d_j is other variable inputs used in F production; A is the area of land used in F production; T is the total household time available for labour; l is leisure; H is the net quantity of labour time sold if $H > 0$ and net quantity of labour time purchased if $H < 0$; P' is a $(1 * h)$ vector of prices of consumed goods; w is wage rate; R is net other income; p_c is prices of own-consumption goods; and p_j is prices of other variable factors.

Incorporating expected utility, risk has been introduced into agricultural household models through several methods. Saha (1994) incorporates price and output risk by including random variables that capture uncertain changes in output and/or prices. He assumes that the household is a price-taker in the goods and factor markets and faces the following expected utility maximization problem:

$$\max_x J \equiv E[U(c, g, l)] \tag{3.9}$$

subject to:

$$\tilde{y} = \tilde{z} + I \equiv \tilde{\pi} + wF - \tilde{p}c + I \tag{3.10}$$

$$\tilde{\pi} = \tilde{p}\tilde{q} - r^T A - wL \tag{3.11}$$

$$\tilde{q} = G(A, L)\tilde{\varepsilon} \tag{3.12}$$

$$T^0 = F + l \tag{3.13}$$

where $E[U(c, g, l)]$ is the expected utility that households derive from consuming farm produced commodity $c = (c_1, \ldots, c_m)$, market purchased goods $g = (g_1, \ldots, g_n)$ and leisure, l;

$\tilde{y}$ is full household income, $\tilde{z}$ denotes household's total income less expenditure on food crops, I is exogenous income; w represents wage rate, $\tilde{\pi}$ is farm profit, F is total available family labour, $\tilde{p}$ is a vector of random prices of households' consumption goods; $\tilde{q}$ is random farm output, $\tilde{\epsilon}$ is the random output coefficient, r^T denotes a $(n * 1)$ vector of non-labour input prices, A is a vector of non-labour farm inputs, L is total labour used in production, G(.) is a twice continuously differentiable function, that is, concave in A and L; and T^0 is the household's total time endowment.

Bhende and Venkataram (1994) used the expected utility theory within an agricultural household framework to study the impact of diversification on household income and risk in Maharashtra, India, where households maximize the expected utility of their net returns. In insurance research, the expected utility theory has been applied to determine optimal insurance policies and risk reducing effects of various insurance contracts (Arrow 1971; Mossin 1968; Young and Browne 2000; Bokusheva, Breustedt and Heidelbach 2006; Heidelbach 2006; Breustedt, Bokusheva and Heidelbach 2008). In Bokusheva et al. (2006) the expected utility framework is used to measure and compare the risk reduction abilities of farm yield, area yield and weather index crop insurance schemes in Kazakhstan. In line with these studies, the expected utility theory forms the theoretical basis for this thesis.

3.3 Household Risk Preferences

In the expected utility framework, the risk preference of the decision-maker imposes restrictions on optimal responses to yield, income, and/or price changes (Saha 1993). Hazell (1982) notes that, household's risk preferences underpin their production and consumption decisions. There are three general categories of risk preferences: risk averse, risk neutral and risk loving. Bardsley & Harris (1987) define risk aversion as a preference for a "sure thing" over a gamble with the same expected value. In the following section we discuss how risk preferences are measured.

3.3.1 Measures of Risk Aversion

There are various methods of measuring risk preferences. Risk preference in the expected utility framework can be inferred from the curvature of the household's utility function, where a linear utility function suggests risk neutrality, while concave and convex functions imply risk aversion and risk loving, respectively (Barry 1984). Alternatively, one can use the relationship between the expected monetary value (EMV) and certainty equivalence (CE) (i.e., a guaranteed outcome or return that an individual would accept, rather than take a chance on a higher, but uncertain outcome) to classify risk preferences. In this case, the EMV of a risky investment always exceeds the CE for a risk averse individual; the CE always exceeds the EMV for a risk-loving one; and equality of the two suggests risk neutrality (Barry 1984). The risk premium, which is the difference between the EMV and CE, is the monetary amount that a risk averse decision-maker would be willing to pay to avoid a risky choice (Barry 1984). The slope of the utility function determines the premium, which rises as the degree of concavity increases. Since the marginal utility of concave functions declines when the level of the pay-off rises, increased concavity indicates a higher degree of risk aversion (Bardsley and Harris 1987).

The Arrow-Pratt coefficient of absolute risk aversion, $A(w)$, and the Arrow-Pratt coefficient of relative risk aversion, $R(w)$, are the two most common ways of measuring risk aversion (Arrow, 1965; Pratt, 1964).

The coefficient of absolute risk aversion, $A(w)$, is derived as the negative of the ratio of the second derivative of the utility function of total wealth, w, to its first derivative:

$$A(w) \equiv -\frac{U''(w)}{U'(w)}, \tag{3.14}$$

where the concavity of $U(w)$ is equivalent to risk aversion, $U''(w)$ denotes the degree of concavity that measures the degree of aversion and $U'(w) > 0$. The greater the curvature of $U(w)$ (*i.e.* $U''(w)$), the greater the absolute value of $A(w)$ and the higher the level of risk aversion. $A(w)$ is often assumed to be a decreasing function of w since, as wealth rises, individuals tend to become less averse to a given gamble (Bar-shira et al. 1997; Moschini and Hennessy 2001).

An alternative type of risk preference is captured by the Arrow-Pratt coefficient of relative risk aversion, which is represented as:

$$R(w) \equiv wA(w) \tag{3.15}$$

This measure of relative risk aversion is typically used where the stochastic and non-stochastic parts of wealth change proportionally (Bar-shira et al. 1997), and when considering the preferences of risk-averse agents towards gambles that are a fraction of their wealth. Unlike the absolute risk aversion case, this version is scale-free and does not depend on the units of measurement (Bardsley and Harris 1987; Gollier 2001). Although $R(w)$ is a function like $A(w)$ and may increase, decrease or remain unchanged with varying w, it is less likely to change as compared to $A(w)$ and its unit free nature makes it comparable for different measures of w (Hardaker et al. 2004; Raskin and Cochran 1986). Arrow (1971) notes that, although $R(w)$ may fluctuate with varying w, the actual value is likely to be around one. On the contrary, Hamal & Anderson (1982) found that $R(w)$ could reach values as high as four or more for extremely resource-poor farmers. Anderson and Dillon (1992) proposed a classification of degree of risk aversion using $R(w)$ of 0.5-4.0, capturing both the Arrow (1965) and Hamal and Anderson (1982) assertions. In this study, we capture risk aversion using the absolute risk aversion coefficient. The relative risk aversion coefficient range proposed by Anderson and Dillon (1992) is used to derive a range for the absolute risk aversion coefficient (see section 5.5.1).

3.3.2 Risk Aversion and the Choice of Utility Functional Form

Gollier (2001) argues that to make problems of uncertainty tractable under the expected utility framework, further assumptions must be made on the form of utility function. As discussed in the previous section, risk aversion can be constant, increasing or decreasing with varying wealth or income. Since Pratt (1964) argued that the behaviour of people support utility functions that exhibit Decreasing Absolute Risk Aversion (DARA), DARA has been regarded as a "stylized" fact (Bar-shira et al. 1997; Moschini and Hennessy 2001; Hardaker et al. 2004; Gollier 2001; Guiso and Paiella 2008; Saha 1993). However, empirical evidence on this issue is mixed. Although several studies have found evidence of risk aversion, it is ambiguous as to whether risk aversion is decreasing, constant or increasing (Saha 1993; Wolf and Pohlman 1983).

Gollier (2001) argues that although the expected utility framework has simple and "intuitively appealing" axioms, the utility functions selected for the application of this theory have been on "the basis of purely technical convenience" (pp.5&6). Depending on the assumptions made, different forms of utility functions such as quadratic, linear, negative exponential, power and logarithmic, have been used. Several studies assume either Constant Relative Risk Aversion

(CRRA) or Constant Absolute Risk Aversion (CARA), which are special cases of Hyperbolic Absolute Risk Aversion utility functions (Domingo, Parton and Mullen 2015; Galanis, Sycheva and Broccardo 2015; Kazianga and Udry 2006; Grimard 1997; Udry 2009; Leblois, Quirion and Alhassane 2014). CRRA (which is necessarily also DARA) implies that preferences remain unchanged if payoffs are multiplied by a positive constant, (Hardaker et al. 2004). CARA on the other hand, implies that preferences do not change if a constant amount is subtracted from or added to payoffs (Hardaker et al. 2004). Hardaker et al. (2004) provide specifications of functional forms commonly used for CRRA (i.e., logarithmic and power utility functions) and CARA (negative exponential), as presented below.

Logarithmic:

$$U = In(w), w > 0 \tag{3.16}$$

where $A(w) = w^{-1}$ and $R(w) = 1$

Power:

$$U = [1/(1-r)]w^{(1-r)}, w > 0 \tag{3.17}$$

where $R(w) = r$ and $A(w) = r/w$

Negative exponential:

$$U = 1 - \exp(-cw)\,, c > 0, \tag{3.18}$$

where $A(w) = c$ (constant) and $R(w) = cw$.

Other utility functional forms such as the polynomial-exponential (Bell 1988) and the expo-power (Saha 1993) have been suggested to have more flexibility in representing increasing and decreasing risk aversion but they remain relatively unpopular since the simpler forms discussed above usually produce comparable results (Hardaker et al. 2004). In this study, we assumed CARA and thus used the negative exponential utility function.

CHAPTER 4 EMPIRICAL METHODS

4.1 Overview

The objective of this thesis is to understand how diversification and index-based insurance work in concert under climate variability. To pursue this objective in a developing country context, we develop non-separable agricultural household models using the expected utility framework. The agricultural household is assumed to maximize its expected utility of consumption by allocating resources (land and labour) among six crop activities. As in Saha (1994), risk is introduced in the models by incorporating stochastic crop yields. Several yield states of nature are used to represent different possible yield scenarios. Absolute risk aversion coefficients representing the risk preference of the household are also incorporated into the objective function. Assuming CARA[4], the objective function of the household is specified as a negative exponential utility function. In the base model, the household manages risk by diversifying its activities and allocating resources among the six crop activities without the option of insurance. In the second model, however, the household, in addition to diversification, has the option to purchase area yield-based insurance. The following sections discuss the details of the empirical models developed in this study.

4.2 Model Development

This section presents the structure of the two empirical models developed in this study. A base model which allows farmers the option to diversify their farm activities with no insurance is presented and extended into a second model with an area yield-based insurance option. The models capture static behaviour using a stochastic framework (i.e., various states of nature)

[4] As in Galanis et al. 2015 and Domingo et al. 2015, we assume that the household's risk aversion does not change with changes in the value of consumption.

since households face multiple period decisions influenced by risk. The households analysed are assumed to be farmers who grow crops mainly for own consumption with few sales, which are usually the surplus after consumption. Income from sales is generally used to purchase consumption goods. The objective of the household is therefore to maximize its expected utility of consumption of the crops it cultivates. In the following sections, we define the activities and parameters used in our models, as well as the mathematical representation of the household's objective function and constraints.

4.2.1 Activities and Parameters

This section defines the activities and parameters used in the models developed in this study. Table 4.1 presents the activities in the base model. In addition to the activities in the base model, the insurance model requires other activities which are defined in Table 4.2. Table 4.3 presents the parameters used in the base model and Table 4.4 presents additional parameters used in the insurance model. Further discussion on the values and procedures used in deriving the activities and parameters are in Chapter 5.

Table 4.1: Base Model Activities

Activities	**Descriptions**
$ACRE_d$	Land allocated to crop *d* (acres), where *d* represents the crops (i.e., cowpea, groundnut, maize, millet, rice and sorghum) considered in our models.
$PROUT_{id}$	Predicted output of crop *d* (kg) in state of nature *i*[a]
$SELL_{id}$	Quantity of crop *d* sold in state of nature *i* (kg)
PUR_{id}	Quantity of crop *d* purchased in state of nature *i* (kg)
CON_{id}	Quantity of crop *d* consumed in state of nature *i* (kg)
HL_d	Hired labour (hours) allocated to *d*
FL_d	Family labour (hours) allocated to *d*

Notes:

[a] 500 states of nature (*i*) are simulated to represent different yield scenarios due to climate variability (see section 5.5.5).

Table 4.2: Additional Activities in the Insurance Model

Activities	**Descriptions**
$ACRE_d^u$	Land allocated to crop *d* with no insurance (acres)[a]
$ACRE_d^n$	Land allocated to crop *d* under insurance (acres)[a]
$TOTPREM$	Total premium (GHC[b]) paid for insurance
$TOTINDEM_i$	Total indemnity in state of nature *i* (GHC). Total indemnity refers to the sum of insurance pay-outs received by the household for crop *d* in each state of nature *i*.

Notes:

[a] In the insurance model, the activity for the land allocated to crop d in the base model (i.e., $ACRE_d$) is split between insured and uninsured.

[b] GHC represents Ghana Cedis, the currency used in Ghana. As at May 9, 2016, GHC 1 was equivalent to $0.34 CAD.

Table 4.3: Base Model Parameters

Parameters	**Descriptions**
EXP	Exponential function
ψ	Risk aversion parameter
$Prob_i$	Probability of occurrence for state of nature *i*
VAL_d^c	Consumption value per unit quantity of crop *d* (GHC/kg)
P_d^s	Selling price per unit quantity of crop *d* (GHC/kg)
P_d^p	Purchase price per unit quantity of crop *d* (GHC/kg)
ϕ_d	Scaling factor necessary to convert purchase price to consumption value for crop *d*
γ_d	Scaling factor necessary to convert purchase price to selling price for crop *d*
w_H	Wage rate for hired labour (GHC/hour)
$TOTFL$	Available family labour (hours)
$TOTHL$	Total hired labour (hours)
YLD_{id}	Yield for crop *d* (kg/acre) in state of nature *i*
VC_d	Variable cost for producing crop *d* (excluding labour cost) (GHC/acre)
$LAND$	Household land base (acres)
$LaHRS_d$	Labour requirement for crop *d* (hour/acre)

Parameters	Descriptions
$OTUSE_d$	Quantity of crop d for other uses (kg). This parameter refers to the quantity of crop *d* used for purposes (e.g., gifts) other than consumption, sale or purchase.
$OTFEXP$	Other farm expenses (GHC). This parameter refers to hired labour and variable expenses incurred on the crop and livestock activities that are not explicitly modelled in this study.
$OTNFEXP$	Other non/off-farm expenses (GHC). This refer to expenses, such as school fees, medical and personal (e.g., clothing), household incur outside the farm.
$OTFINCOME$	Other farm income (GHC). This parameter represents revenues from other crop (e.g., tomato, yam) and livestock activities that are not explicitly modelled.
$OTNFINCOME$	Other non/off-farm income (GHC). This parameter captures household income from non-farm sources such as remittances.

Table 4.4: Additional Parameters in Insurance Model

Parameters	Descriptions
$OBSAREAYLD_{id}$	Observed area yield for crop *d* in state of nature *i* (kg/acre)
$AVGYLD_d$	Average area yield of crop *d* (kg/acre)
YC_d	Critical yield of crop *d* (kg/acre). This parameter refers to the yield below which insurance pay-out is triggered.
$YLDIF_{id}$	Difference between $OBSAREAYLD_{id}$ and YC_d in state of nature *i* (kg/acre)
EL_d	Expected loss of crop *d* (kg/acre). This parameter is the average of the difference between the observed and critical yields for all states of natures in which the observed yield is lower than the critical yield.
θ	Premium subsidization factor. Governments and donor agencies might have to subsidize premiums to make insurance programmes attractive. We therefore include this parameter to vary the level of subsidies given.
λ	Insurance coverage level factor. Insurance coverage level is a choice variable that determine the percentage of area yield below which pay-outs are triggered (i.e., the critical yield). This parameter therefore allows the household to vary its coverage level.
β	Insurance scale factor. Scale is a choice variable, in monetary units per acre, which the insured varies to align expected indemnities with expected farm-level losses. This parameter therefore allows the insured to choose the percentage of the pre-determined price used in estimating pay-outs.
σ	Premium load factor. This parameter allows the insurer to add mark-ups (profit) to premiums paid by the insured to serve as profit for taking up the risks of the insured.

4.2.2 Objective Function

The objective function of the household in the models (both the base and insurance models) is to maximize its expected utility of consumption of the crops it cultivates.

The household's objective function is represented as:

Maximize:

$$\sum_{i}\left[Prob_i\left(1 - EXP\left\{\psi * \sum_{d}(VAL_{id}^{c} * CON_{id})\right\}\right)\right] \tag{4.1}$$

4.2.3 Constraints

4.2.3.1 Output Constraint

This constraint requires the total output of any crop in each state of nature to be equivalent to the product of its yield per acre and number of acres under cultivation.

In the base model, this constraint is specified as:

$$PROUT_{id} = YLD_{id} * ACRE_d \quad \forall i, d \tag{4.2}$$

In the insurance model, this constraint considers both acreage with and without insurance, and requires the total output of any crop in each state of nature to be equivalent to the product of its yield per acre and number of acres under cultivation with and without insurance:

$$PROUT_{id} \equiv YLD_{id} * (ACRE_d^{u} + ACRE_d^{n}) \quad \forall i, d \tag{4.3}$$

4.2.3.2 Land Constraint

Land used in production cannot exceed the household's land resource base in each state of nature. This constraint ensures that the total land area used in the optimal solution does not exceed the total area of farmland available to the household. In the base model, this constraint is presented as:

$$\sum_{d} ACRE_d \leq LAND \tag{4.4}$$

In the insurance model, since land used is split between insured and uninsured production, the land constraint is specified as:

$$\sum_{d} (ACRE_d^u + ACRE_d^n) \leq LAND \tag{4.5}$$

4.2.3.3 Labour Constraint

Households have the option of hiring additional labour to supplement family labour. The labour constraint ensures that total labour hours used in production do not exceed the sum of available family and hired labour hours. This constraint is represented in the base model with three equations as:

$$LaHRS_d * ACRE_d \leq FL_d + HL_d \quad \forall\, d \tag{4.6}$$

$$\sum_{d} FL_d \leq TOTFL \tag{4.7}$$

And

$$\sum_{d} HL_d \leq TOTHL \tag{4.8}$$

The only difference between this constraint in the base and insurance models is the split of available labour between insured and uninsured acreage in the insurance model, thus equation (4.6) is specified in the insurance model as:

$$LaHRS_d * (ACRE_d^u + ACRE_d^n) \leq FL_d + HL_d \quad \forall\, d \tag{4.9}$$

4.2.3.4 Crop Use Constraint

The crop use constraint balances the availability and uses of the crops that households produce and/or purchase in each state of nature. The constraint states that the use of any crop cannot exceed its availability and ensures that the quantity of a crop consumed, sold and/or used for other purposes is equal to the sum of the quantity produced and/or purchased in each state of nature. This constraint is specified in the base model as:

$$CON_{id} + SELL_{id} + OTUSE_d = (YLD_{id} * ACRE_d) + PUR_{id} \quad \forall\, i, d \tag{4.10}$$

The crop use constraint in the insurance model is similar to the base model, except that production from insured acreage is differentiated from uninsured production and is specified as:

$$CON_{id} + SELL_{id} + OTUSE_d \leq \{YLD_{id} * (ACRE_d^u + ACRE_d^n)\} + PUR_{id} \quad \forall\, i, d \tag{4.11}$$

4.2.3.5 Income-Expenditure Constraint

This constraint expresses the fact that households cannot spend what they do not have; household expenditures cannot exceed household income inflows in each state of nature. The constraint specifies that the sum of variable production costs, hired labour expenses, crop purchases and other farm and non-farm expenses must at least be equal to the sum of revenues from crop sales and other farm and non-farm income. In the base model, this constraint is given as:

$$\begin{aligned} &\sum_d \{(VC_d * ACRE_d) + (w_H * HL_d) + (P_d^p * PUR_{id})\} + OTFEXP + OTNFEXP \\ &\qquad \leq \sum_d (P_d^s * SELL_{id}) + OTFINCOME + OTNFINCOME \quad \forall\, i \end{aligned} \tag{4.12}$$

The difference between the income-expenditure constraint in the base and the insurance models is that in the latter, variable production costs are separated for insured and uninsured acreage, with premiums paid for the insured acreage and pay-out received when triggered.

In the insurance model, this constraint is specified as:

$$\sum_{d}\{(VC_{id} * (ACRE_d^u + ACRE_d^n)) + \left(P_d^p * PUR_{id}\right) + (w_H * HL_d)\} + OTFEXP$$
$$+ OTNFEXP + \ TOTPREM$$
$$\leq \sum_{d}(P_d^s * SELL_{id}) + OTFINCOME + OTNFINCOME$$
$$+ \ TOTIDEM_i \quad \forall \, i \tag{4.13}$$

4.2.3.6 Additional Insurance Constraints and Parameter Estimations

The average area yield for crop *d* ($AVGYLD_d$), critical yield (YC_d), yield deviation ($YLDIF_{id}$) and expected loss (EL_d) are parameters estimated and used in specifying two other constraints (i.e., indemnity and premium) that are used in addition to the ones above for the insurance model.

The average yield of crop *d* is estimated as the mean of the observed area yields:

$$AVGYLD_d = \sum_{i}(OBSAREAYLD_{id})/i \quad \forall \, d \tag{4.14}$$

The critical yield for crop *d* is given as the average area yield multiplied by the insurance coverage level:

$$YC_d = AVGYLD_d * \lambda \quad \forall \, d \tag{4.15}$$

The yield deviation of crop *d* in state of nature *i* is the difference between the critical yield of crop *d* and the observed area yield in state of nature *i* multiplied by a trigger factor. The trigger factor ensures that yield deviation of the crops would be greater or equal to zero in each state of nature.

$$YLDIF_{id} = \pi * (YC_d - OBSAREAYLD_{id}) \quad \forall\, i, d$$

where,

$$\pi = \begin{pmatrix} 1\ if\ (YC_d - OBSAREAYLD_{id}) > 0 \\ 0\ if\ (YC_d - OBSAREAYLD_{id}) \leq 0 \end{pmatrix} \tag{4.16}$$

The expected loss for crop *d* is given as the sum of the yield deviation of crops for all states of nature multiplied by the probability of each state of nature occurring:

$$EL_d = Prob_i * \sum_i YLDIF_{id} \quad \forall\, d \tag{4.17}$$

When insured households experience losses, they receive pay-outs (indemnities) from the insurer. An indemnity constraint ensures that the value of realized output and pay-out received by a household in any given state of nature do not exceed the total value of production under insurance. The indemnity in state of nature *i* must be equal to the sum of yield deviation for all crops in state of nature *i* multiplied by pre-determined insurance price, scale and insured acreage:

$$TOTIDEM_i = \sum_d (YLDIF_{id} * (P_d^s * \beta * ACRE_d^n) \quad \forall\, i \tag{4.18}$$

Households who purchase insurance are required to pay premiums. An actuarially fair premium is estimated as the sum of expected loss for crops *d* multiplied by pre-determined insurance price, scale and premium load factor. Insurance may not be attractive to households if they are to pay actuarially fair premiums. Thus, our premium constraint includes a variable factor to allow for different levels of premium subsidization.

$$TOTPREM = (1 - \theta) \sum_{d} ((P_d^s * \beta * ACRE_d^n * EL_d) * (1 + \sigma) \quad (4.19)$$

4.2.3.7 Non-negativity Constraint

The non-negativity constraint requires all variables to be greater than or equal to zero:

$$All\ Variables \geq 0 \quad (4.20)$$

CHAPTER 5 STUDY SITE, DATA, PARAMETER ESTIMATIONS AND MODEL CALIBRATION

5.1 Overview

As a basis for our empirical models, we employ data from the Integrated Modelling Platform for Mixed Animal Crop systems (IMPACT) Lite household survey on Ghana collected by the Consultative Group on International Agricultural Research (CGIAR) Program on Climate Change, Agriculture and Food Security (CCAFS)[5]. This information was supplemented with data from the Ghana Meteorological Agency (GMA), the Ministry of Food and Agriculture (MoFA), Ghana, the Ghana Statistical Services (GSS), the Food and Agriculture Organization (FAO) database and the World Bank databank. The following sections discuss in detail the IMPACT Lite survey, study site and data used in this study, as well as the procedures used for deriving the parameters in the models.

5.2 IMPACT Lite Survey

The IMPACT Lite database was developed initially to share data to facilitate evaluations of various farming systems (Rufino et al. 2012). The IMPACT Lite survey tool was implemented between May 1, 2012 and November 1, 2012 in 15 CCAFS benchmark sites in twelve countries across West Africa (one site each in Burkina Faso, Ghana, Mali, Niger and Senegal), East Africa (two sites each in Kenya and Uganda and one each in Tanzania and Ethiopia) and South Asia (two sites in India, one in Nepal and one in Bangladesh).The data help capture the diversity of farming activities and characterize the main agricultural production systems. The

[5] Questionnaire and the dataset from the IMPACT Lite survey used for this study can be found at http://data.ilri.org/portal/dataset/implite-ghana

datasets collected by IMPACT Lite provide detailed information on household composition, agricultural production systems and activities, land and labour allocation, on-farm and off-farm activities and income, as well as household consumption and assets (Rufino et al. 2012). For the purpose of this thesis, the Ghana site is used as a case study because I had site-specific knowledge and personal contacts, which were helpful in gathering other secondary information and data.

5.2.1 Sampling Procedure

The IMPACT Lite land survey teams, in collaboration with stakeholders (e.g., village chiefs, elders, local research and development partners) geographically divided the research site into several major production systems that determine the land use, farming activities and market characteristics that affect the combinations of farming activities available (Rufino et al. 2012). A list of villages was constructed for the research site and an equal number of villages were randomly selected for each production system. Each village and household were assigned to one production system. The number of villages per production system was determined as:

$$HRD = P * V * HV$$

where *HRD* is the number of households per research site, P is the number of production systems per site, *V* is the number of villages per production system and *HV* is the number of households per village. For each site, a total sample of 200 households (with 10 households per village) was targeted. Thus, the number of villages per research site (VS) depended only on the number of production systems (P) identified (i.e., VS=200/(10*P)).

For the purposes of this survey, a household was defined as “a group of people living in the same home and sharing meals and income generating activities, and acknowledging the authority of the household head" (Rufino et al. 2012). In order to sample households in selected villages, a list of households in each village was compiled. Only land-using households (i.e., households cultivating land, involved in aquaculture and/or keeping livestock) were considered for the survey. The pre-determined number of households was randomly selected from the constructed list.

5.2.2 Study Site and Data

A representative household was defined as a basis for the models developed in this study. This household was defined using the IMPACT Lite survey data from the CCAFS Ghana site, Lawra-Jirapa. Lawra-Jirapa is located in the Guinea Savannah agro-ecological zone in the Upper West region of Ghana, as indicated in Figure 5.1. The CCAFS Lawra-Jirapa site covers parts of the neighbouring Lawra and Jirapa districts, two of the eleven districts in the Upper West region. Lawra-Jirapa has ferrallitic soils and an average annual rainfall of approximately 950-1100 mm (Förch et al. 2011). The primary cropping system is smallholder mixed crop and livestock.

The most important food crops in Ghana, in terms of total area planted and total output, respectively, are maize and cassava. In contrast, groundnuts and sorghum are the most important crops in terms of both total area planted and total output in the Jirapa and Lawra districts, respectively (MoFA 2011). Agricultural production constraints in the region, characterized by high poverty levels, include limited access to capital and climate variability, especially seasonal rainfall. CCAFS sampled 200 households from 20 villages (10 households per village) at the Lawra-Jirapa site.

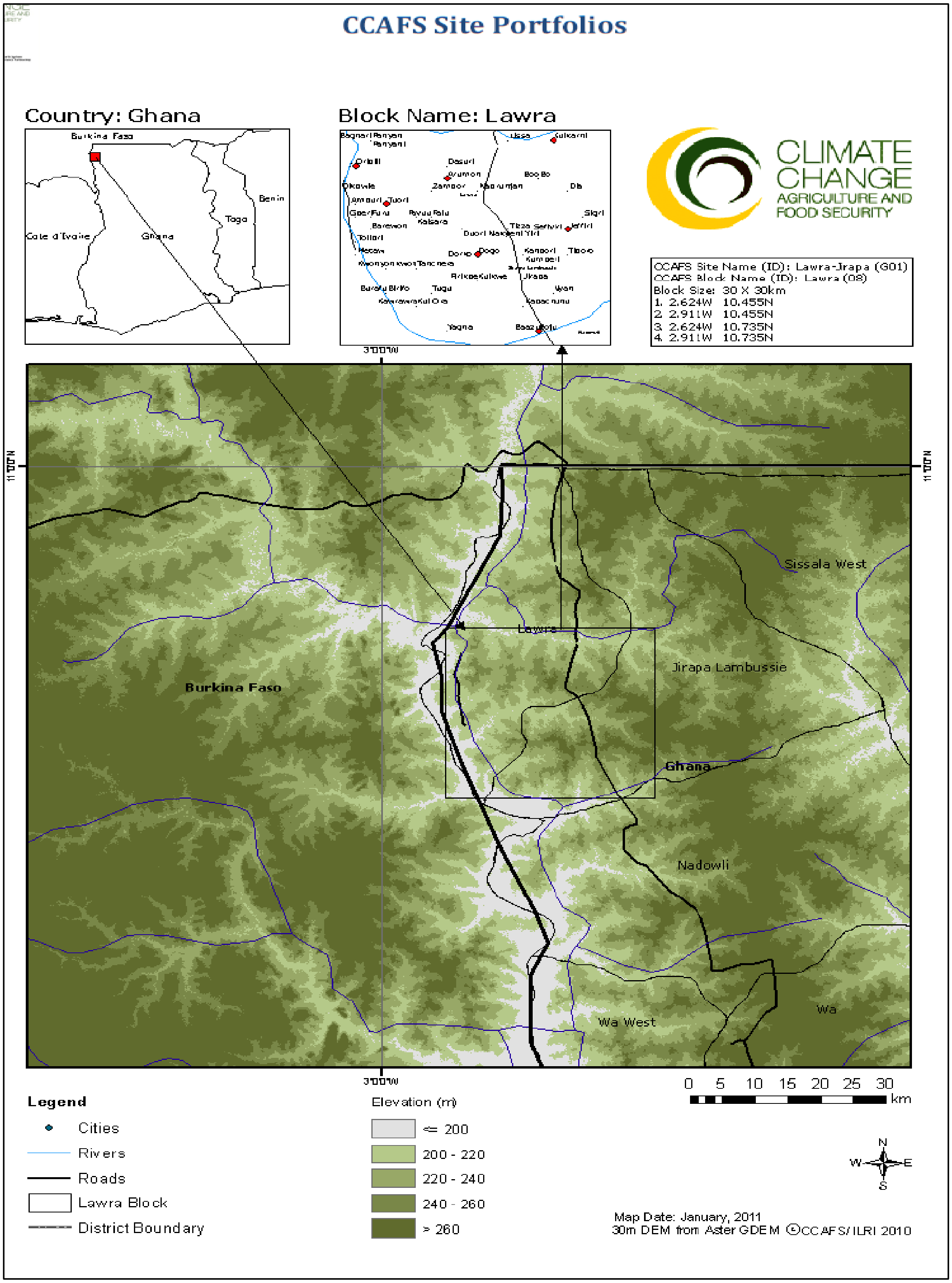

Figure 5.1: CCAFS Lawra-Jirapa Site Portfolio (Source: Förch et al. 2011).

5.3 Specifying a Representative Household

This section guides the choice of the model(s) needed to represent the households in our sample. Different models could be necessary for different representative households if there are differences among variables, such as output, input (labour) usage and output/labour (labour productivity).

Binswanger-Mkhize (2012) argues that insurance and diversification may interact differently for households of varying agricultural productivities and wealth. He stresses that formal insurance may not be valuable to wealthier and high productivity farmers who may already be self-insured. Poor farmers with low productivity, although less self-insured, are cash/credit constrained and may not be willing to pay insurance premiums that only pay out after harvest. Such differences could result in insurance operating differently for these various households. We thus investigated the data to ascertain whether or not multiple models are needed to represent different categories of households.

The sample was divided into four quantiles based on the distribution of land area used by each household. We used land as the basis for dividing the quantiles because it is argued to be correlated with wealth (Bhalotra and Heady 2003; Frankenberg, Smith and Thomas 2003; Mulder et al. 2009; VanWey 2005; Glewwe and Jacoby 2004; Ganjanapan 1986). Several studies acknowledge the potential differences in productivity due to land size, but the relationship (positive or negative) between land size and productivity seems to be contentious. Ahmad (2003) argues that small farms under-utilize various factors of production, which leads to lower output and income. Adamopoulos & Restuccia (2011) contend that large farms are likely to have higher labour productivity than small ones. On the contrary, several studies have found an inverse relationship between farm size and productivity in developing countries due primarily to missing and imperfect markets (Berry and Cline 1979; Feder 1985; Heltberg 1998; Assunção and Ghatak 2003). One could therefore expect higher or lower output for households with either large or small land sizes.

If households in all quantiles have similar output, inputs and output/input, then it can be argued that they have similar production technologies and productivity, and can therefore, be combined into one model. Otherwise, it could be more appropriate to group household with similar output, input (labour) and output/input and run different models based on those groupings. In the following sections, we discuss the differences and/or similarities among the quantiles in terms of land area, household size, as well as output, input (labour) and output/input for various crop activities.

5.3.1 Land Area and Quantiles

As discussed earlier, households are divided into four quantiles based on their total landholdings. Households with 0 to 5 acres are grouped into the 1st quantile, 5.01 to 8 acres into the 2nd quantile, 8.01 to 13 acres for households in the 3rd quantile and households with landholdings of more than 13 acres are found in the 4th quantile. Overall, households have an average landholding of 12.7 acres. Households in the 1st, 2nd, 3rd and 4th quantiles have average land sizes of approximately 3.83, 6.07, 10.79 and 19.89 acres, respectively. Out of 200 household sampled in this survey, 54 were in the 1st quantile, 57 in the 2nd quantile, 44 in 3rd quantile and 45 in the 4th quantile[6].

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[6] By definition, each quantile is supposed to have the same number of observations (50 households each in our case). Here, the differences in the number of households in each quantile stem from "ties" in land area. For example, the 51st - 57th households which should belong to the 2nd quantile are considered quantile 1 households because they have land area of 5 acres as does the 50th household, which is the border household for quantile 1.

5.3.2 Landholdings and Household Size

The popular aphorism that "the rich get richer and the poor get children" by Fitzgerald (1925) suggests that poorer people in society have more offspring and presumably larger households when compared to their richer counterparts. Banerjee and Duflo (2007) argue that the extremely poor (that is, households living on less $2 a day) have large family/household sizes. Netting (1982) draws the opposite conclusion from comparing wealth level as measured by estate values, landholdings, or livestock ownership and mean household sizes. He contends that "it is safe to say that where resources gather, so do people". Lanjouw and Ravallion (1995) found a positive relationship between household size and poverty up to a point, after which the relationship becomes negative due to size economies of consumption. There are, thus, mixed positions on the relationship between household size and wealth.

As shown in Figure 5.2, the 'exact' household sizes of the different quantiles in our data reflect these mixed positions but, an Analysis of Variance (ANOVA) test on the mean household sizes of the quantiles indicates that there is no statistically significant difference among the households in terms of household size. On the average, households in our sample have seven members[7].

[7] In discussing the relationship between wealth (landholdings in our case) and household size, several studies (Lanjouw and Ravallion 1995; Lancaster, Ray and Valenzuela 1999; Musgrove 1980) stress the importance of household composition (where households with more adults tends to be wealthier than those with more children) but in this study we do not consider the composition of the households.

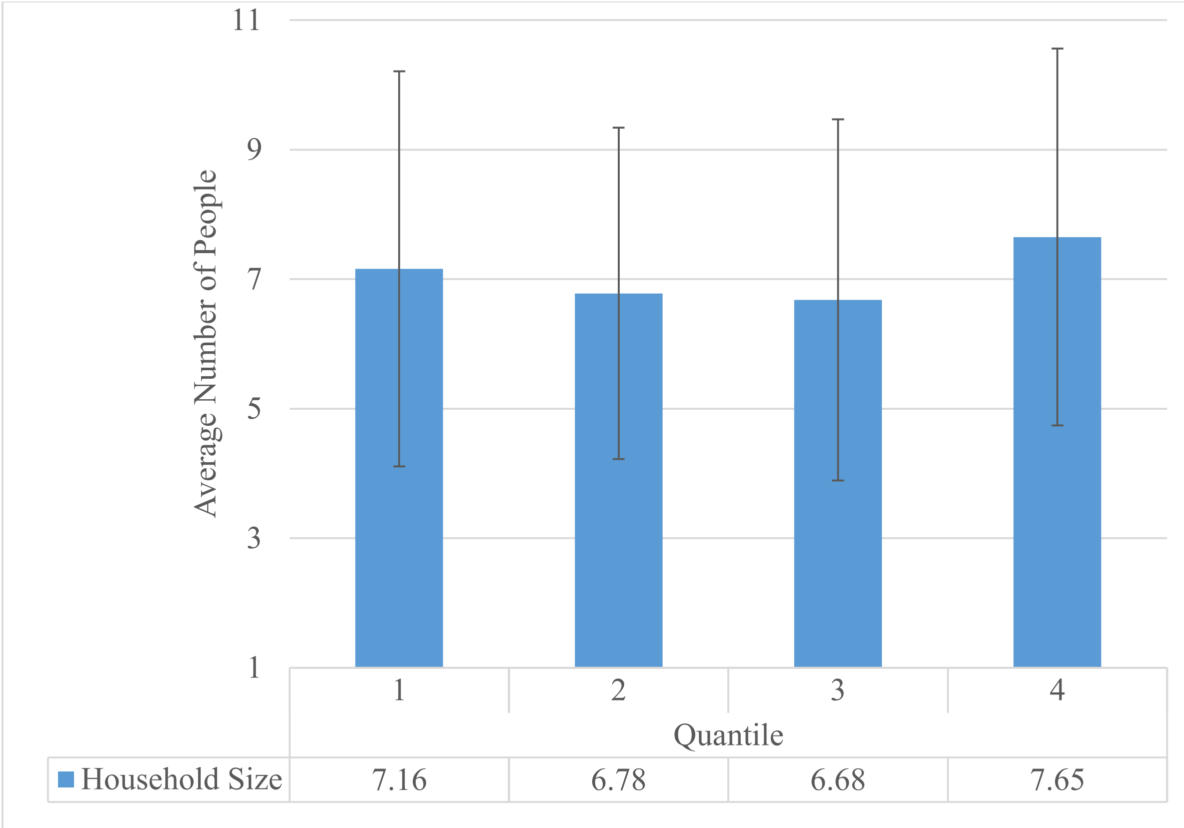


Figure 5.2: Mean Household Size.

Note: Error bars represent standard deviation

5.3.3 Crop Activities and Resources

In total, there were combinations of 19 different crop activities reported by the households in the survey (Table 5.1). For the purpose of our analysis, the top eight crops (groundnut, maize, millet, sorghum, Bambara beans, beans, cowpea and rice) accounting for 89.4% of the total available land were selected. Due to the lack of district level price and yield data for Bambara beans and beans, cowpea was used to represent the entire beans group (i.e., Bambara beans and beans and cowpea), bringing the considered household crop activities to six. Summaries of output and the labour requirement in each quantile for the six crops are shown in Table 5.2. In Table 5.2, for each crop and variable of interest, quantiles with the same letter indicate that they are significantly different from one another at a 95% confidence interval.

Table 5.1: Proportion of Land Allocated to Crops

Crop	Area (acres)	Average Area (acres)[a]	Average Area (acres) (N)[b]	Proportion of Land Allocated
Groundnuts	560.00	2.814	3.164 (177)	0.222
Maize	500.00	2.513	2.674 (187)	0.198
Millet	395.00	1.985	2.705 (146)	0.156
Sorghum	239.00	1.201	2.779 (86)	0.095
Bambara beans	225.00	1.131	2.711 (83)	0.089
Beans	210.00	1.055	2.838 (74)	0.083
Cowpea	130.00	0.653	2.826 (46)	0.051
Rice	120.00	0.603	1.714 (70)	0.047
Yams	43.00	0.216	1.024 (42)	0.017
Fallow	40.00	0.201	4.444 (9)	0.016
Soyabean	30.00	0.151	1.765 (17)	0.012
Pepper (Chillie)	16.00	0.080	1.000 (16)	0.006
Okra	6.00	0.030	1.200 (5)	0.002
Sweet Potatoes	3.00	0.015	1.000 (3)	0.001
Tomato	3.00	0.015	1.000 (3)	0.001
Melonseed	2.00	0.010	2.000 (1)	0.001
Other	2.00	0.010	2.000 (1)	0.001
Vegetables, assorted orchard	2.00	0.010	2.000 (1)	0.001
Tobacco	1.00	0.005	1.000 (1)	0.000
TOTAL	**2527.00**	**12.698**	**39.844**	**1.000**

Notes:

[a] Average taken over the whole sample.

[b] Average taken over the households who grow that particular crop. Numbers in parentheses represent the number of households who grow the crop.

As shown in Table 5.2, there are no consistent patterns or relationships among the means of the variables considered for the crops to sufficiently suggest pattern in the quantile groupings. We therefore ran an ANOVA to test whether the difference in the means of the variables across quantiles are statistically significant. While ANOVA is able to determine whether there are significant differences in the means of the various groups (quantiles), it is unable to determine the exact groups that differ. The Tukey Honestly Significant Difference (HSD) post-hoc test was used to determine the specific groups whose means differed significantly. The detailed results of the ANOVA test and the Tukey's HSD test for the various crops and variables of interest (Output/acre, Labour hours/acre and Output/ labour hour) are presented in Appendix A (Figure A 1 to Figure A 17 and Table A 1 to Table A *8*).

The ANOVA tests suggest that, for maize and groundnut, at least one quantile is significantly different in terms of labour hours/acre and output/labour hour; for millet, at least one quantile is significantly different in terms of all the variables of interest; for cowpea, at least one quantile is significantly different in terms of output/acre. For rice and sorghum, the quantiles are not significantly different from each other in all the variables considered. But the results for the Tukey's HSD test do not disclose consistent patterns in statistical differences among the quantiles. Given the lack of systematic difference between the quantiles, we conclude that a single model is sufficient to represent the whole sample.

Table 5.2: Quantile Mean Output/Acre, Labour/Acre and Output/Labour Summaries for Crop Activities[8]

Quantiles	Mean Output Kg/Acre	Mean Labour Hours/Acre	Mean Output Kg/Labour Hour
Maize			
Whole Sample	207.27	525.96	2.29
1st Quantile	242.39	233.93[a]	2.85
2nd Quantile	189.50	747.07[a]	2.12
3rd Quantile	172.62	536.91	1.13[a]
4th Quantile	189.50	531.43	3.18[a]
Groundnut			
Whole Sample	272.57	257.45	2.30
1st Quantile	299.17	132.16[a]	4.16[a,b]
2nd Quantile	233.99	291.37	1.62[a]
3rd Quantile	244.17	366.66[a]	1.34[b]
4th Quantile	247.47	230.62	2.57
Millet			
Whole Sample	120.50	328.55	0.83
1st Quantile	173.56[a,b,c]	212.36[a]	1.75[a,b,c]
2nd Quantile	115.59[a]	319.20	0.85[a]
3rd Quantile	99.22[b]	517.30[a,b]	0.49[b]
4th Quantile	79.16[c]	259.60[b]	0.83[c]

[8] To account for outliers, all averages were taken over 10% trimmed data. This was done by sorting the data in ascending order and deleting 10% of the observations from both the top (lowest values) and the bottom (highest values).

Quantiles	Mean Output Kg/Acre	Mean Labour Hours/Acre	Mean Output Kg/Labour Hour
Cowpea			
Whole Sample	97.83	208.96	1.38
1st Quantile	55.25[a]	154.17	1.65
2nd Quantile	275.00[a]	641.56	0.96
3rd Quantile	62.50	432.68	0.40
4th Quantile	125.83	190.85	1.84
Sorghum			
Whole Sample	117.85	530.35	0.66
1st Quantile	109.5	335.61	1.50
2nd Quantile	121.25	550.99	1.15
3rd Quantile	122.60	784.67	0.20
4th Quantile	133.89	463.63	0.88
Rice			
Whole Sample	176.91	387.26	0.92
1st Quantile	145.83	166.32	0.62
2nd Quantile	137.82	294.14	1.13
3rd Quantile	193.33	562.59	0.87
4th Quantile	237.78	489.69	0.94

Note: For each crop and variable of interest, quantiles with the same letter indicate that they are significantly different at a 95% confidence interval.

5.4 The Representative Household

Table 5.3 shows the values of the parameters of our representative household as required in section 4.2; on the average, our representative household is endowed with 12.7 acres of land. The representative household has seven members and a total of 3,746.43 hours of agricultural labour, of which 44.2% is provided by the household and 55.8% is hired. This available labour is estimated by summing the labour used for all crop activities. The household pays a wage of GHC0.70/hour for hired labour. The household spends a total of GHC 527.89 on other expenses, of which 58.3% is on other farm activities (i.e., farm activities that are not explicitly modelled in this study) and 41.7% is on non-farm activities, such as school fees, medical and personal (e.g. clothing) expenses. The household receives a total of GHC 499.38 income from other sources, of which 86.5% is from other farm activities that are not explicitly modelled and 13.5% from non-farm sources, such as remittances.

Table 5.3: Summary of Representative Household Derived from IMPACT Lite Dataset[a]

Variables	Value
Household Size	7
Land (Acres)	12.70
Family Agricultural Labour (Hours)	1656.05
Hired Labour (Hours)	2090.38
Wage for Hired Labour (GHC/Hour)	0.70
Other Farm Expenses (GHC)	307.70
Other Non-Farm Expenses (GHC)	220.19
Other Farm Income (GHC)	431.82
Other Non-Farm Income (GHC)	67.56

Notes:

[a] The data for the representative household is derived as a 10% trimmed mean values of the IMPACT Lite survey data.

5.5 Derivation of Other Model Parameters and Simulation Procedure

In addition to the parameters derived from the IMPACT Lite (i.e., Table 5.3), this section discusses the values and methods for deriving other parameters used in the empirical models, including the estimation of the coefficient of risk aversion and prices, as well as simulating yield series to represent states of nature.

5.5.1 Coefficient of Risk Aversion Estimation

In this study, the risk preferences of households are incorporated in the objective function through ψ in equation (4.1). As discussed in section 3.3.2, we assumed that our representative household has a constant absolute risk aversion. We therefore needed an estimate of the coefficient of absolute risk aversion (CoARA) of our representative household. A review of empirical studies points to a wide range of variation in estimates of the CoARA for smallholder agriculture in developing countries (Table 5.4).

As Raskin and Cochran (1986) noted, the Arrow-Pratt measure of absolute risk aversion is difficult to compare or transfer from one study to another. We therefore approximated a plausible range for the CoARA of our representative household using a range of coefficient of relative risk aversion (CoRRA), which, as discussed in section 3.3.1, is comparable due to its unit-less nature.

Ideally, the CoARA derived from other studies would be converted to a coefficient of CoRRA using a measure of wealth. However, with the exception of Bar-shira et al. (1997), who report the two measures of risk aversion, the measure of wealth is not clear in most studies, preventing conversion between the two risk aversion measures. We therefore reviewed additional studies that report the coefficient of relative risk aversion. The coefficient of relative risk aversion from Bar-shira et al. (1997) and the additional studies, as shown in Table 5.4, fall between the 0.5-4 range proposed by Anderson and Dillon (1992). For example, Harrison, Humphrey and Verschoor (2008) estimated relative risk aversion ranges of 0.874 to 0.951 for Ethiopia and 1.01 to 1.104 for Uganda. Elamin and Rogers (1992) and Wiens (1976) found the risk aversion coefficient to be different for large and small African and Asian farms, reflecting the general consensus that wealthier farmers are less risk averse than poorer farmers.

Table 5.4: Summary of Empirical Estimates of Absolute and Relative Risk Aversion in Developing Countries.

Source	Country	Method	Absolute Risk Aversion Estimate	Relative Risk Aversion Estimate
Dillon and Scandizzo (1978)	Brazil	DEU[9]	0.04 to -3.46.	N/A
Harrison, Rutström, and Veiga (2005)	Timor-Leste	DEU		0.608 to 0.613
Harrison, Humphrey and Verschoor (2008)	India, Ethiopia and Uganda	DEU	N/A	India: 0.841 to 0.896 Ethiopia: 0.874 to 0.951 Uganda:1.01 to 1.104
Domingo, Parton and Mullen (2015)	Philippines	DEU	0.000317 to – 0.00000816	N/A
Wiens (1976)	Asia	OEB[10]	Large farms (0.0085) and small farms (0.091).	N/A

[9] DEU - Direct Elicitation of Utility functions. Decision makers' risk preferences are inferred from the choices they make in "reaction to a large number of randomly arranged hypothetical bets and insurance schemes". (Moscardi & de Janvry, 1977, pp.710).

[10] OEB - Observed Economic Behaviour. Risk preferences of decision makers are inferred from the relationship between observed (actual) behaviour and the behaviour predicted from an underlying behavioural model (Hedden-Dunkhorst 1997; Antle 1987).

Source	Country	Method	Absolute Risk Aversion Estimate	Relative Risk Aversion Estimate
Moscardi and de Janvry (1977)	South America	OEB	The distribution of risk aversion was centred on the risk aversion parameter, K, where K-1.12. K was the marginal rate of substitution between net income and risk.	N/A
Antle (1987)	Asia	OEB	Mean of 3.272.	N/A
Elamin and Rogers (1992)	Africa	OEB	N/A	The coefficient of relative risk aversion for small, median and large farms was found to be 1.93, 1.50 and 2.54, respectively
Hedden-Dunkhorst (1993)	Africa	OEB	0.58 to -0.06.	N/A
Bar-Shira *et al* (1997)	Middle East	OEB	The median and mean coefficients of absolute risk aversion were 0.0000044 and 0.0000045, respectively.	The median and mean coefficients of relative risk aversion were 0.615 and 0.611, respectively.

In estimating our CoARA, we used the bounds of CoRRA as proposed by Anderson and Dillon (1992) to the estimate bounds for CoARA and the Observed Economic Behaviour (OEB) method to elicit the CoARA of our representative household (see section 5.6.2 for further discussion on the elicitation process).

Wealth is used as the argument for risk aversion in Arrow and Pratt's original measure, but, due to difficulties in defining and estimating wealth, several studies have used other measures, such as income (Zindi 2006; Schechter 2005; Gandelman and Hernández-Murillo 2014; Elamin and Rogers 1992). Moreover, the expected utility axioms do not delineate between using wealth, income or consumption as the argument for the utility function. In this study, we used the market value of household consumption because we assume that the objective of the household is to maximize its expected utility of consumption. Therefore, the value of consumption should be able to define the household's risk preference well. The steps below are taken to convert CoRRA to CoARA.

First, the total value of average household consumption (C) is estimated as the product of the mean quantities of crops consumed and their respective prices. Since this estimate is an average of the whole sample, an upper bound and lower bound were derived as 150% and 50% of C, respectively, to define a reasonable range of C values to be used for the CoRRA to CoARA conversion as in Zindi (2006).

CoARA is estimated using the formula $r_a = r_r/C$, where r_a is CoARA and r_r is CoRRA. Values of 0.5 and 4 were used for r_r as proposed by Hamal and Anderson (1982) and used by Hardaker et al. (2004). The lowest and highest values of r_a (i.e., 0.004 and 0.020) calculated from this procedure for the representative household are used to represent the lower and upper bounds of CoARA in the models to limit the range of risk aversion considered.

5.5.2 Yield Series

To capture climate variability in our models, as discussed in section 4.2, we need area (i.e., district[11]) and farm-level yield series to represent various yield states of nature. We collected district (Lawra and Jirapa) historical data (2000-2013) from the Ministry of Food and Agriculture. The average yields of the two districts in each year were used as our historical area yields. There were no farm-level historical yields. Thus, as in Zindi (2006), we used the observed yields (representative household yields) from the available cross-sectional data (CCAFS IMPACT Lite dataset) and the area yields (2000-2013) to derive household's farm-level yield series. Observed yields were used for the base year (2012), with the remaining values derived by extending the observed yields (2000-2011, 2013).

Swinton and King (1991) argue that crop yield time-series data must be de-trended to eliminate "technology bias", and for practical purposes, the method used must be simple, efficient and unbiased. They further argue that the method should only require yields and time and be able to accommodate short series. OLS thus remains a popular method for de-trending yields series and is employed in this study.

With the OLS method, de-trending is generally accomplished by regressing yields on time and the estimated coefficient tested for significance (Haan 2002; Swinton and King 1991). In this study, historical district yields are regressed on year (results shown in Table B 1, Appendix B) and crop yield series with significant time trends (i.e., cowpea and rice) are de-trended using:

$$Y_t^* = \hat{Y}_{2012} * \frac{Y_t}{\hat{Y}_t},$$

[11] Districts are decentralized administrative subdivisions of the government of Ghana. It can be considered as synonymous to counties in Canada in terms of structure and governance.

where Y_t^* is the de-trended yield for year t, $\hat{Y}_{2012}$ is the predicted yield for the base year, Y_t is the actual yield for year *t* and $\hat{Y}_t$ is the predicted yield for year *t*.

We used the relative variation in the de-trended historical district yields to convert district yield series to farm-level yield series (Table B 2, Appendix B). For example, to calculate the farm-level yield for 2002, we first estimate the relative variation in 2002 area yields by dividing the 2002 district yields by the base year (i.e., 2012) district yields. This relative variation estimation is done individually for each year. The household's farm-level yield for each year is consequently estimated by multiplying the relative variation in that particular year by the household's 2012 observed farm-level yield obtained from the cross-sectional data (Table B 2).

5.5.3 Selecting the Index for the Insurance Programme: Weather-Based Index or Area Yields?

This section discusses the considerations made in selecting an index for our insurance programme. Index insurance contracts are complex to design and require an index that is "sufficiently" correlated with crop loss (Dick and Stoppa 2011; Sina 2012; Stoppa and Hess 2003; Skees, Barnett and Murphy 2007; Zeuli and Skees 2005; Collier et al. 2009). In the case of weather-based insurance, Dick and Stoppa (2011) contend that the weather variables used must be closely correlated with crop yields. Sina (2012) notes that the lower the correlation, the higher the basis risk.

Although there is a consensus that weather variables must be well correlated with crop yields for weather-based insurance to work, what constitutes sufficient correlation is not well defined in the literature. For example, in their Morocco weather insurance study, Stoppa and Hess

(2003) found a 67% correlation between cumulative rainfall and yields, but contend that it does not sufficiently explain yield variability. McNally et al. (2015), in their Water Stress Index (WRSI) study using remotely sensed soil moisture, suggest that a correlation greater than 0.5 is sufficient.

Since numerous factors influence crop yields, several studies have used combinations of crop modelling approaches, satellite imagery, statistical tools and rainfall simulators to circumvent data challenges that might be present in weather stations, especially in developing countries, in order to develop a weather index that is highly correlated with crop yields (Sina 2012). For this study, historical data of cumulative rainfall (1990-2013) from two weather stations in the study districts collected from the Ghana Meteorological Agency was converted to a cumulative rainfall index (Table B 2, Appendix B). The cumulative rainfall index for each year (I_t) is given by dividing the cumulative rainfall for year *t*, R_t^c , by the average annual cumulative rainfall for all years *T* (Zeuli and Skees 2005).

$$I_t = R_t^c \Big/ \left(\sum_t R_t^c / T \right)$$

Sina (2012) iterates that weather insurance contracts are limiting and offer "minimal risk protection"' in places where there are microclimates (i.e., weather conditions vary within short distances) like the Sahel region of Africa, including our study site. Dick and Stoppa (2011) also argue that weather-based insurance may be limiting in the humid subtropics where there are complex causes of crop loss, such as pests and diseases; they contend that in such cases, it might be appropriate to use other insurance products such as area-yield index insurance.

Ideally, we would have used a weather index for our insurance since it captures weather variability directly and is commonly suggested in the index-based insurance literature (for mostly pilot cases). However, the maximum correlation between yields and our weather variable (cumulative rainfall) is less than 17% for all considered crops (Table B 7, Appendix B) which, according to both Stoppa and Hess (2003) and McNally et al.(2015), is not sufficient for a weather-based insurance. We thus used area-based yields as the index for our insurance contract, as suggested by Dick and Stoppa (2011).[12]

5.5.4 Empirical Literature on Correlations between Farm and Area Yields

The procedure we used in converting historical area yields to farm-level yields produces a perfect correlation between the two. This is not realistic as it completely eliminates basis risk (see sections 5.5.2 and 5.5.5). We therefore reviewed empirical studies to suggest an appropriate correlation to use in simulating yield states of nature.

Empirical research on the correlation between farm-level and area yields under index-based insurance is limited. Wang et al. (1998) used optimization and stochastic techniques to assess the performance of individual farm and area yield crop insurance programmes for a representative southwest Iowa corn farmer. Their simulation model used the average sample correlation of 0.85 between individual farm and county (area) yield predictions from 1983 to 1992. Similarly, Deng, Barnett and Vedenov (2007) analysed the relative performance of farm-level multiple peril crop insurance and area yield insurance contracts for cotton and soybeans production in Georgia and South Carolina between 1971-2000 and 1972-2000, respectively. Their findings indicate average correlations of 0.63 and 0.32 between farm-level and area yields for cotton and soybean, respectively. Using farm level data on corn and sugar

[12] Note that the type of index used for this analysis will not influence the gist of our empirical investigations. Whether weather or area yield based, the general objective of the index is to get an indirect measure of actual losses.

beet farms in the US, Barnett, Black, Hu and Skees (2005) compared the performance of multiple peril crop insurance and area yield insurance contracts. They found a wide range of average correlation between farm and area corn yields by state, from 0.36 in Michigan to 0.82 in Illinois. Also, their results suggest that area yield insurance performed better relative to multiple peril crop insurance in states where there were high correlations between farm-level and area yields. From the above review, we assume that a correlation of 0.8 between farm-level and area yield series is reasonable and thus used this correlation in our yield simulations.

5.5.5 Simulating Yield Series to Represent States of Nature

As discussed in sections 4.2 and 5.5.2, yield states of nature are required to represent possible yield scenarios due to climate variability, as in equations (4.3), (4.10) and (4.11). In this section we discuss the procedure used in simulating yield series to represent these states of nature.

The "fit distribution" function in the @RISK add-in for Microsoft Excel is used to fit the best distribution for the 14 years (2000-2013) area and farm yield series (Table B 2, Appendix B). @RISK uses five statistical criteria (Akaike Information Criteria, Bayesian Information Criteria, Chi-Square statistic, Anderson–Darling statistic and Kolmogorov-Smirnov statistic) to determine the distribution that best fits the historical data. The first ranked distribution for each crop (i.e., the distribution with the least sum of rank scores) from these statistics is used for the yield simulations.

Table B 3 and Table B 5 in Appendix B respectively, present the ranking of the three best distributions of each crop's area and farm-level yields. Table B 4 and Table B 6 in Appendix B respectively, present summaries of the best distribution of each crop used in our area and farm-level yield simulations.

Because our farm-level yields are derived from historical area yields (see section 5.5.2), there is a perfect correlation between the two, for each crop. We therefore used the distribution of the historical area yields and the estimated farm-yield series to simulate series that have a correlation coefficient of 0.8 between area and farm yields for each crop.

In order to do these simulations in @RISK, we need a complete correlation matrix. To complete the correlation matrix, we need inter-crop correlations (i.e., the correlations between the different crops). Since the procedure we used in deriving the farm-level yield series from the area yield series only considered the correlation between area and farm yields for each crop, the correlations between the different crops from this procedure were implausible, given the agronomic relationship between the crops (Table B 7, Appendix B). For example, there is a negative correlation between sorghum and maize, but these two crops are agronomically similar and should, at the very least, have a weak positive relationship.

To decide on the appropriate area and farm yields between-crop correlations, we had the option of using the inter-crop correlations of historical national yield from the Food and Agriculture Organisation's database (Table B 8, Appendix B) or area yield series from the Ministry of Food and Agriculture, Ghana. These sets of correlations (Table B 9, Appendix B) were presented to two experts[13] who selected the inter-crop correlations of the national yield series as being more consistent with agronomic expectations compared to that of the area yield series. For cowpea, because there was no historical national yields data, we used the national beans yields inter-crop correlations since we consider cowpea as a proxy for the beans group (i.e.,

[13] Dr. Christiana Amoatey, Head, Department of Crop Science, University of Ghana and Dr. John K. M. Kuwornu, Senior Lecturer, Department of Agricultural Economics and Agribusiness, University of Ghana.

Bambara beans, beans and cowpea) in our models. Table B 10 in Appendix B presents the complete correlation matrix specified in @RISK.

@RISK assesses the validity of any specified correction matrix using the basic principle that if two inputs are each strongly correlated to a third, they must be at least weakly correlated to each other. @RISK thus adjusted the matrix we specified to generate a self-consistent correlation matrix[14] (Table B 11, Appendix B). Several yield simulations are then run to find the number of iterations that gives the closet correlation matrix to the @RISK adjusted one. We found the correlation matrices of simulations at 500 iterations (Table B 12, Appendix B) to be close to the @RISK adjusted one. We thus used the 500 simulated area and farm yields to represent 500 yield states of nature in our GAMS models. These states of nature are assumed to represent 500 possible yield events with equal probabilities of occurrence (i.e., $Prob_i = 0.002$) and capture the climate and yield risks in the models.

5.5.6 Prices

In the models developed, we required three sets of prices for the crops, purchase prices, selling prices and consumption values, as in equations (4.1), (4.12) and (4.13). For purchase prices, historical district retail price data (2009-2013) from the Ministry of Food and Agriculture was used (Table B 13, Appendix B). The nominal historic retail prices were deflated using the CPI to give real price series using the formula:

$$P_k^r = \frac{P_k^n}{CPI_k}$$

[14] The @RISK procedure for adjusting matrices is discussed in Appendix B1.3.

where P_k^r is the real price in year k; P_k^n is the nominal price in year k and CPI_k is the consumer price index (agriculture) in year k. We assumed that price is exogenous and deterministic and thus used the average real retail prices (2009-2013) for the crops as their purchase prices in our models (Table 5.5).

For selling prices, we needed farm-gate prices, but they were not available. There was also no available literature to suggest the relationship between them and retail (purchase) prices in our study area. However, Kalinda & Campenhout (2011) found farm gate prices for food crops in Tanzania to be 10%-20% less than retail (purchase) prices due to marketing costs. Given that similar economic conditions prevail in the site considered in this study, we assumed selling prices in our model to be 20% less than the purchase (retail) prices (Table 5.6).

With consumption values, there was no literature to suggest their relationship with purchase prices, even in other countries, and we therefore could not approximate them using other sources. As a result, a grid search was programmed in GAMS to calibrate the model by searching for consumption values and CoARA that closely predict the observed baseline land allocation behaviour of the representative household (procedure further discussed in section 5.6.2).

5.6 Model Calibration and Validation

Calibration is defined as the process of adjusting uncertain parameters in a model to improve its agreement with data (Thacker et al. 2004). Validation is defined as a subjective process of assessing the appropriateness and soundness of a model for its intended purpose (Thacker et al. 2004; Finlay and Wilson 1991). In the literature, quantitative validation mostly concentrates on testing the goodness of fit between the behaviour of a model and the observed real world data. Since this study assumed that the household's land allocation behaviour is optimal, a well calibrated model should be able to closely replicate that behaviour. The next sections discuss the measure of model performance and the procedure for the calibration and validation of the base model developed in this study. There is no empirical data on households' land allocation behaviour in the presence of insurance. Thus, the insurance model cannot be explicitly validated. Since the insurance model is an extension of the base model, it can be argued that a well calibrated base model produces a well calibrated insurance model.

5.6.1 Measure of Model Performance

The base model in this study focuses on how resources are allocated to competing crop activities in the absence of insurance. Thus, how well the model predicts the allocation of land to the crops is the primary criterion for the assessment of model fit. Several measures of goodness of fit, such as percentage deviation, mean absolute deviation, sum of squared deviation and root squared deviation, can be used to measure the performance and validity of models (Buisson et al. 2014). As in Zindi (2006), we used the sum of squared deviation between predicted and observed land allocations calculated as $\sum_d [Acre_p(d) - Acre_o(d)]^2$, where, $Acre_p(d)$ is predicted acres allocated to crop d and $Acre_o(d)$ is observed acres allocated to crop d, as the measure of goodness of fit to validate our model.

5.6.2 Procedure for Model Calibration and Validation

In calibrating our model, we concentrated on two sets of values for which we had little information for our site: consumption values and risk preferences. With consumption values, we assumed that the consumption values for the crops are at most equal to their purchase prices. And for risk preferences, the range of CoARA established in section 5.5.1 (i.e., 0.004 to 0.020) was used as the lower and upper bounds in searching for the risk preference for our representative household.

A grid search using seven loops, one for the CoARA and one each for the consumption values of the six crops, was programmed in GAMS to find the combination of risk aversion coefficient and consumption values that minimized the sum of squared deviations between the predicted and observed land allocated to the crops using several iterations. During each iteration, the risk aversion coefficient increased by 0.004 until it reached the upper bound of 0.020 and the relative values of consumption to purchase prices for the crops changed by a factor of 0.25 from 0 to 1. The grid search indicates that the best combination that minimizes the sum of squared deviation between observed and predicted land allocation is an absolute risk aversion coefficient of 0.016 and consumption values half the respective purchase prices of the crops (Table 5.5).

Table 5.6 shows the observed household land allocation behaviour from the survey data and the predicted allocation based on this combination. The observed and predicted allocations of maize and millet are equal and that of the other crops are quite close. In total, the observed and predicted land allocation to crops have a sum of squared deviation of 0.734, with cowpea having the largest (0.385). The absolute risk aversion coefficient and consumption values established from the grid search procedure are used in subsequent analyses in the base and insurance models. Also sensitivity analyses are done to assess the effect of changing risk aversion, as in equation (4.1) and insurance parameters such as premium subsidies and coverage level, as in equations (4.18) and (4.19) on household land allocation behaviour and welfare.

Table 5.5: Purchase, Selling Prices and Consumption Values Used in Models

Crop	Purchase Price (GHC)[a]	Selling Price (GHC)[b]	Consumption Value (GHC)[c]
Groundnut	1.67	1.34	0.84
Rice	1.26	1.01	0.63
Cowpea	1.11	0.89	0.56
Sorghum	0.76	0.61	0.38
Millet	0.75	0.60	0.38
Maize	0.53	0.42	0.27

Notes:

[a] Purchase prices of the crops are derived as their mean district real retail prices from 2009 to 2014.

[b] Selling prices of the crops are estimated as 80% of their purchase prices as discussed in section 5.5.6.

[c] As established by our calibration process (section 5.6.2), consumption values of the crops are estimated as 50% of their respective purchase prices.

Table 5.6: Observed vs. Best Predicted Household Land Allocation Behaviour

Crops	Observed Acres	Predicted Acres	Squared Deviation
Millet	1.985	1.988	0.000
Maize	2.513	2.534	0.000
Groundnut	2.814	2.636	0.032
Sorghum	1.201	1.498	0.088
Rice	0.603	1.081	0.229
Cowpea	2.839	2.218	0.385
SUM	**11.955**	**11.955**	**0.734**

CHAPTER 6 RESULTS AND DISCUSSIONS

6.1 Overview

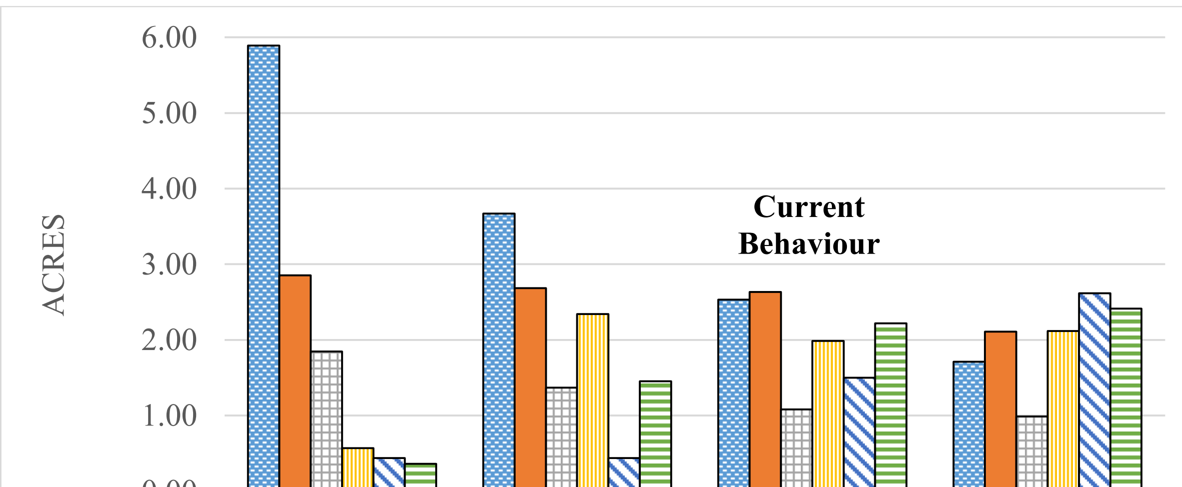
This chapter presents the results and discussions from the base and insurance models developed in this study. The base model was structured to give the representative household the option of diversifying its activities among six crop activities with no insurance. As discussed in section 5.6, the base model was established by calibrating the model to the baseline land allocation behaviour of the household. Using the calibrated model, the results for the base model discussed in this chapter concentrate on the sensitivity of the representative household's crop diversification behaviour to changes in its risk preference.

The insurance model is an extension of the base model, where in addition to the option of crop diversification, the representative household can buy area yield insurance to ameliorate its yield risk. The insurance model is structured to allow the representative household to put some or all of its available landholdings under insurance based on the attributes of the insurance programme such as the scale, coverage level, and premium subsidy. As discussed in 2.4.1, scale is a choice variable, in monetary units per acre, that the insured varies per acre to align expected indemnities with expected farm-level losses. In the insurance model, the results focus on how changes in these attributes influence the household's decision to insure or not to insure. In addition, we consider the relationship between diversification and insurance and how changing risk preferences and insurance attributes influence this relationship.

6.2 Risk Aversion and Diversification

Using the Transformed Herfindahl Index (THI) discussed in section 2.1 as a measure of diversification, we assess how diversification varies with changes in the Coefficient of

Absolute Risk Aversion (CoARA) (see sections 5.5.1 and 5.6.2) in the base and insurance models. We used CoARA values of 0.008, 0.012, 0.016 and 0.020 to represent low, moderate, high and very high risk aversions, respectively. We expect that since diversification is a risk management strategy, highly risk averse households would diversify more than others to spread their risk. Figure 6.1 shows changes in the household's land allocation behaviour as risk aversion increases in the base model. In the base model, the representative household tends to allocate its land more evenly among the crops as risk aversion increases. For example, at the low risk aversion level, the household allocates 5.89 acres to maize and 0.36 to cowpea but, at the very high risk aversion level, the household allocates 1.71 and 2.22 acres to maize and cowpea, respectively. The high risk aversion level fits the current ("observed") land allocation behaviour of the household based on the calibration model.

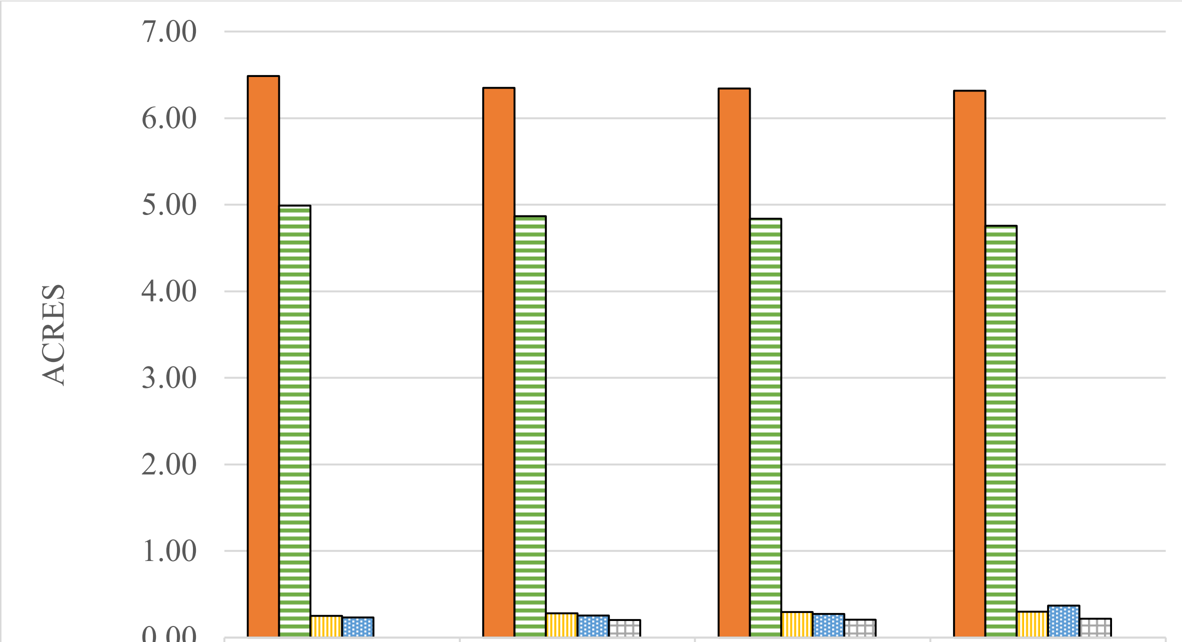


	Low	Moderate	High	Very High
Maize	5.89	3.67	2.534	1.713
Groundnut	2.852	2.686	2.636	2.109
Rice	1.845	1.367	1.081	0.986
Millet	0.568	2.34	1.988	2.117
Sorghum	0.438	0.438	1.498	2.616
Cowpea	0.362	1.454	2.218	2.414

Figure 6.1: Risk Aversion and Land Allocation (Acres) Behaviour in the Base Model.

As baseline insurance attributes to compare the diversification behaviour of the household with increasing risk aversion in the base and insurance models, we assume 70% coverage (which implies that the household's observed yield must be less than 70% of the average area yield to trigger pay-out), 100% scale (which implies that pay-out is valued at 100% of pre-determined retail prices) and actuarially fair premiums (i.e., premiums are equal to expected indemnities) with a 10% load factor (which is the mark-up (profit) to the insurer for taking up the risks of the insured). Using these baseline insurance attributes, the household puts all available land under insurance; thus, land allocations discussed here represent insured acres.

Figure 6.2 shows that although the extent of even land allocation among the crops as risk aversion increases in the insurance model is lower compared to the base model, as risk aversion rises, more land is allocated to crops which have low allocation at lower risk aversion levels and vice versa. For example, at the low risk aversion level, the representative household allocates no land to rice, compared to 0.22 acres at the very high risk aversion level.



	Low	Moderate	High	Very High
Groundnut	6.485	6.350	6.342	6.315
Cowpea	4.988	4.867	4.838	4.758
Millet	0.250	0.280	0.296	0.298
Maize	0.232	0.255	0.274	0.369
Rice	0.000	0.203	0.206	0.216
Sorghum	0.000	0.000	0.000	0.000

Figure 6.2: Risk Aversion and Land Allocation (Acres) Behaviour in the Insurance Model.

It is important to note that although the base and insurance models show that diversification rises with risk aversion, the degree of diversification in the base model is higher than in the insurance model at all risk aversion levels, as shown in Figure 6.3. The THI increases with risk aversion in the base and insurance models, although the THI values in the base model are higher than those in the insurance model. In the base model, THI increases by approximately 22% from 0.672 at low risk aversion to 0.822 at the very high risk aversion level. But in the insurance model, THI increases from 0.531 at low risk aversion by 6% to 0.561 at in the very high risk aversion level. Also, at the low risk aversion level, the degree of diversification is approximately 23% more in the base model than in the insurance model. And at the very high risk aversion level, the extent of diversification in the base model is approximately 38% more than in the insurance model. This finding can be argued to be a result of the perceived risk-reducing effect of insurance. With the assurance that it can rely on insurance should anything go wrong, the representative household diversifies less than it might have without insurance. Our results are consistent with findings from several other studies, which suggest that to reduce price and production risks, highly risk averse farmers tend to diversify more than those who are less risk averse (Bhende and Venkataram 1994; Mishra and El-Osta 2002; Mishra, El-osta and Sandretto 2004; Lu, Xi and Ye 2006).

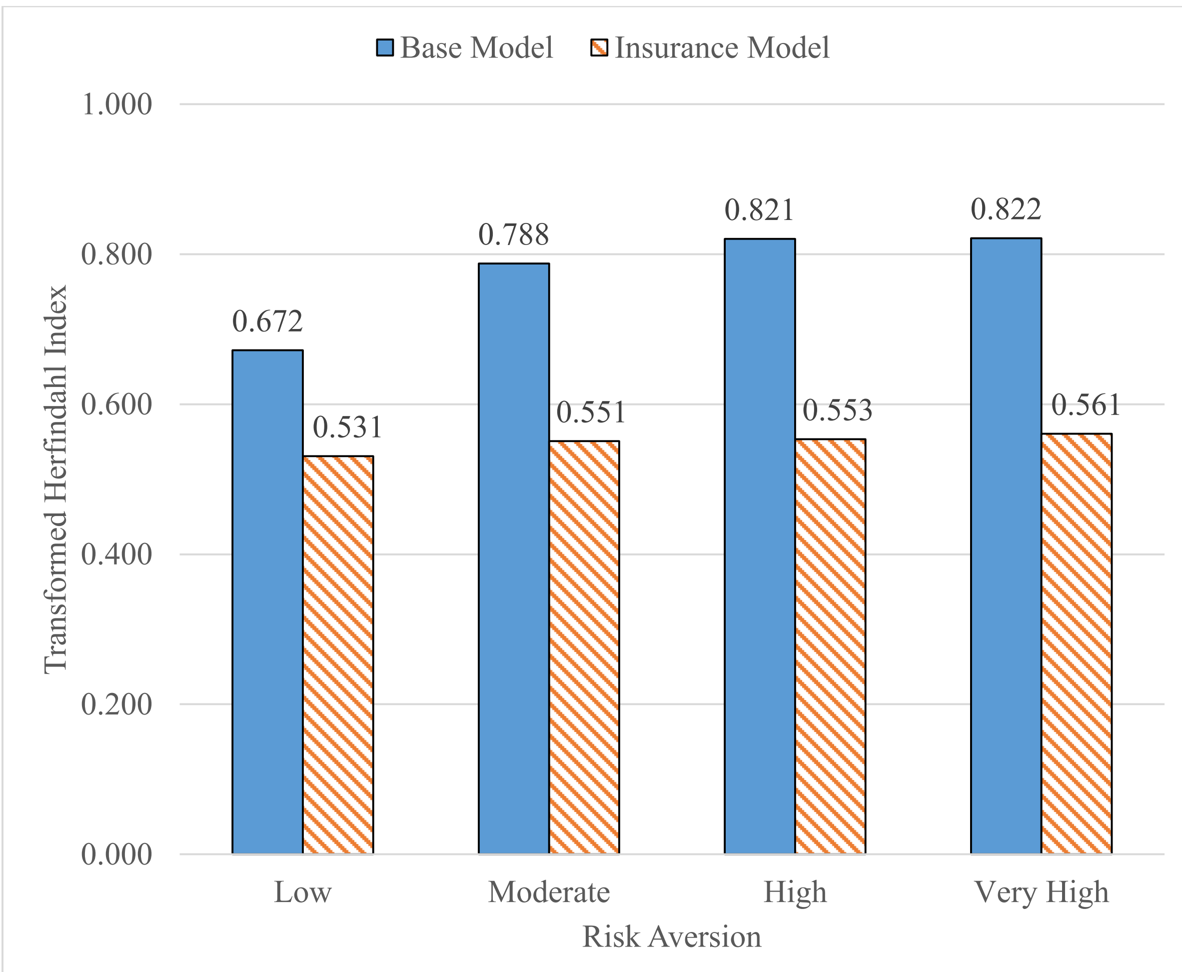


Figure 6.3: Risk Aversion and Diversification.

6.3 Risk Aversion and Expected Value of Consumption

The expected value of consumption is the value the household places on the quantity of crops it expects to consume across states of nature. It is estimated as:

$$Prob_i * \sum_{i,d} CON_{i,d} * VAL_d,$$

where $Prob_i$ is the probability of each state of nature i, $CON_{i,d}$ is the amount of crop d consumed in state of nature i and VAL_d is the value of consumption of crop d. Since maximising the expected value of consumption is the objective of our representative household, it can be regarded as a household's measure of welfare. Thus, increasing expected values of consumption imply increasing welfare. In this section, our aim is to analyse how the expected value of consumption (welfare) changes with risk aversion and the addition of insurance.

The results from the base and insurance models show that regardless of the level of risk aversion, the expected value of consumption from the insurance model is higher than in the base model, as illustrated in Figure 6.4. Insurance increases welfare by approximately 45% and 55% at the low and very high risk aversion levels, respectively. Figure 6.4 also indicates that in the base and insurance models, the more risk averse a household is, the lower its expected value of consumption. For example, at the low risk aversion level, the expected value of consumption is GHC 429.41 and GHC 623.29 in the base and insurance models, respectively, but progressively decreases as risk aversion rises, reaching GHC 379.23 and GHC 586.38 at the very high risk aversion level, which represents approximately 12% and 6% reductions in the base and insurance models, respectively. In the base model, this relationship can be explained by the fact that the higher the risk aversion of the household, the more land it allocates to crops with lower yield variance (i.e., lower yield risk) even if the expected output from those crops are lower than those with higher yield variance. Figure 6.5 shows the yield variance of the various crops. From Figure 6.5 and the risk aversion and base model land allocation behaviour in Figure 6.1, we see that land allocation to sorghum, which has relatively lower yield variances, increases with risk aversion (i.e. from 0.44 acres at the low risk aversion level to 2.62 acres at the very high risk aversion level) but the opposite is the case for groundnut, which has relatively higher yield variances (i.e., from 2.86 acres at the low risk aversion to 2.11 at the very high risk aversion level). This finding is similar to that of Mishra and Goodwin (1997), who also found that risk averse farmers allocate more resources to activities which they perceive have lower variance in outcomes, compared to those with higher variance, even if the expected benefits from the latter is more. The above argument does not hold for the insurance model, however. In the insurance model, as shown in Figure 6.2, even as risk aversion increases, the household allocates a substantive amount of land to groundnut (i.e., 6.49 acres at low risk aversion and 6.32 acres at high risk aversion), which is the most valuable crop (in terms of selling and purchase prices) and has a high yield variance. This result can be attributed to insurance reducing the household's yield risk and therefore making yield variability less of a concern in determining the household's land allocation behaviour.

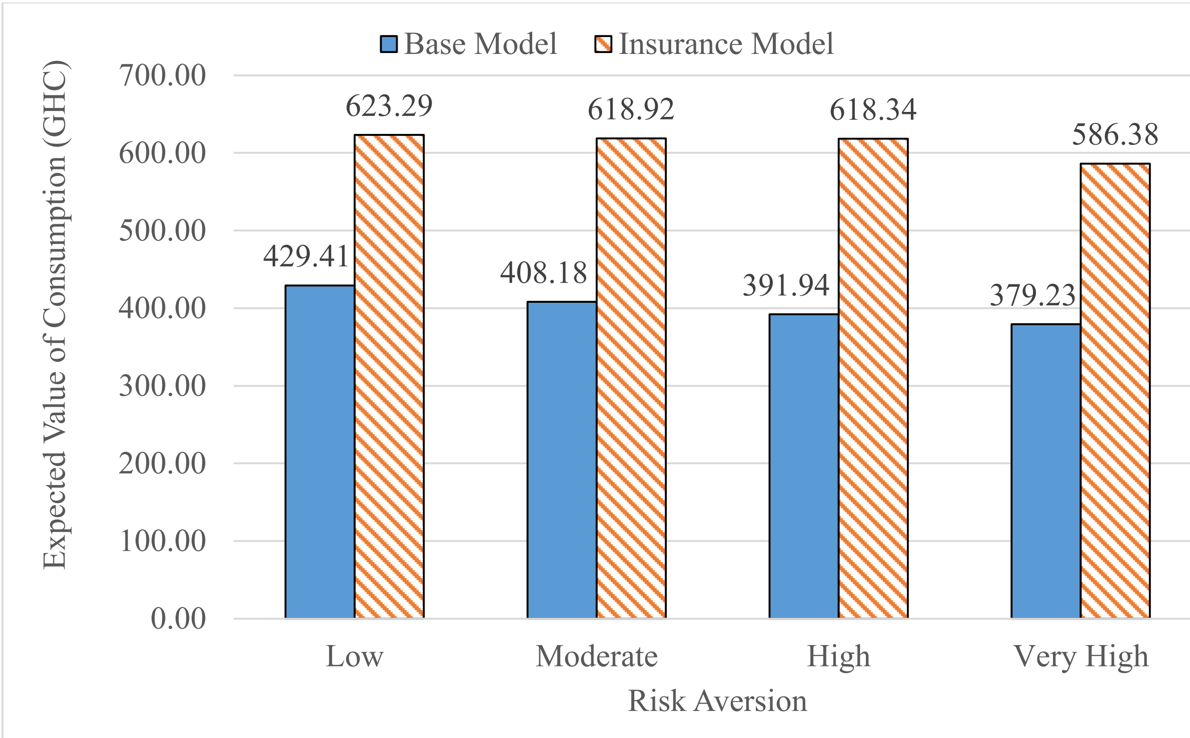


Figure 6.4: Risk Aversion and Expected Value of Consumption.

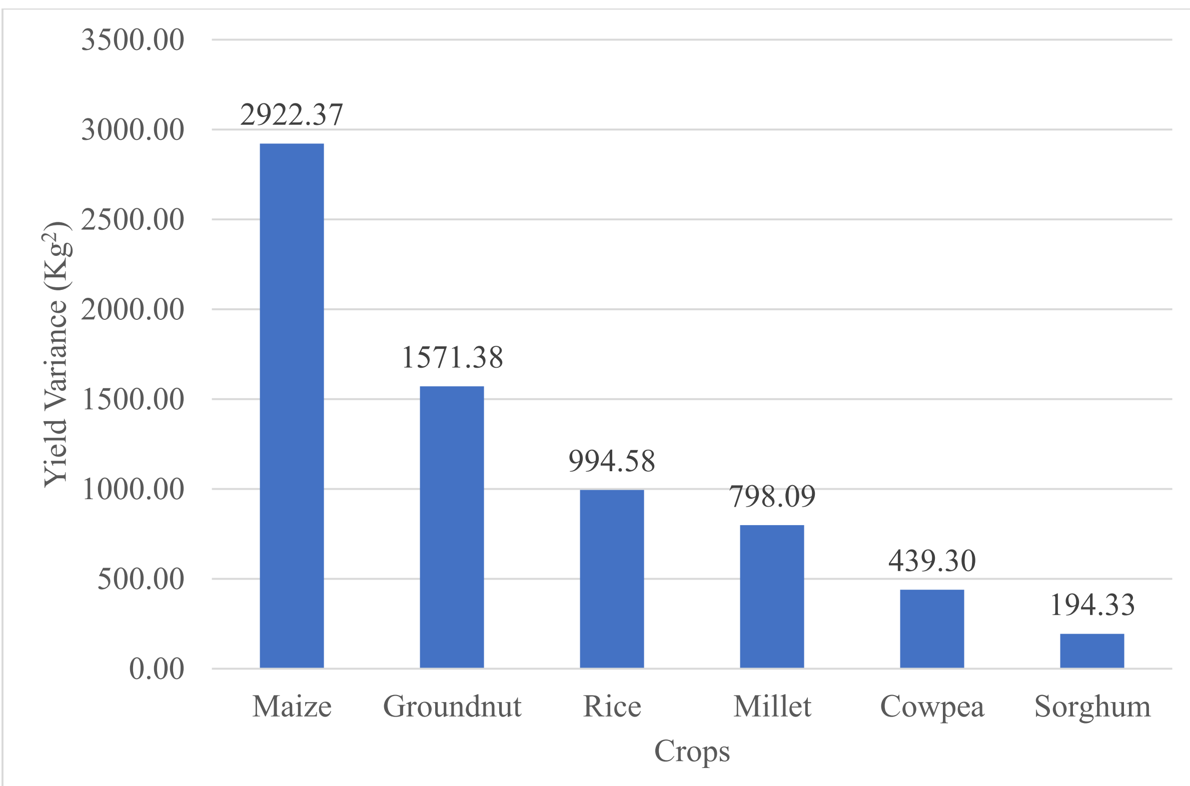


Figure 6.5: Yield Variance of the Modelled Crops.

6.4 Sensitivity of Insurance Model to Insurance Attributes

For the purpose of discussion in this section, all other insurance attributes are fixed at the assumed baseline levels (see section 6.2), with the exception of coverage levels and subsidies.

6.4.1 Coverage Level, Insurance and Diversification

We examine the representative household's diversification and insurance behaviour at 70% and 90% coverage with changing risk aversion levels. The 70% coverage level was used as the baseline value. This section presents results for the 90% coverage level and compares the household's diversification and insurance behaviour, as well as welfare measure, with the 70% coverage level. Unlike at the 70% coverage level where the household insures all of its available land regardless of risk aversion as discussed in section 6.2, at 90% coverage, the household insures only part of the total available land and the portion under insurance decreases as risk aversion rises, as shown in Figure 6.6. While this result is contrary to Wu and Adams' (2001) argument that higher coverage should shift more land into insurance, it can be explained by the fact that high coverage levels come with high costs of premium. And, as reported by Du et al. (2014), households generally prefer insurance schemes that have relatively low out-of-pocket premiums.

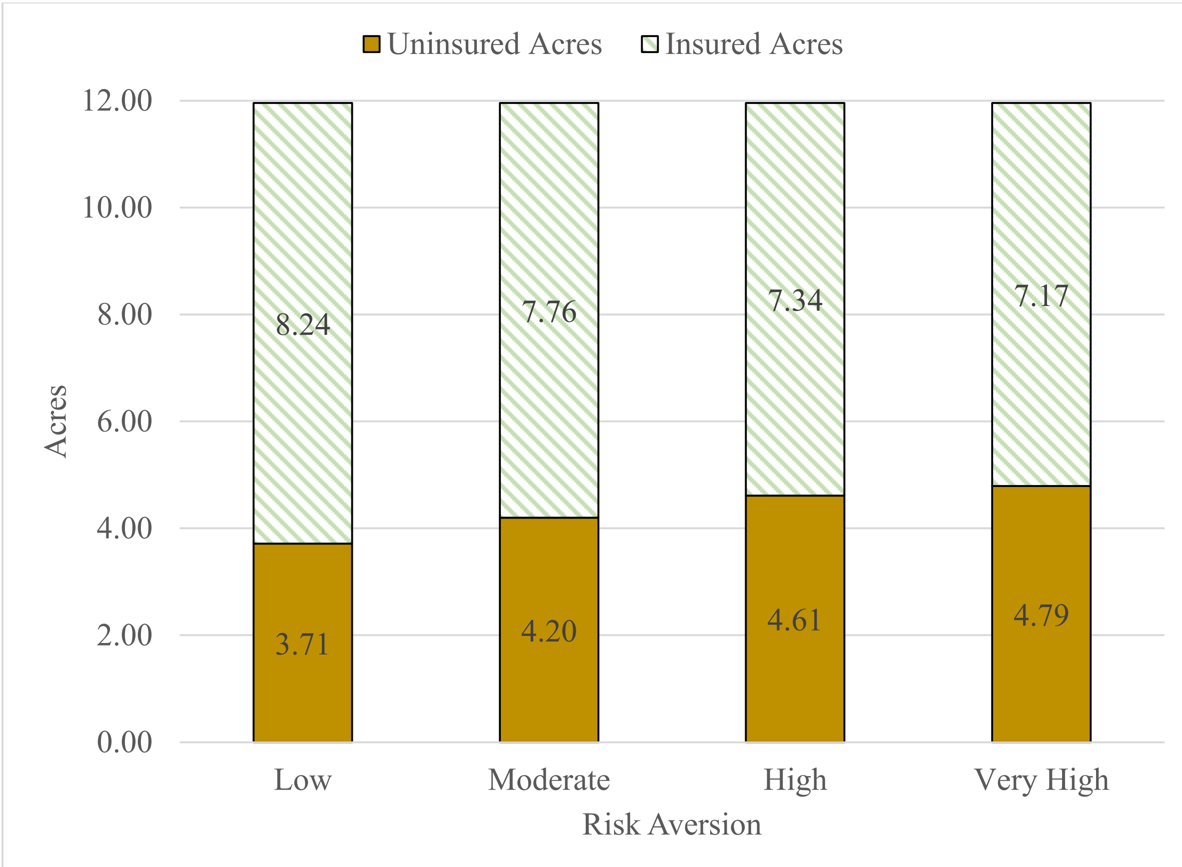


Figure 6.6: Risk Aversion and Insurance Behaviour at 90% Coverage Level.

Figure 6.7 shows that although the representative household diversifies more with increasing risk aversion at both the 70% and 90% coverage levels, the degree of diversification is higher at the 90% coverage level. At the 70% coverage level, THI increases by approximately 6% from 0.531 at the low risk aversion level to 0.561 at the very high risk aversion level. At the 90% coverage level, THI increases from 0.544 at the low risk aversion level by approximately 12% to 0.607 at the very high risk aversion level. Also, at the low risk aversion level, the degree of diversification is approximately 2% more at the 90% coverage level than at the 70% coverage level. And at the very high risk aversion level, the extent of diversification at the 90% coverage level is approximately 8% more than at the 70% coverage level. This result is contrary to the expectation that higher coverage would reduce expected yield risk and thereby lower the degree of diversification. This observation can also be attributed to the associated higher premium cost of the 90% coverage level, which makes it less beneficial compared to the 70% coverage level.

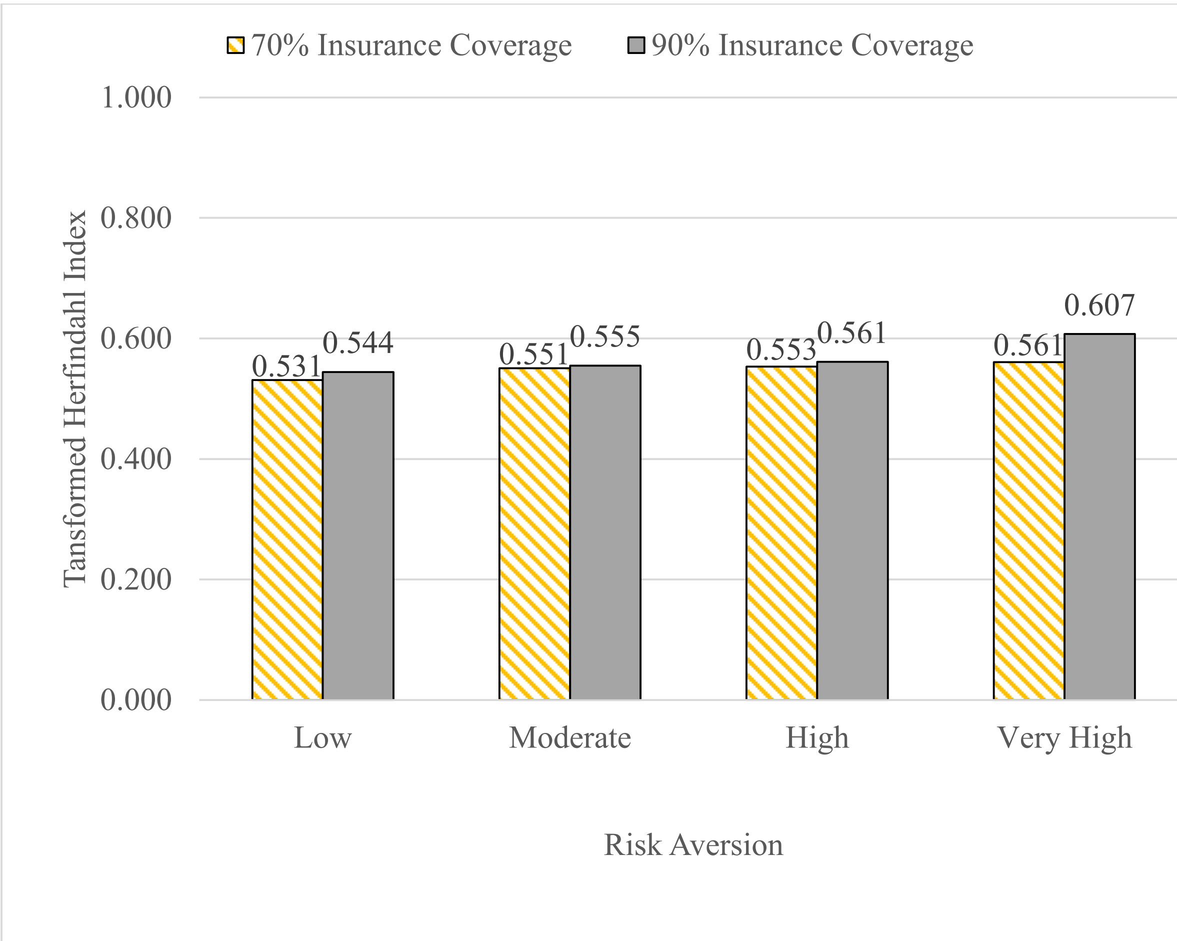


Figure 6.7: Risk Average, Insurance Coverage and Diversification

In regards to welfare, as per Figure 6.8, the expected value of consumption decreases with increasing risk aversion at the 70% and 90% coverage levels. At 70% and 90% coverage levels respectively, the expected value of consumption decreases by approximately 3% and 5% from low risk aversion level to very high risk aversion level. With the exception of the very high risk aversion level, the expected value of consumption is greater at the 70% coverage level than at the 90% coverage level at all risk aversion levels. The expected value of consumption is higher at the 70% coverage level than the 90% coverage level by approximately 1.33%, 0.78% and 0.86% at the low, moderate and high risk aversion levels, respectively, but about 3.12% lower at the very high risk aversion level. These results suggest that, holding other attributes of the insurance scheme fixed, the representative household is better off at the 70% coverage level than at the 90% coverage level, unless the household is very highly risk averse. This observation can be explained by the fact that high coverage also implies high premiums (costs). Therefore, if the expected benefit from increased coverage is lower than the added cost, the household would be better off at the lower coverage level, except for a very risk averse household whose extreme risk attitude would make the high cost of a high coverage level worthwhile.

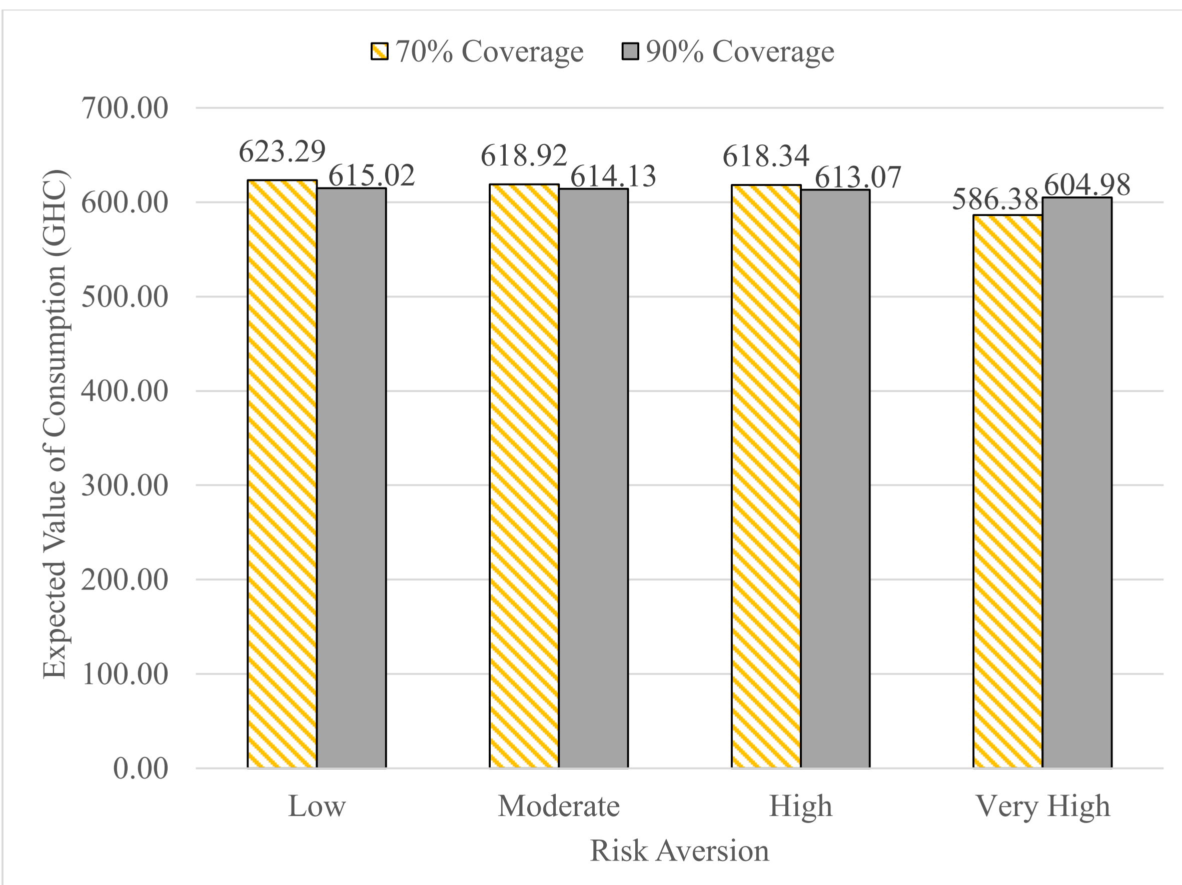


Figure 6.8: Risk Aversion, Insurance Coverage and Expected Value of Consumption.

6.4.2 Subsidy, Insurance and Diversification

For the purpose of discussion in this section, the representative household is assumed to be highly risk averse (i.e., CoARA=0.016) as elicited from the calibration model. We discuss how subsidising premiums influences the insurance and diversification behaviour of the household, as well as its welfare, at both 70% and 90% coverage levels. As shown in Figure 6.9, at the 70% coverage level, the household insures all of its available land irrespective of the level of subsidy, but, at 90% coverage, it only insures part of its available land, with the insured portion increasing with the subsidy. This figure also suggests that as coverage rises, more subsidies are required to make insurance attractive than it would be otherwise. For the representative household to insure all of its available land at the 90% coverage level, 80% of its premiums must be subsidised.

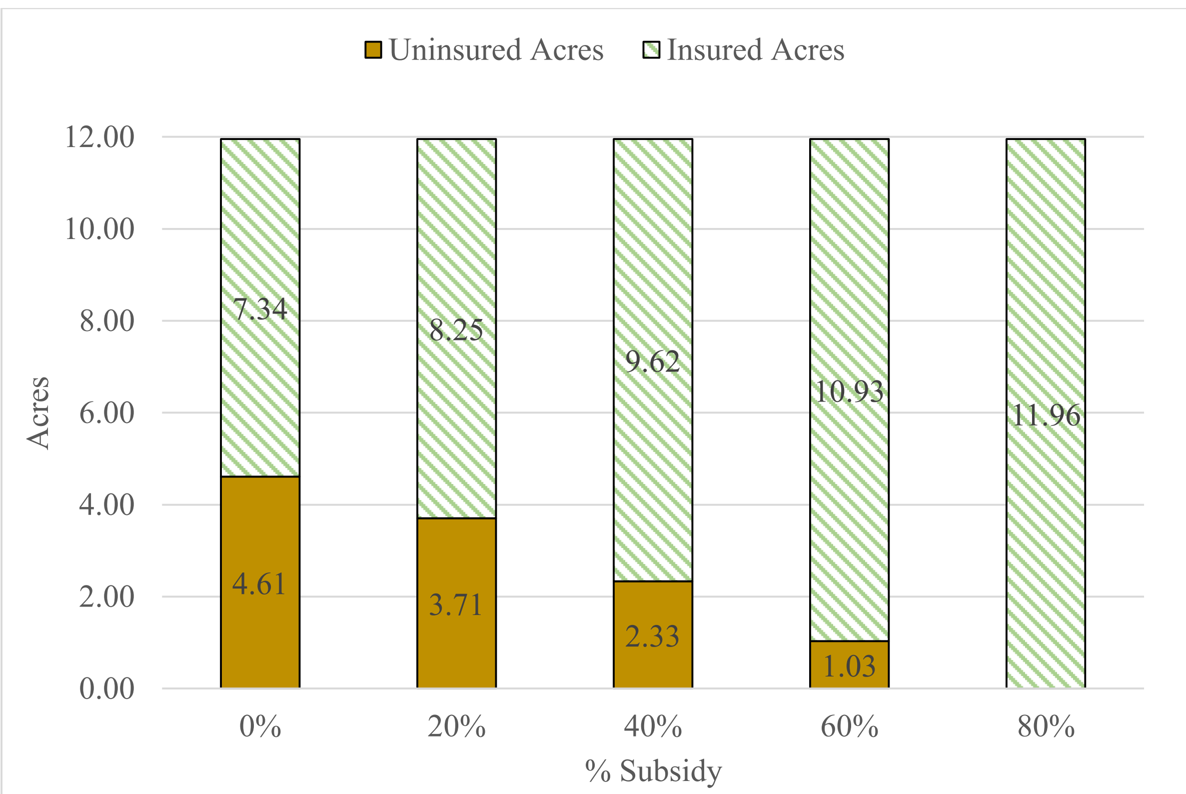


Figure 6.9: Premium Subsidy and Insurance Behaviour at 90% Coverage Level.

Figure 6.10 shows that at 70% coverage, the degree of diversification is fairly constant regardless of the level of subsidies, indicating that subsidies do not substantively influence the household's diversification behaviour. But at the 90% coverage level, changing levels of subsides influence the representative household's diversification behaviour, but there is no consistent pattern to suggest the direction of diversification. For instance, as the level of subsidy increases from 0% to 20%, THI decreases from 0.561 to 0.556; this reduction in diversification in response to increased subsidies is also reported by O'Donoghue et al. (2009). However, as the level of subsidy increases from 40% to 60%, THI increases from 0.558 to 0.599. O'Donoghue et al. (2009) argue that theory remains inconclusive on the effect of subsidies on diversification and thus different levels of subsidies might have different effects on diversification, which may underpin the inconsistency observed in the direction of diversification as subsidies rise. Goodwin and Smith (2013) also argue that insurance subsidies introduce production distortions at several margins, which suggests that production behaviour may vary depending on the level of subsidy.

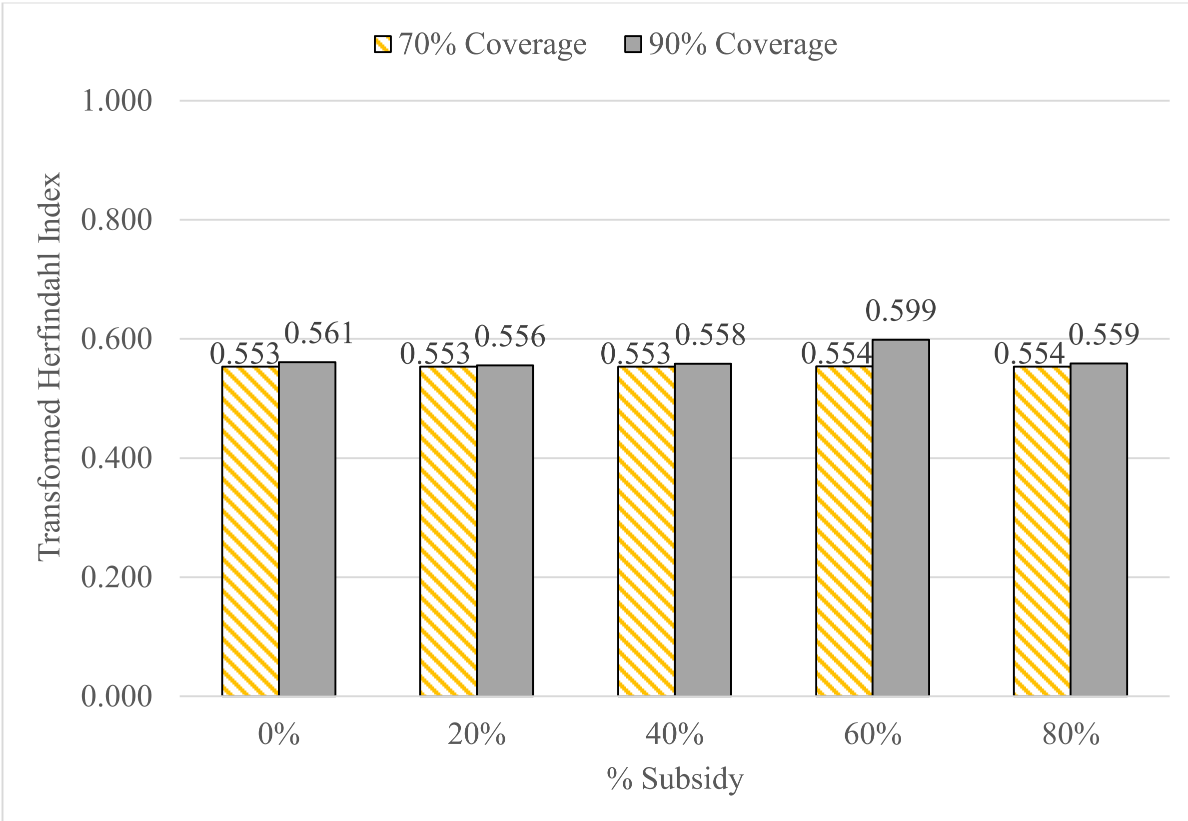


Figure 6.10: Premium Subsidy, Insurance Coverage and Diversification.

In regards to welfare, Figure 6.11 shows that at 70% coverage, the expected value of consumption is fairly constant as the subsidy increases, suggesting that subsidies do not contribute much to welfare. At the 90% coverage, the expected value of consumption increases as the level of subsidy rise. In addition, as illustrated in Figure 6.11, the expected value of consumption is higher at the 90% coverage level than at the 70% coverage when premiums are subsidised. The expected value consumption is approximately 1.22%, 3.80%, 5.95% and 11.35% higher at 90% coverage level than at the 70% coverage level the when premiums are subsidised by 20%, 40% 60% and 80%, respectively. These results suggest that increasing levels of insurance coverage is beneficial to the household only if it is accompanied by increasing subsidies. But even so, the percentage gain in welfare is less than the percentage reduction in premiums.

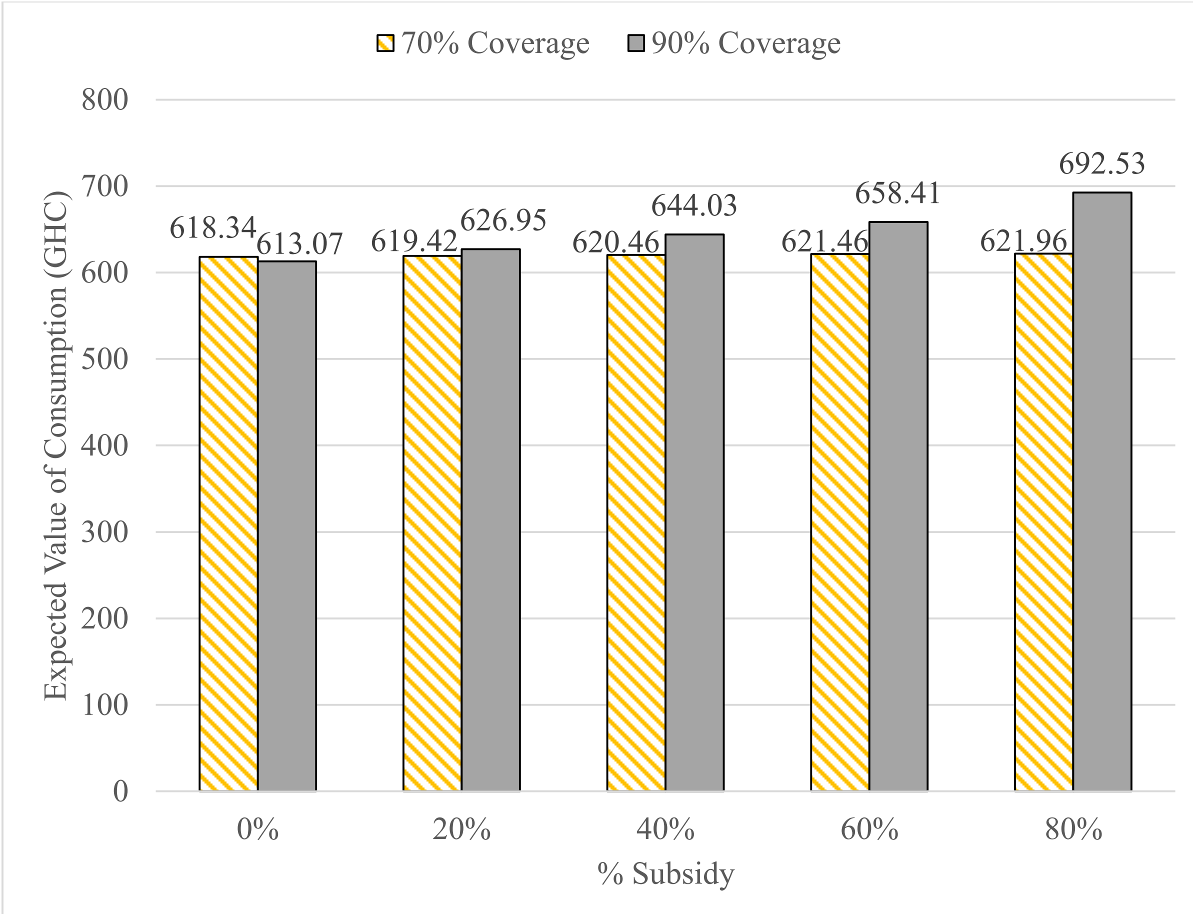


Figure 6.11: Premium Subsidy, Insurance Coverage and Expected Value of Consumption

6.5 General Discussion and Possible Implications of Results

This section discusses general issues and possible implications from the results of this study, that extend beyond the scope of a representative household and the models developed. The introduction of an insurance market is likely to have spill-over and unintended effects which go beyond the scope of this study but are worth discussing to give a better understanding of the overall policy implications of such a programme.

In terms of diversification, our models show that insurance substitutes for diversification to a large extent. In the absence of insurance, the household cultivates more crops and balances its production activities among crops that are more likely to be used for home consumption (e.g., maize and millet) and crops such as groundnut and cowpea that are more valuable (in terms of selling prices) and thus mostly sold. But in the presence of insurance, the household cultivates fewer crops by growing less "staples" and more "commercial" crops. Assuming that most households in a given area behave in this manner in the presence of an insurance market, a broader implication from this change in cropping behaviour would be the changes in the dynamics of local markets. Households would want to sell their "commercial" crops and purchase "staples" for home consumption, but thinning markets for these staples and over supply of commercial crops could cause price volatility in the short-run. In the long run, however, a new market equilibrium might be established.

The results presented in this chapter also suggest that at the 70% coverage level, subsidies would not be required for insurance uptake. If that is the case, however, why is there a lack of insurance markets? It may be the case that assuming a 10% load factor in the model underestimated the margins, making the insurance program inexpensive and attractive to households but not to insurers. On the supply side, it is possible that insurers would require higher margins to make running an insurance programme worth their while. On the demand side, our model does not consider the timing of cash-flow and the fact that households might not have money to pay for the insurance premiums when needed and might therefore not be able to take up insurance even if it is inexpensive and they are willing to pay.

In regards to welfare, our results suggest that insurance increases household welfare, but on a larger scale, the changes in behaviour and market dynamics due to insurance might present a different reality in regards to the overall welfare gains. Also, our results show that at high coverage levels, substantive premium subsidies are required to make the insurance programme attractive to households. Since high coverage levels provide more risk protection and higher welfare benefit in the presence of subsidies, if governments and donor agencies decide to subsidize the insurance programme, more households would choose high coverage schemes, which would be costly. Therefore, more must be done to assess whether the welfare gains from insurance would offset this subsidy cost. At least from our results, the percentage increases in welfare from subsidies are less than the percentage reductions in premiums. The above discussion suggests that the implementation and attributes of an insurance programme would have to be thoroughly considered to tackle these potential issues.

CHAPTER 7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Overview

The chapter is organised into a summary of the context, specific objectives, methods and results as well as conclusions, policy recommendations, limitations of the study and suggestions for further research.

7.2 Context of Study

Climate variability is an eminent source of risk in agriculture, especially in rain-fed agricultural systems in developing countries. Although climate variability and its accompanying challenges affect the globe as a whole, its negative impact is prominent in developing countries, aggravating production, income and price risks, and ultimately, poverty and food insecurity.

Diversification and insurance are important risk-mitigating strategies for coping with climate variability in the developing world. Conventionally, agricultural insurance assesses the risk of the insured on an individual basis (Skees, 2008). Indemnity payments are then made to compensate for actual individual losses (Linnerooth-Bayer et al. 2011; Ali 2013). But, this form of insurance has been troublesome in the developing world due to various market imperfections, including underdeveloped or non-existent insurance markets, poor contract enforcement, information asymmetry, high transaction costs, and high exposure to spatially covariate risks (Linnerooth-Bayer et al. 2011). Index-based insurance has arisen as a new form of agricultural insurance that assesses losses using measures, such as area-wide yields or weather, that cannot be influenced by the actions of the insured, but are correlated with yields as a proxy for individual losses (Binswanger-Mkhize, 2012). In this case, indemnity payments are made based on deviations from the index and not on individual losses (Ali 2013). Index-based insurance seems to address challenges of traditional insurance, particularly by reducing transaction costs and information asymmetry, in developing economies (Leblois et al. 2013).

Although diversification and insurance are acknowledged as important in ameliorating risk, little research has investigated how the two approaches work in concert. Studies on the relationship between insurance and diversification have been done mostly on developed countries and have focused on traditional crop insurance (Goodwin, Vandeveer, & Deal, 2004; O'Donoghue, Key, & Roberts, 2005). To our knowledge, no comparable empirical studies have examined the relationship between crop insurance (traditional or index-based) and diversification in a developing world context. The main objective of this study was, therefore, to understand how crop diversification and index-based (area yield) insurance work together as risk management strategies under climate variability using non-linear mathematical programming.

7.3 Specific Objectives and Methods

Using the Expected Utility Framework and the IMPACT Lite household survey on Ghana collected by the Consultative Group on International Agricultural Research Program on Climate Change, Agriculture and Food Security, we developed two non-separable agricultural household mathematical programming models to:

1. recover the risk preference of a representative household using observed economic behaviour;
2. assess how a household's risk preference influences its behaviour with respect to the degree to which it diversifies its crop activities (measured by the Transformed Herfindahl Index (THI));

3. investigate the behavioural relationship between crop diversification and area yield insurance by analysing the extent to which a household diversifies its crop activities in the presence of insurance;
4. examine how a household's risk preference influences its behaviour with respect to the acres of land it insures;
5. assess how insurance coverage level and premium subsidization influence household participation by examining changes in the acres of land the household insures considering coverage levels and premium subsidies;
6. evaluate the household's welfare benefit from insurance by assaying changes in the expected value of consumption with insurance; and
7. analyse how sensitive the household's welfare benefit from insurance is to changes in coverage levels and premium subsidies.

The agricultural household was assumed to maximize its expected utility of consumption by allocating resources (land and labour) among six crop activities. As in Saha (1994), risk was introduced in the models by incorporating stochastic crop yields. Several yield states of nature were simulated to represent different possible yield scenarios due to climate variability. Absolute risk aversion coefficients representing the risk preferences of the household were also incorporated into the objective function. In the base model, the household managed their risk by diversifying their activities and allocating resources among the six crop activities without the option of insurance. In the second model, however, the household had the option of both diversification and area yield-based insurance.

7.4 Summary of Results

In line with other studies (Yesuf and Bluffstone 2009; Wiens 1976; Antle 1987; Antle 1989), our results show that the representative household is highly risk averse, with a coefficient of absolute risk aversion of 0.016. Although the household's level of diversification increases with risk aversion in both base and insurance models, the extent of diversification is more in the base model than in the insurance model. In the base model, THI increases by approximately 22% from 0.672 at low risk aversion to 0.822 at the very high risk aversion level. But in the insurance model, THI increases by approximately 6% from 0.531 at low risk aversion to 0.561 at the very high risk aversion level. This result also suggests that although insurance does not completely substitute for diversification, it reduces the degree of diversification. At the low risk aversion level, the degree of diversification is approximately 23% more in the base model than in the insurance model. And at the very high risk aversion level, the extent of diversification in the base model is approximately 38% more than in the insurance model.

At 70% insurance coverage, the representative household insures all of its available land, regardless of risk aversion and premium subsidies. However, it only insures part of its available land at 90% coverage, and the portion under insurance decreases as risk aversion rises. At a low risk aversion level, the household insures 8.243 acres of its available land, compared to 7.165 acres when risk aversion is very high. For the household to insure all of its available land at the 90% coverage level, 80% of premiums must be subsidised.

In regards to risk aversion, coverage level and diversification, the results show that although the representative household diversifies more with increasing risk aversion at both the 70% and 90% coverage levels, the degree of diversification is higher at the 90% coverage level. At the low risk aversion level, the degree of diversification is approximately 2% more at the 90%

coverage level than at the 70% coverage level. And at the very high risk aversion level, the extent of diversification at the 90% coverage level is approximately 8% more than at the 70% coverage level.

Regardless of risk aversion, level of coverage or subsidy, the availability of insurance increases the household's expected value of consumption and thus increases welfare. But, welfare decreases with risk aversion. For example, in the base model, the expected value of consumption decreases by approximately 12% from GHC 429.41 at low risk aversion level to GHC 379.23 at the very high risk aversion level. In the baseline insurance model (i.e., no subsidy and 70% coverage level), the expected value of consumption decreases by approximately 6% from GHC 623.294 at the low risk aversion to GHC 586.383 at high risk aversion. This result represents approximately 45% and 55% increased welfare due to insurance at low and very high risk aversion levels, respectively. In the absence of subsidies, the 70% coverage level provides higher welfare benefits compared to the 90% coverage level at all risk aversion levels, except at the very high risk aversion level. The expected value of consumption at the 70% coverage level is higher than at the 90% coverage level by approximately 1.33%, 0.78% and 0.86% at the low, moderate and high risk aversion levels, respectively, but about 3.12% lower at the very high risk aversion level.

Although subsidising premiums increases the expected value of consumption at both 70% and 90% coverage levels, the expected value of consumption is higher at the 90% coverage level. The expected value of consumption is approximately 1.22%, 3.80%, 5.95% and 11.35% higher at 90% coverage level than at the 70% coverage level when premiums are subsidized by 20%, 40%, 60% and 80%, respectively.

7.5 Conclusion and Policy Recommendation

Results indicate that households in the study site are highly risk averse and diversify their activities to manage their climate and yield risk. The extent of diversification depends on their risk preference, with high levels of diversification associated with high risk aversion. On the relationship between diversification and insurance, we have shown that although insurance does not completely substitute for diversification, it significantly reduces its degree.

For policy makers, this study provides empirical evidence which suggests that even in the presence of diversification, introducing area yield insurance would help reduce the perceived riskiness of rain-fed agriculture and increase agricultural households' welfare. Given that most developing countries heavily depend on agriculture, governments and donor agencies should intensify efforts aimed at introducing insurance to help agricultural households manage their climate and yield risks. But due to the potential differences in the performance of insurance across various regions, implementation must be with caution and tailored to the needs and dynamics of the particular area. The results from this study show that although insurance schemes with premium subsidies provide relatively higher welfare benefits, at 70% coverage, households in our study area would take up insurance even without subsidies. Therefore, for a start, the Ministry of Food and Agriculture in Ghana and other donor agencies can pilot an area yield insurance scheme with 70% coverage with no subsidies in the Lawra and Jirapa districts. This scheme would come at a very low cost since no subsidies would be required for uptake. The models developed can also be easily adapted to suggest appropriate insurance schemes for other areas.

7.6 Limitations and Suggestions for further Research

Our study area is identified as a mixed crop-livestock agricultural system. Thus, a major limitation of this study was not explicitly modelling the livestock sector due to time and data challenges. The models we developed are static; including the livestock sector would require dynamic models that explicitly incorporate time. Further research can investigate how insurance and diversification may interact, considering livestock production.

Another challenge faced in this study was the lack of household level time series data on yields and prices. As a result, we used district level data to approximate household data. This resulted in considerable differences between the values of area and farm yields. Also, while basis risk is known as a major challenge associated with index-based insurance, the effect of different levels of farm and area yield correlations on the relationship between diversification and insurance was not investigated. Further research can consider how different levels of basis risk affect diversification and insurance.

Similarly, using weather-based insurance as our insurance programme would have better captured climate variability, but, given data challenges, we used area yield insurance. Further studies could compare the effectiveness of weather-based and area yield insurance programmes and how they both influence household diversification and welfare. We also contemplated whether insurance might work differently for households with different wealth. But our data was not sufficiently different between wealth groups to support differentiated analysis. Further studies could consider the relationship between diversification and insurance among households of different wealth.

Another simplification in our modelling was ignoring price risk. By assuming that prices are deterministic, we did not consider price risks. The relative variability in prices for the crops might have a significant implication on the relationship between diversification and insurance. Thus, further studies can consider price risks.

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APPENDICES

Appendix A: Deciding on Household Groupings

A1: Quantile Comparisons

Figure A 1 to Figure A 17 and Table A 1 to Table A 8 to summarize the ANOVA and Tukey HSD test used in analysing the similarities of the household quantiles in terms of output/acre, labour and output/labour.

The ANOVA has the null hypothesis that the means of the household quantiles in terms of the variables of interests are the same and an alternate hypothesis that at least one household quantile is different from the others in some of the variables of interest. Tukey's Honestly Significant Difference (HSD) is a post hoc test that uses the q distribution to compute the HSD between two means based on the studentized range distribution. Tukey's method simultaneously applies to all pairwise comparisons of means $(\mu_i - \mu_j)$ (NIST/SEMATECH n.d.; Williams and Abdi 2010).

Given r independent observations $y_1, \dots, y_r$ from a distribution (μ, σ^2), where w is the range for the set, i.e., $\bar{y}_{max} - \bar{y}_{min}$, and s^2 is the pooled sample variance with v degrees of freedom (n-1), then the studentized range for the difference between any two groups is defined as:

$$q_{r,v} = \frac{w}{s^2}$$

For the same sample sizes, the confidence coefficient is $1 - \alpha$ but greater when sample sizes differ. The Tukey confidence limit for pairwise comparisons with a confidence coefficient of at least $1 - \alpha$ is:

$$\bar{y}_{i\cdot} - \bar{y}_{j\cdot} \pm \frac{1}{\sqrt{2}} q_{a;r,N-r}\ \hat{\sigma}_{\varepsilon} \sqrt{\frac{2}{n}} \quad i,j = 1,\ldots,r;\ i \neq j$$

A1.1: Crop Output/Acre Quantile Comparisons

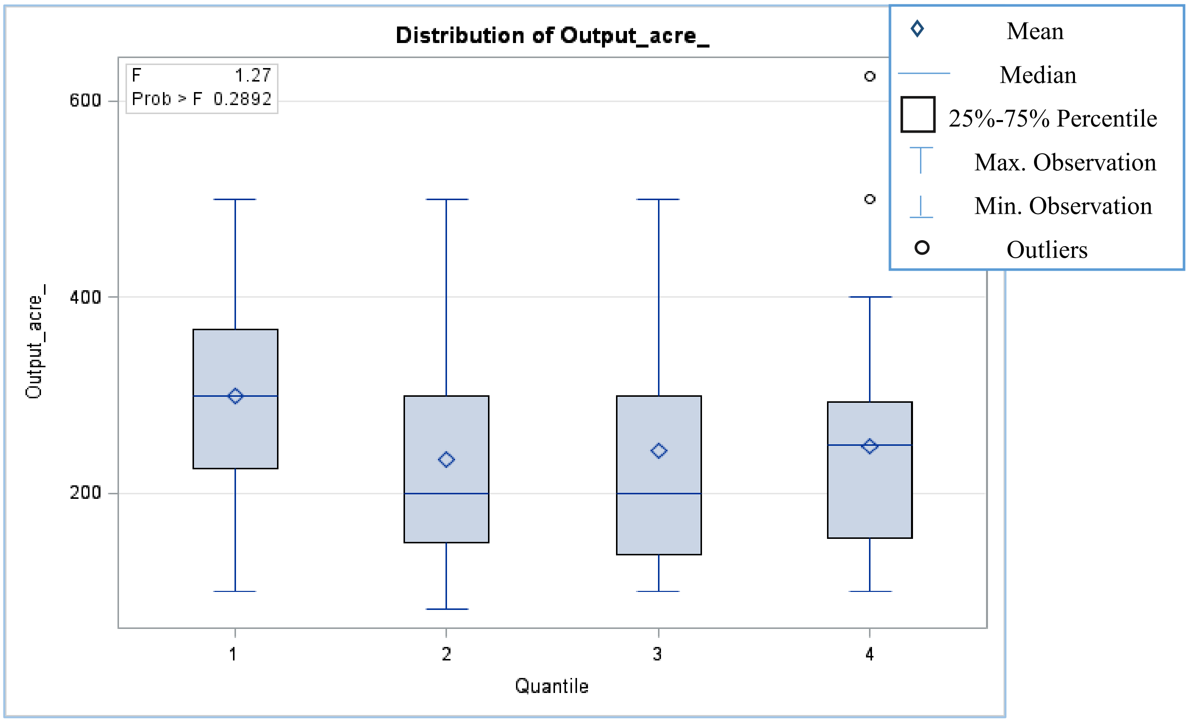


Figure A 1: ANOVA of Quantile Means of Groundnut Output/Acre.

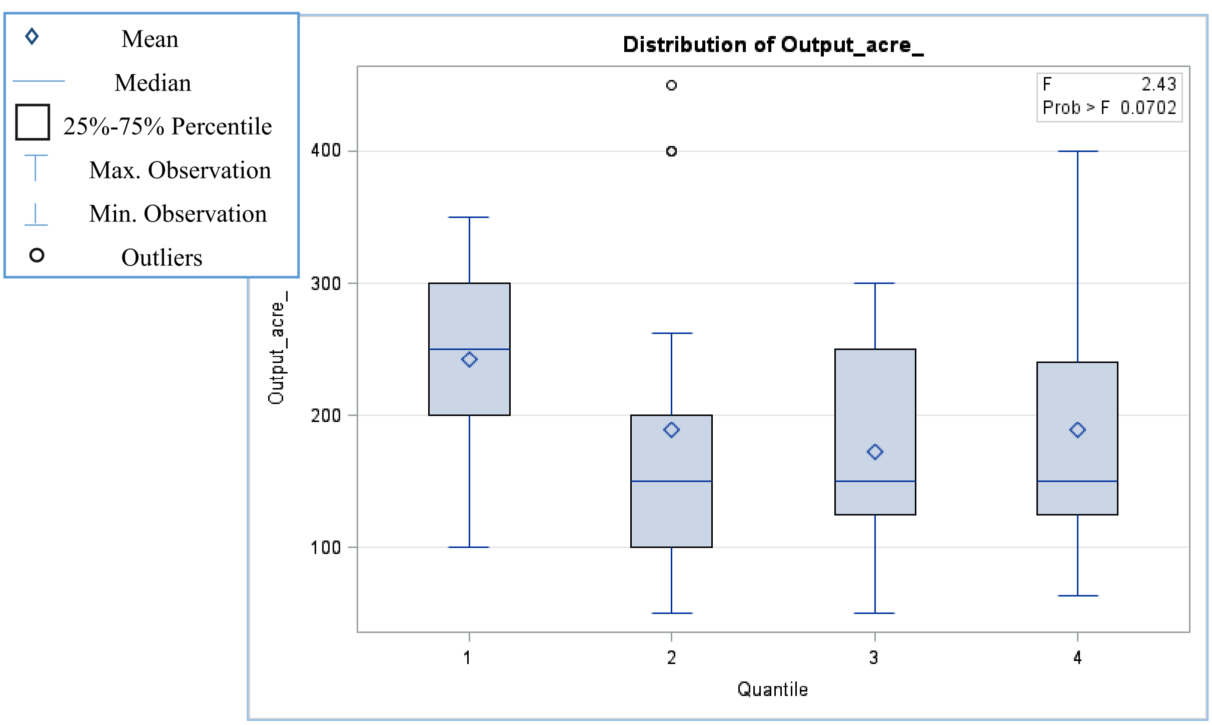


Figure A 2: ANOVA of Quantile Means of Maize Output/Acre.

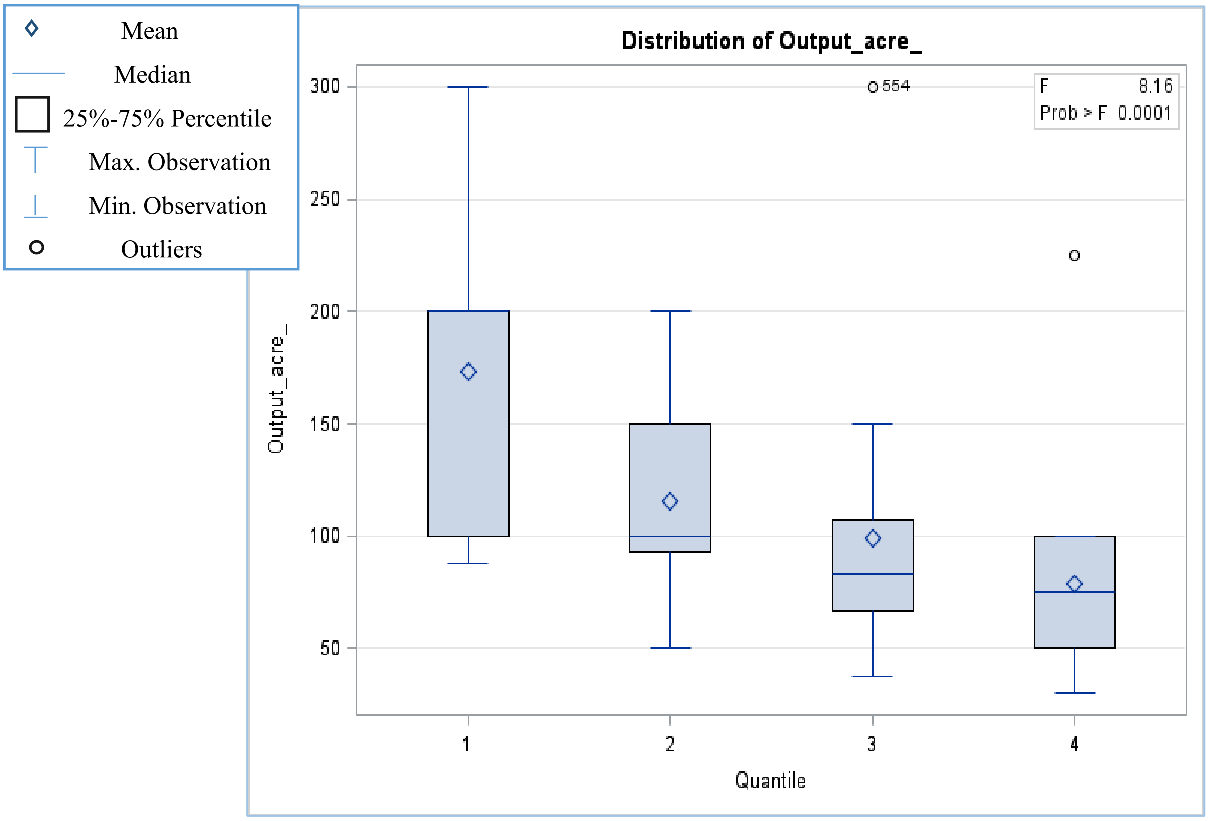


Figure A 3: ANOVA of Quantile Means of Millet Output/Acre.

Table A 1: Tukey HSD Test for Millet Output/Acre

Quantile Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
1 - 2	57.97	8.97	106.96	***
1 - 3	74.33	22.29	126.38	***
1 - 4	94.40	40.65	148.15	***
2 - 3	16.37	-32.63	65.36	
2 - 4	36.43	-14.37	87.24	
3 - 4	20.07	-33.68	73.81	
***** Comparisons significantly different at the 0.05 level.**				

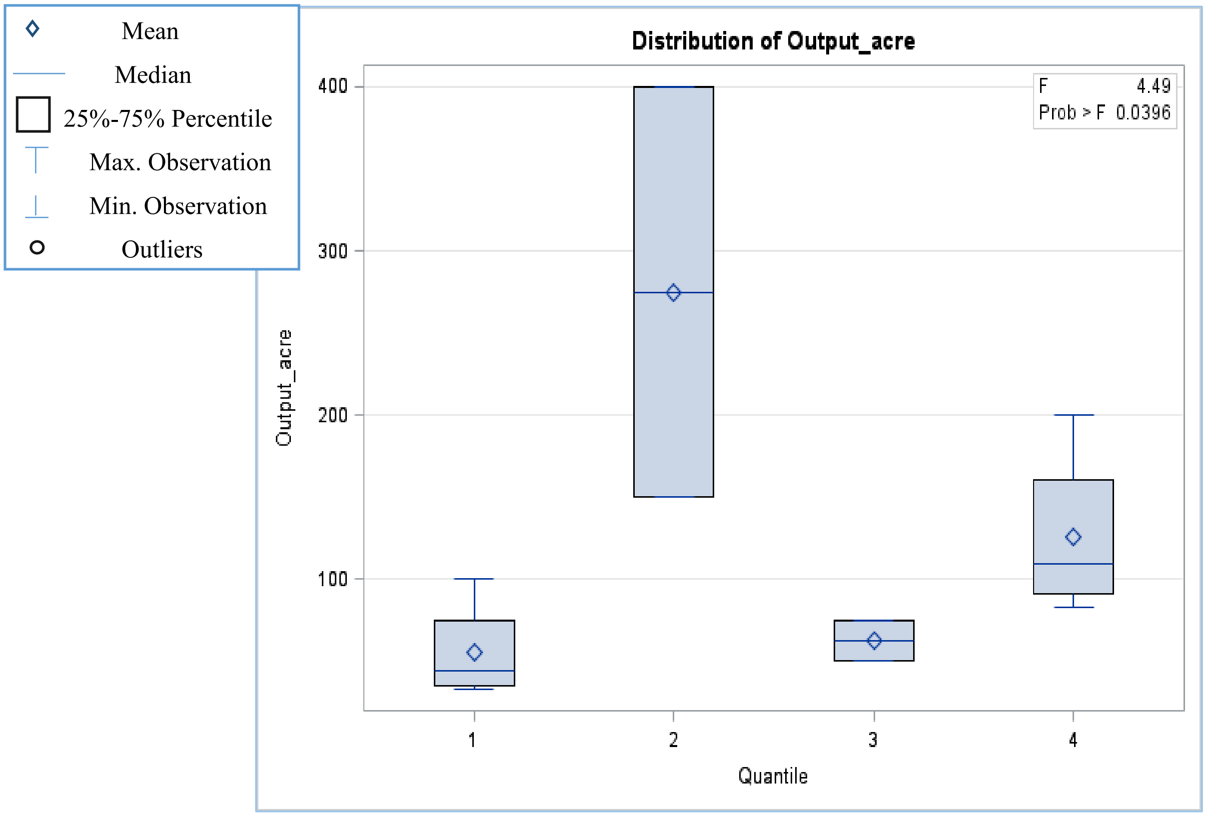


Figure A 4: ANOVA of Quantile Means of Cowpea Output/Acre.

Table A 2: Tukey HSD Test for Cowpea Output/Acre

Quantile Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
1 - 2	-219.75	-421.63	-17.87	***
1 - 3	-7.25	-209.13	194.63	
1 - 4	-70.58	-235.42	94.26	
2 - 3	212.50	-20.62	445.62	
2 - 4	149.17	-52.72	351.05	
3 - 4	-63.33	-265.22	138.55	
***** Comparisons significantly different at the 0.05 level.**				

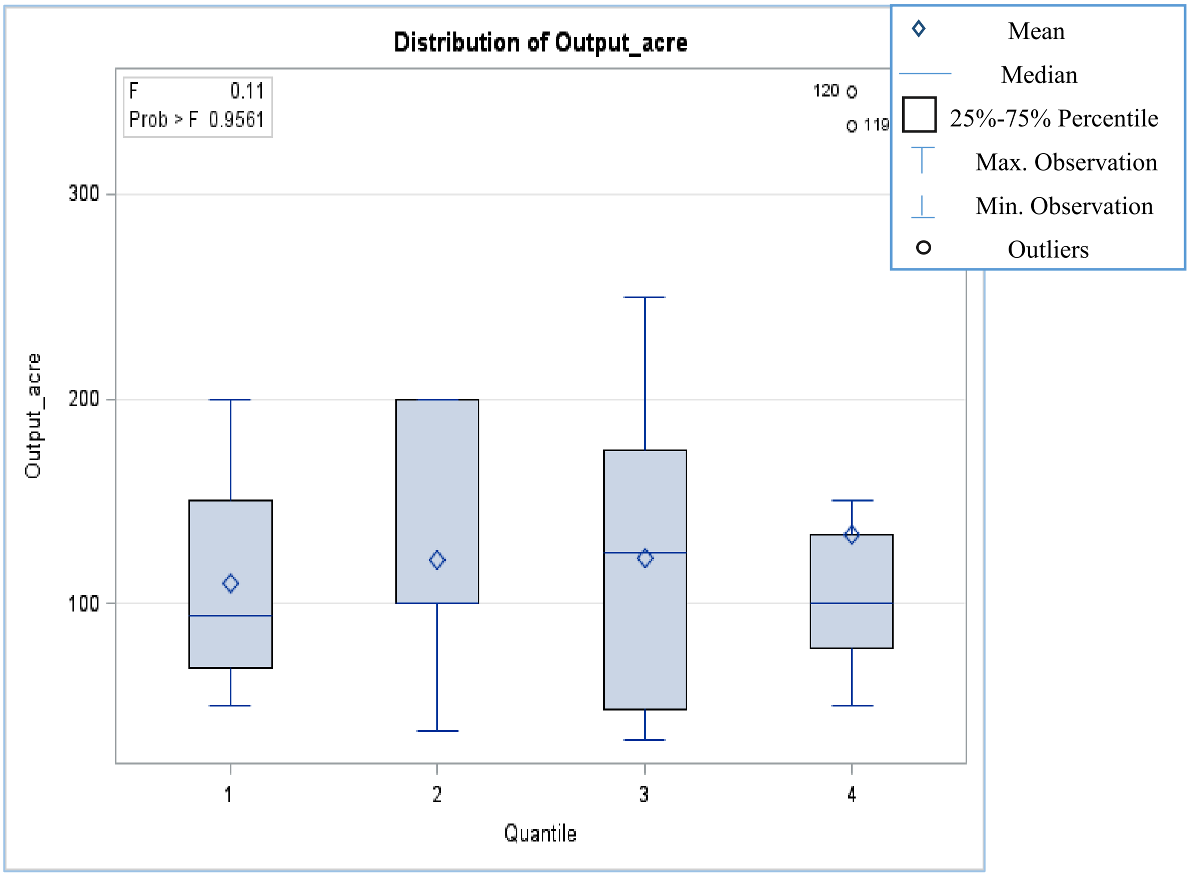


Figure A 5: ANOVA of Quantile Means of Sorghum Output/Acre.

A1.2: Crop Labour/Acre Quantile Comparisons

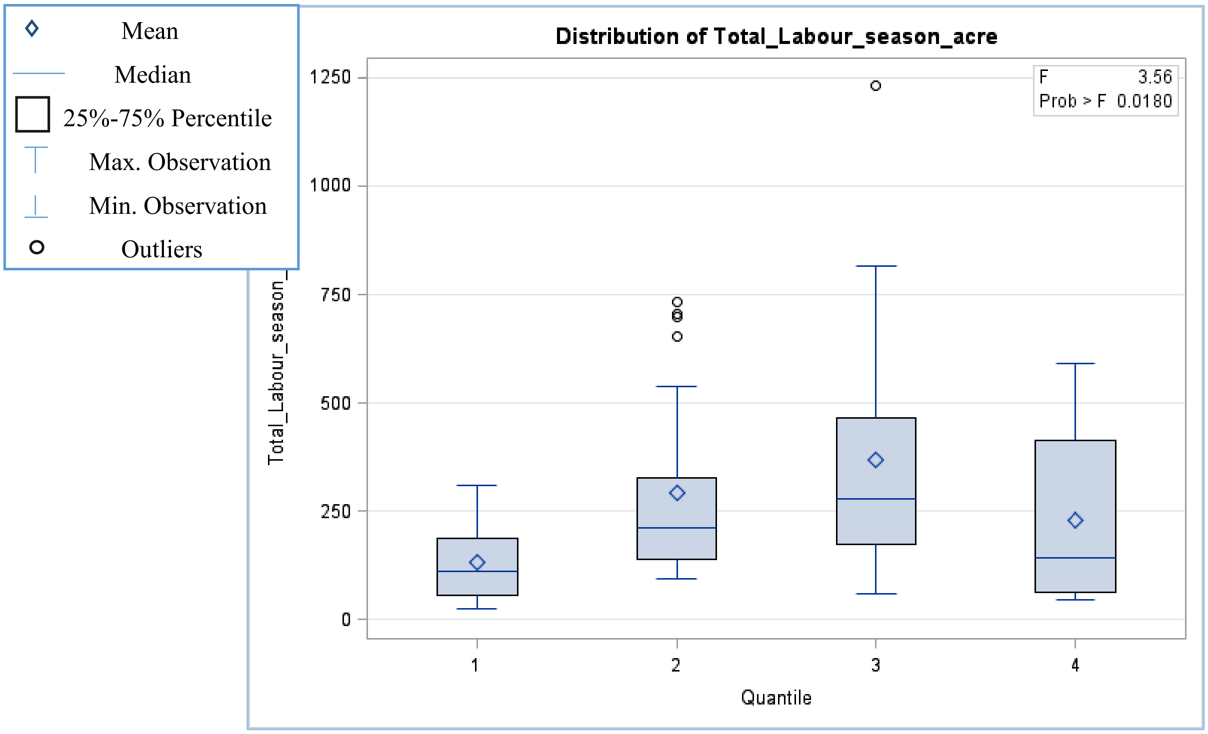


Figure A 6: ANOVA of Quantile Means of Groundnut Labour Hours/Acre.

Table A 3: Tukey HSD Test for Groundnut Labour/Acre

Quantile Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
1 - 2	-159.21	-339.68	21.26	
1 - 3	-234.50	-432.33	-36.67	***
1 - 4	-98.46	-285.07	88.15	
2 - 3	-75.29	-252.44	101.86	
2 - 4	60.75	-103.78	225.28	
3 - 4	136.04	-47.37	319.45	
***** Comparisons significantly different at the 0.05 level.**				

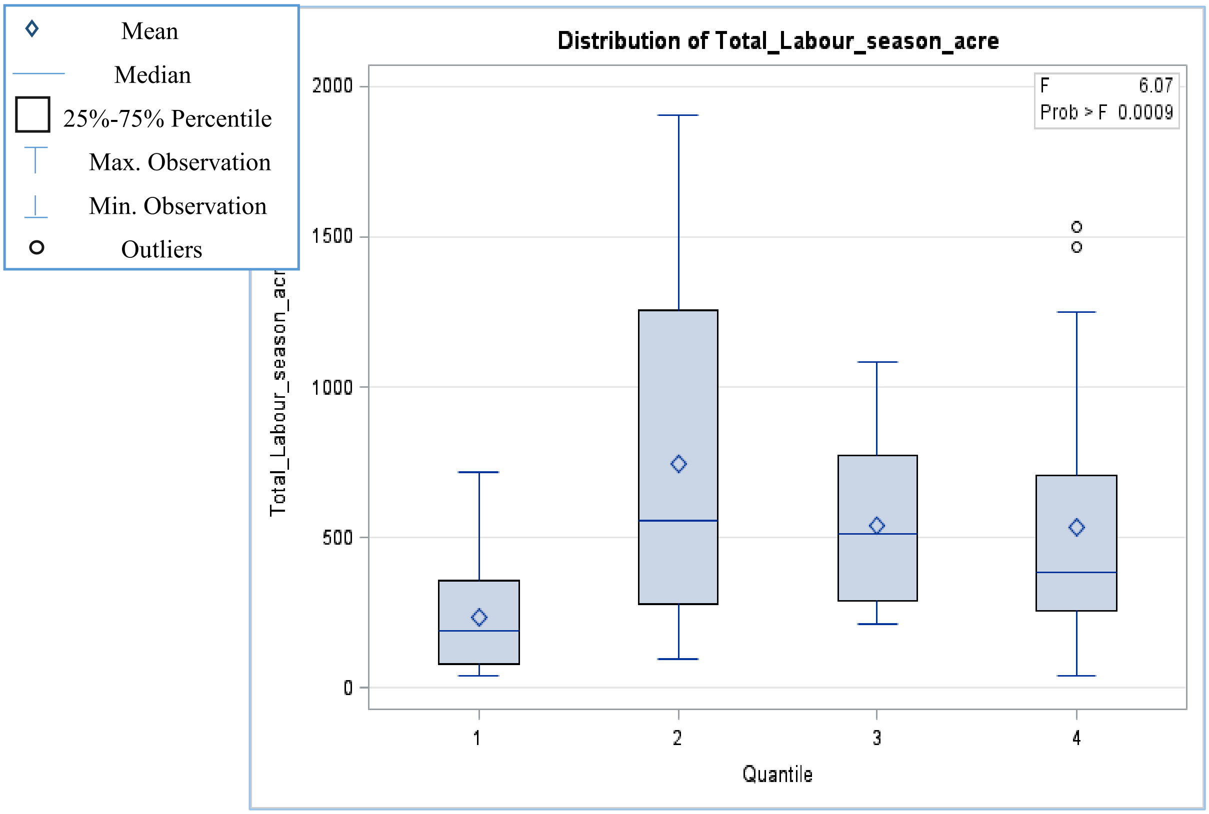


Figure A 7: ANOVA of Quantile Means of Maize Labour Hour/Acre.

Table A 4: Tukey HSD Test for Maize Labour/Acre

Quantile Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
1 - 2	-513.1	-828.7	-197.6	***
1 - 3	-303.0	-635.6	29.6	
1 - 4	-297.5	-615.9	20.9	
2 - 3	210.2	-105.3	525.7	
2 - 4	215.6	-84.9	516.2	
3 - 4	5.5	-312.9	323.9	
***** Comparisons significantly different at the 0.05 level.**				

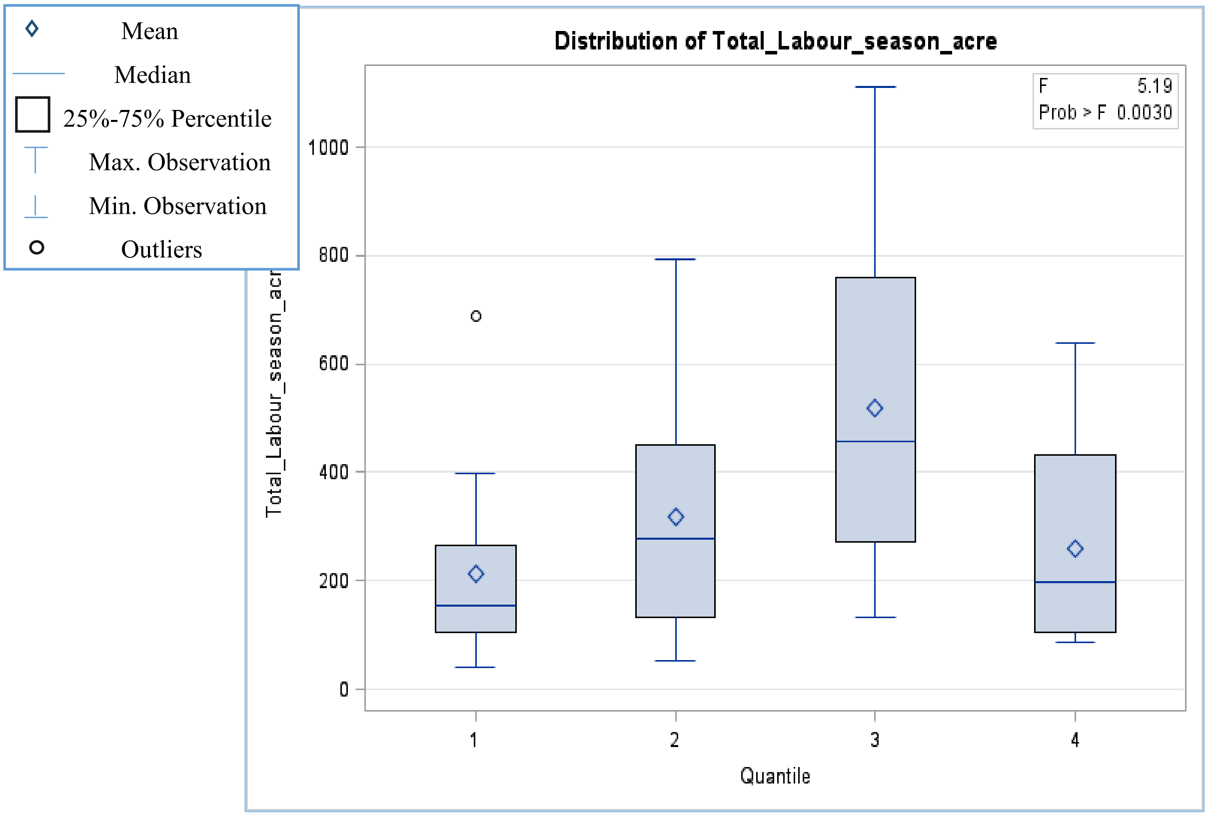


Figure A 8: ANOVA of Quantile Means of Millet Labour Hour/Acre.

Table A 5: Tukey HSD Test for Millet Labour/Acre

Quantile Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
1 - 2	-106.84	-320.52	106.84	
1 - 3	-304.94	-531.03	-78.86	***
1 - 4	-47.24	-276.68	182.20	
2 - 3	-198.10	-399.03	2.82	
2 - 4	59.60	-145.09	264.29	
3 - 4	257.70	40.09	475.31	***
***** Comparisons significantly different at the 0.05 level.**				

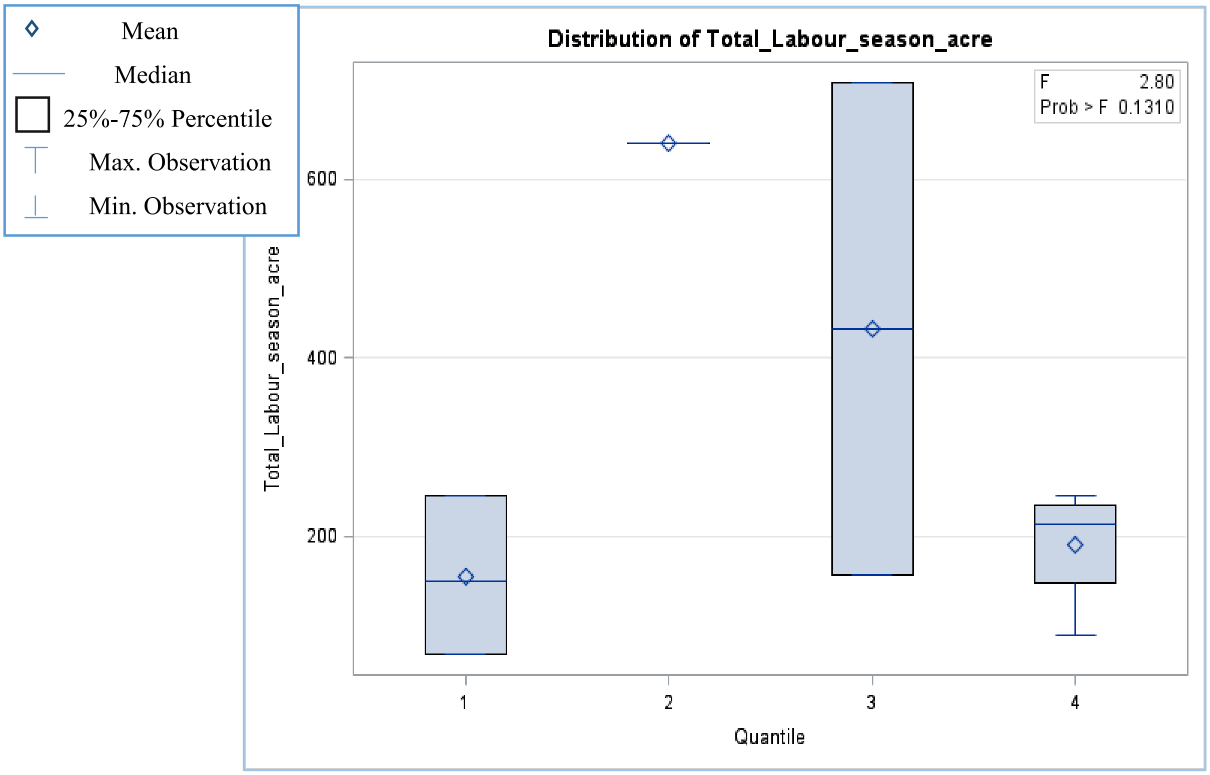


Figure A 9: ANOVA of Quantile Means for Cowpea Labour Hour/Acre.

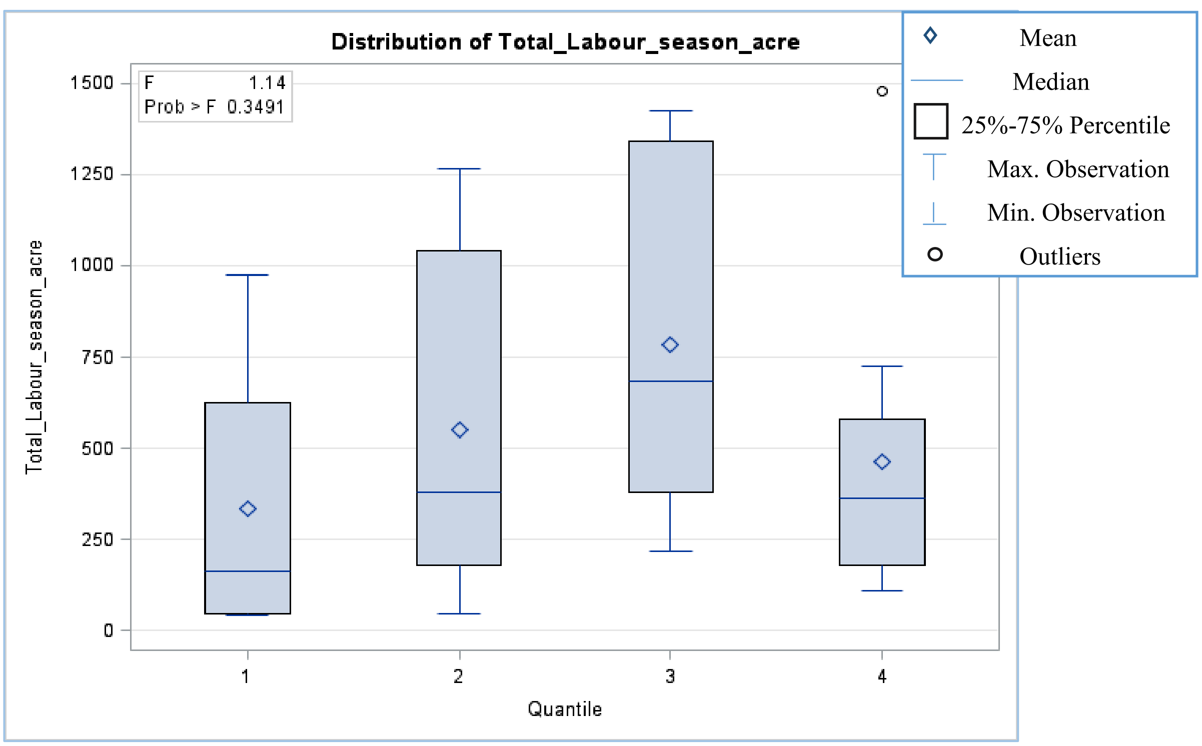


Figure A 10: ANOVA of Quantile Means for Sorghum Labour Hour/Acre.

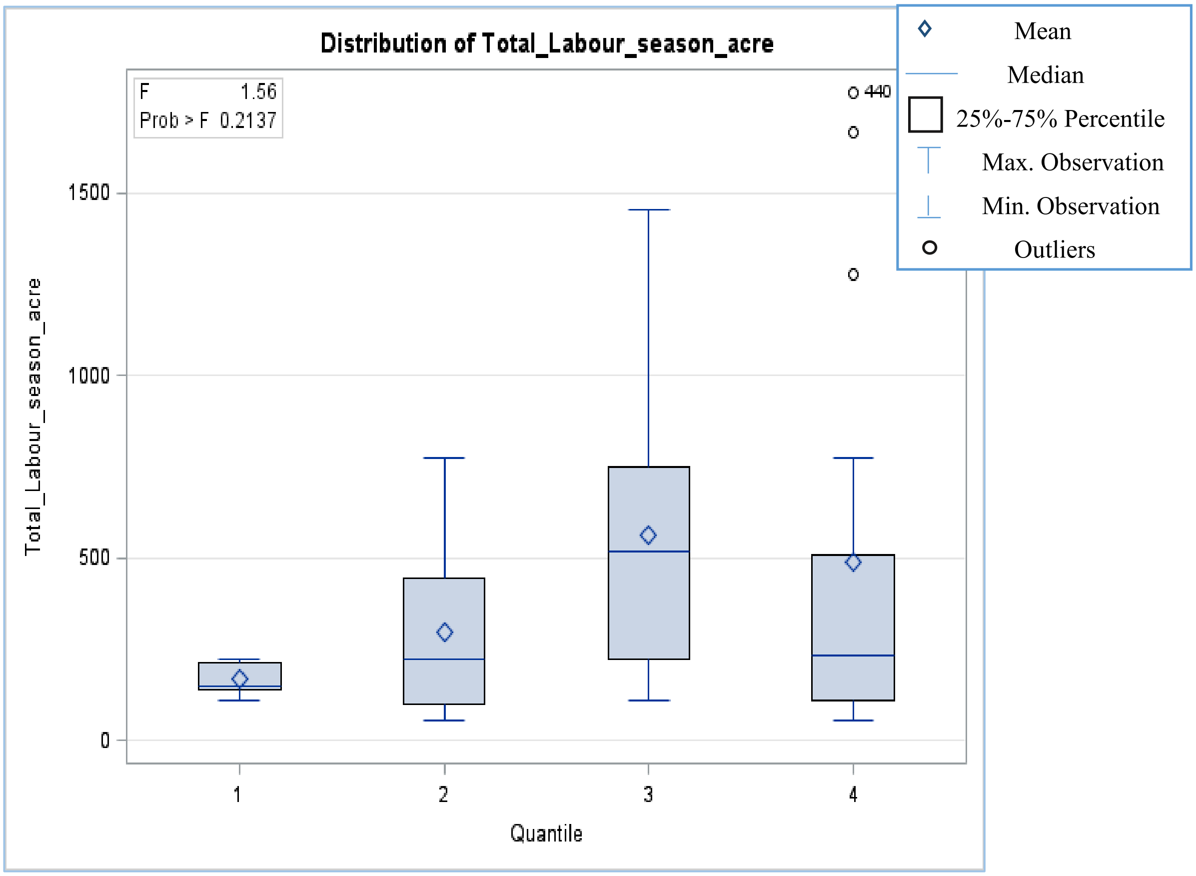


Figure A 11: ANOVA of Quantile Means for Rice Labour Hour/Acre.

A1.3: Crops' Output/Labour Hour Quantile Comparisons

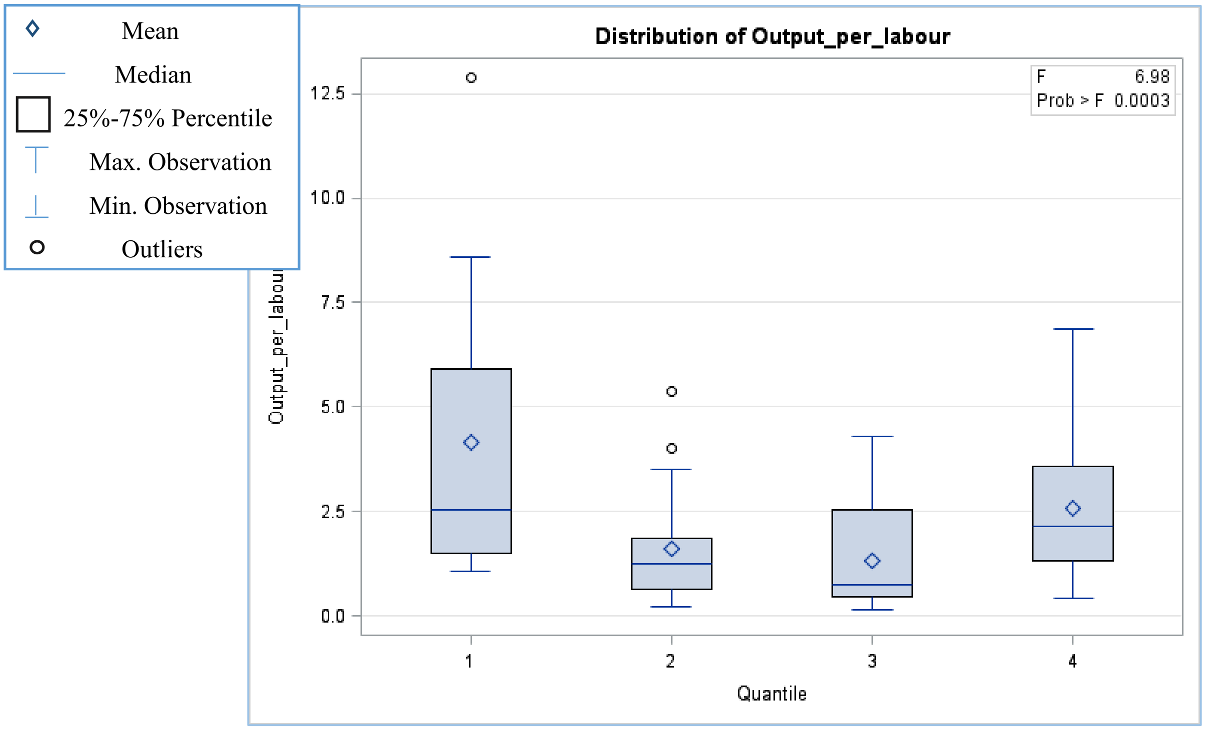


Figure A 12: ANOVA of Quantile Means for Groundnut Output/Labour Hour.

Table A 6: Tukey HSD Test for Groundnut Output/Labour Hour

Quantile Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
1 - 2	2.5403	0.8738	4.2068	***
1 - 3	2.8137	0.9594	4.6681	***
1 - 4	1.5845	-0.1559	3.3250	
2 - 3	0.2734	-1.3931	1.9399	
2 - 4	-0.9558	-2.4946	0.5830	
3 - 4	-1.2292	-2.9697	0.5112	
***** Comparisons significantly different at the 0.05 level.**				

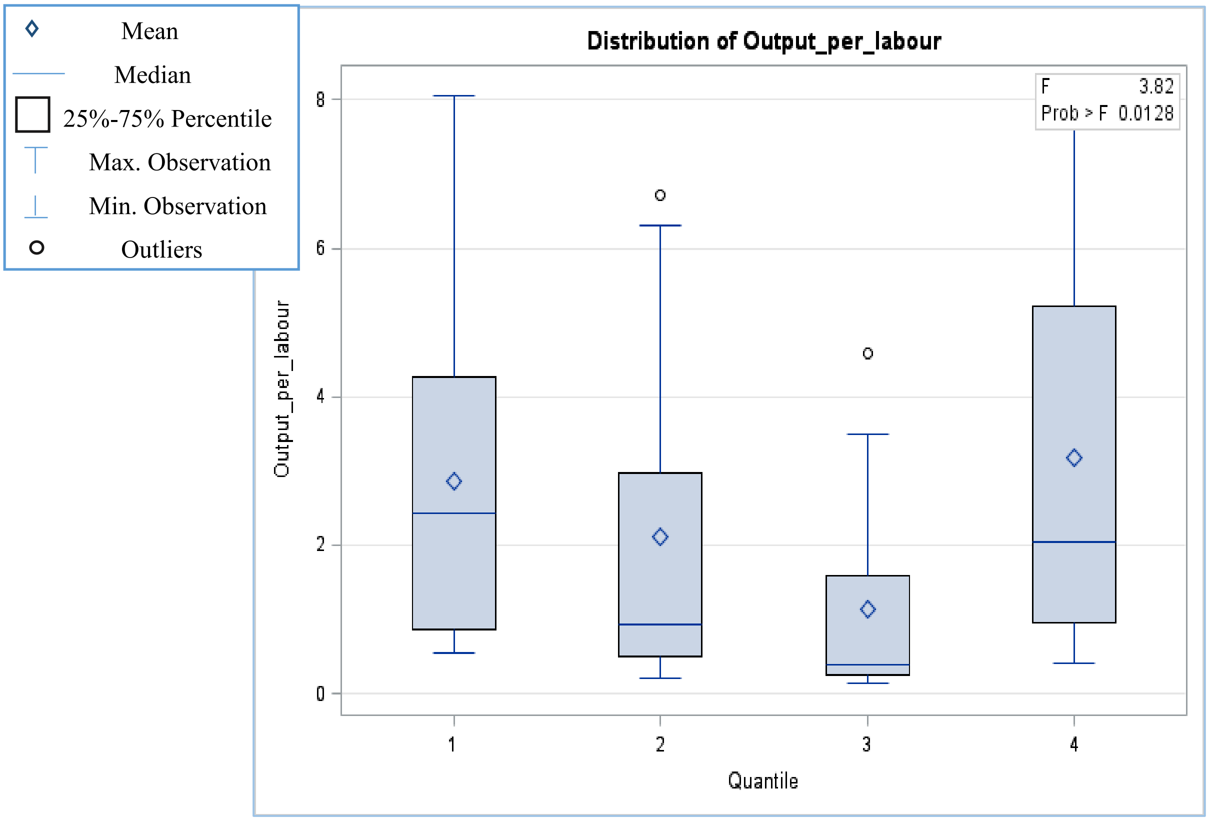


Figure A 13: ANOVA of Quantile Means of Maize Output/Labour Hour.

Table A 7: Tukey HSD Test for Maize Output/Labour Hour

Quantile Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
1 - 2	0.7323	-0.9536	2.4182	
1 - 3	1.7238	-0.0533	3.5008	
1 - 4	-0.3258	-2.0272	1.3756	
2 - 3	0.9915	-0.6944	2.6773	
2 - 4	-1.0581	-2.6640	0.5479	
3 - 4	-2.0495	-3.7510	-0.3481	***
***** Comparisons significantly different at the 0.05 level.**				

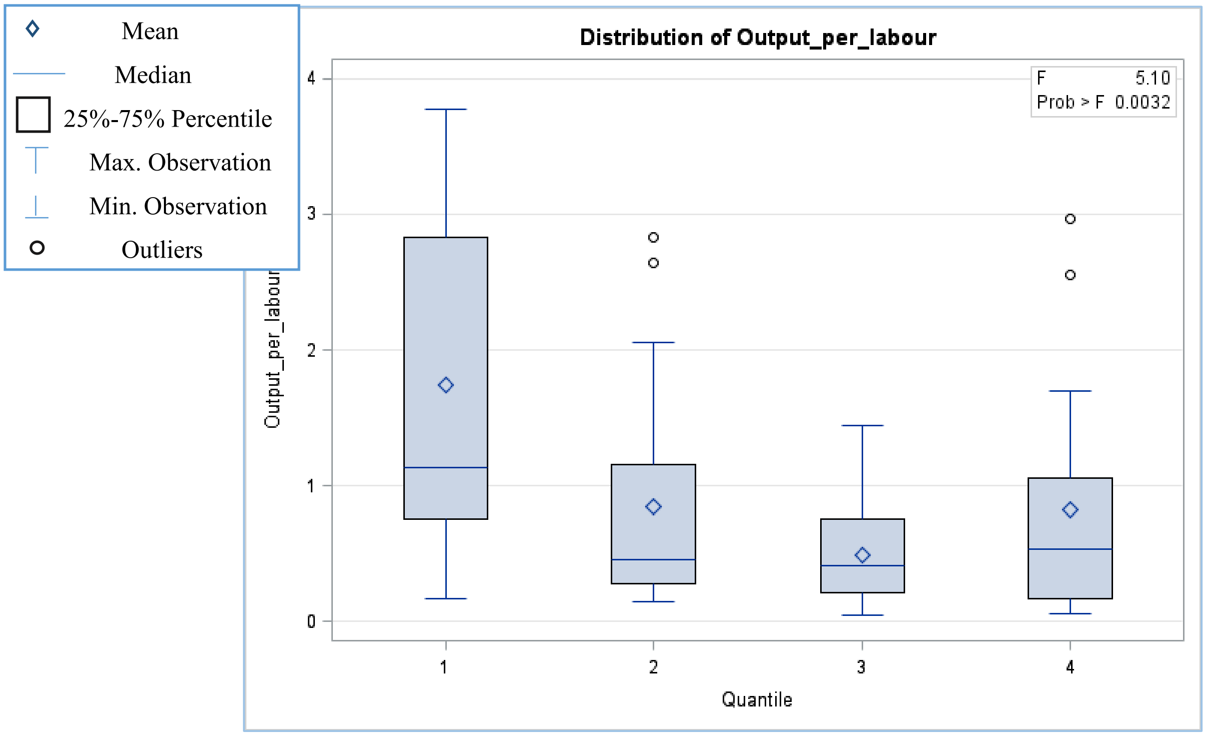


Figure A 14: ANOVA of Quantile Means of Millet Output/Labour Hour.

Table A 8: Tukey HSD Test for Millet Output/Labour Hour

Quantile Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
1 - 2	0.8984	0.0719	1.7249	***
1 - 3	1.2542	0.3796	2.1287	***
1 - 4	0.9195	0.0450	1.7941	***
2 - 3	0.3558	-0.4214	1.1330	
2 - 4	0.0211	-0.7561	0.7983	
2 - 3	0.3558	-0.4214	1.1330	
3 - 4	-0.3346	-1.1627	0.4934	
***** Comparisons significantly different at the 0.05 level.**				

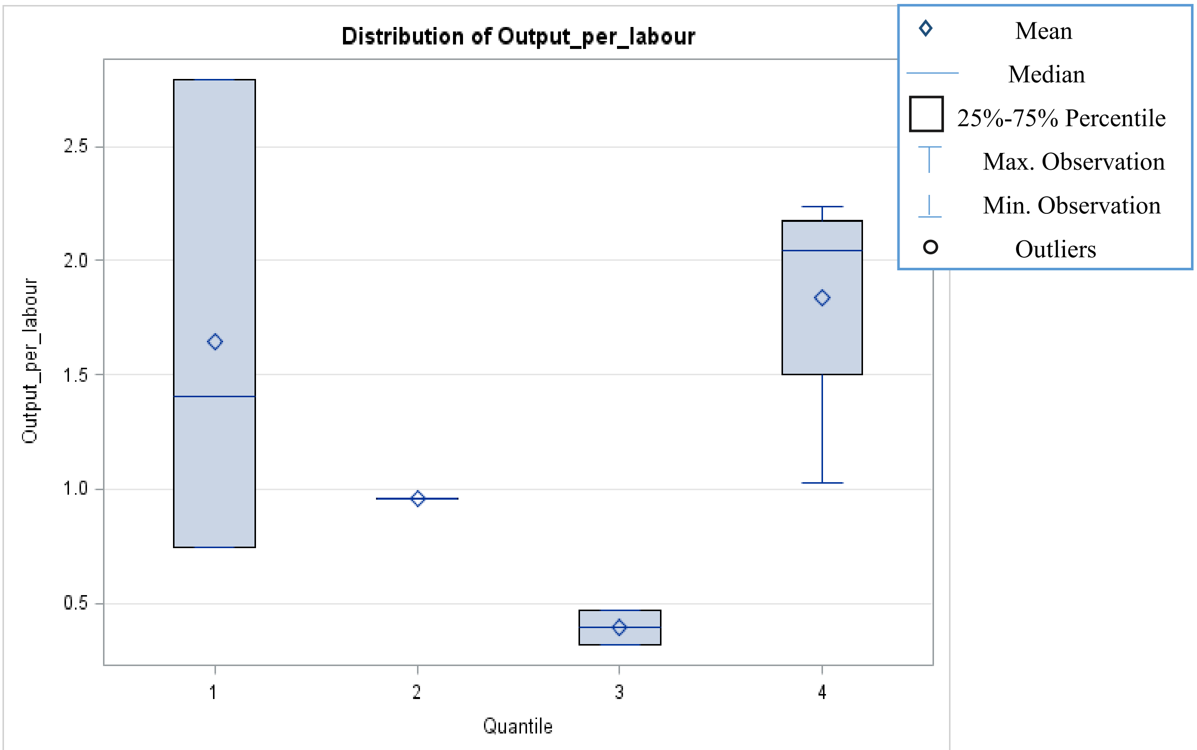


Figure A 15: ANOVA of Quantile Means of Cowpea Output/Labour Hour.

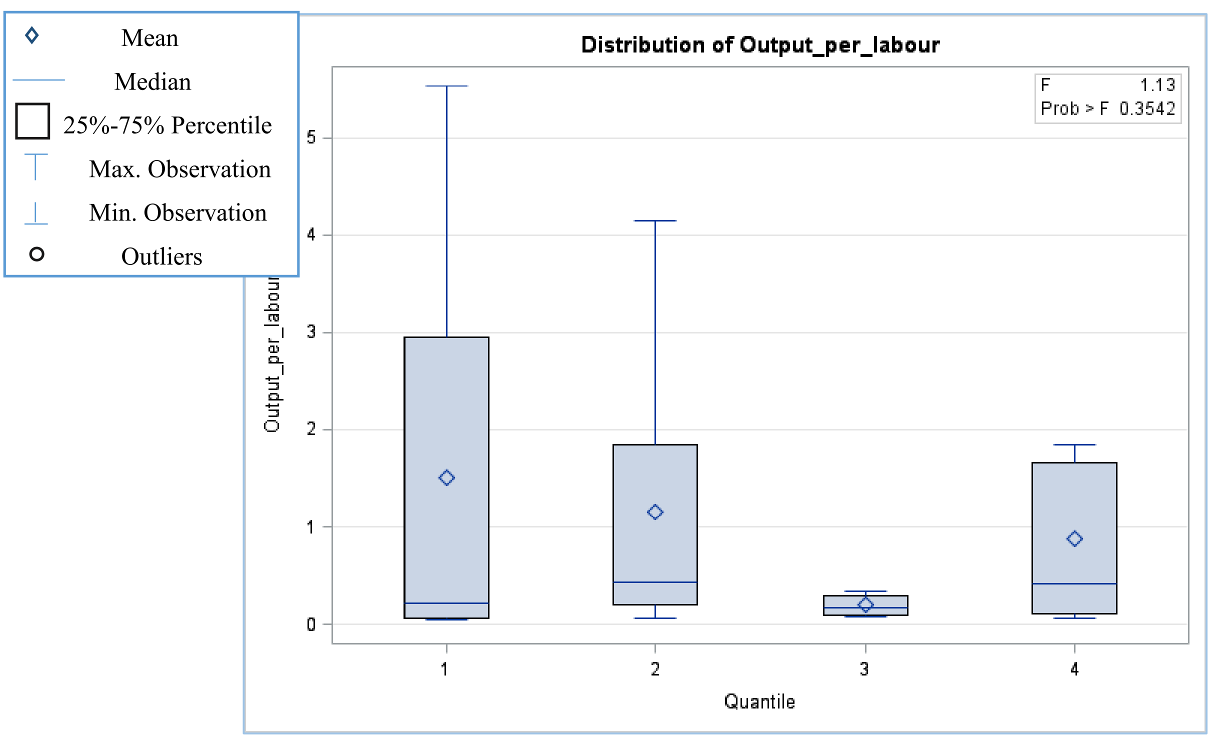


Figure A 16: ANOVA of Quantile Means of Sorghum Output/Labour Hour.

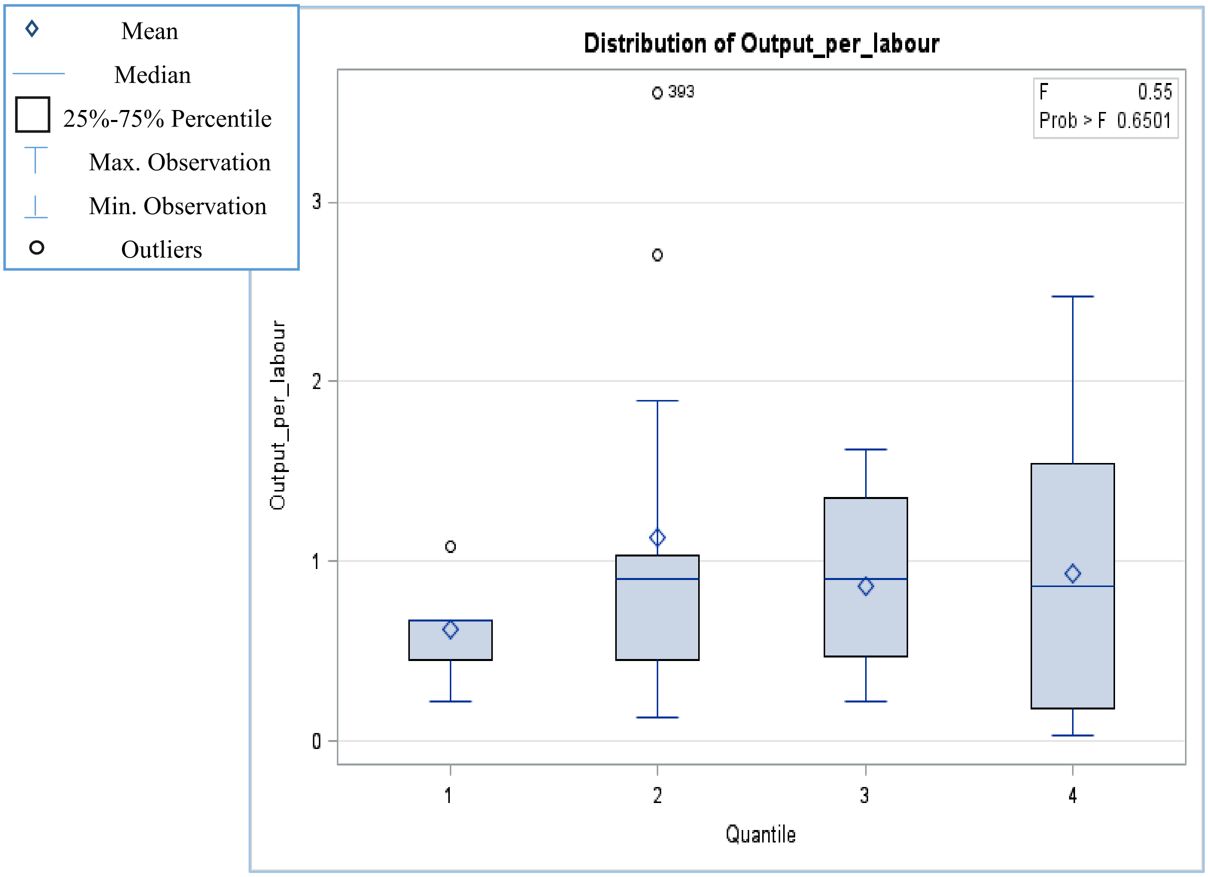


Figure A 17: ANOVA of Quantile Means of Rice Output/Labour Hour.

Appendix B: Historical Yields, CRI and @RISK Simulations

Table B 1: Regression Results for Area Crop Yields against Year

	Parameter Estimate	Standard Error	t Value	Pr > |t|
Dependent Variable= Maize Yield				
Intercept	1495.391	12860.600	0.120	0.909
Year	-0.518	6.409	-0.080	0.937
Dependent Variable= Groundnut Yield				
Intercept	520.016	10871.990	0.050	0.999
Year	-0.001	5.418	0.000	0.963
Dependent Variable= Millet Yield				
Intercept	-268.934	9974.114	-0.030	0.979
Year	0.300	4.971	0.060	0.953
Dependent Variable= Cowpea Yield				
Intercept	-41844.330	9452.763	-4.430	0.001***
Year	21.028	4.711	4.460	0.001***
Dependent Variable= Sorghum Yield				
Intercept	607.043	5124.780	0.120	0.908
Year	-0.136	2.554	-0.050	0.959
Dependent Variable= Rice Yield				
Intercept	55137.570	17693.000	3.120	0.009***
Year	-27.185	8.818	-3.080	0.009***

*** Significant at 1% significance level.

Table B 2: De-trended Area Yields, Estimated Farm Yields and Cumulative Rainfall Index (CRI) Series

Year	Area Yields						Farm Yields						CRI
	Maize	Groundnut	Millet	Cowpea	Sorghum	Rice	Maize	Groundnut	Millet	Cowpea	Sorghum	Rice	
2000	595.00	474.62	361.41	444.30	334.82	465.18	358.51	257.60	162.11	101.01	130.46	173.81	0.99
2001	447.11	496.26	284.62	323.23	280.90	434.04	269.40	269.34	127.66	73.48	109.45	162.17	1.04
2002	486.77	693.90	326.80	453.96	320.46	475.63	293.29	376.62	146.58	103.21	124.87	177.71	1.22
2003	434.29	540.04	322.03	376.25	360.70	494.49	261.67	293.11	144.44	85.54	140.54	184.76	1.25
2004	389.86	459.53	294.58	660.77	324.96	585.37	234.90	249.41	132.13	150.22	126.62	218.72	0.66
2005	444.35	410.17	329.90	329.63	358.43	254.41	267.74	222.62	147.97	74.94	139.66	95.06	1.31
2006	403.27	486.02	279.47	478.25	318.56	339.71	242.98	263.79	125.35	108.73	124.12	126.93	1.45
2007	353.27	429.04	325.34	548.75	358.47	296.95	212.86	232.86	145.93	124.75	139.67	110.95	0.79
2008	311.08	534.88	363.59	534.00	393.18	389.55	187.44	290.31	163.08	121.40	153.20	145.55	0.88
2009	536.79	597.55	527.28	552.79	395.99	529.35	323.43	324.32	236.51	125.67	154.29	197.78	1.25
2010	498.64	620.86	416.06	478.46	358.96	531.38	300.45	336.97	186.62	108.78	139.87	198.54	0.73
2011	624.92	543.73	328.37	487.51	284.93	438.36	376.53	295.11	147.28	110.83	111.02	163.79	1.06
2012	344.00	502.20	268.65	430.32	302.46	473.48	207.27	272.57	120.50	97.83	117.85	176.91	1.10
2013	511.91	452.51	232.90	353.57	298.96	478.72	308.44	245.60	104.47	80.38	116.49	178.87	0.79

B1: @RISK Simulations

B1.1: Summary of @Risk Tests of Best Fit Distribution for Area and Farm Yield Series

Below is a brief discussion of the statistical criteria used by @RISK to determine the best fit distribution for the area and farm-level yield series.

Akaike Information Criterion (AIC)

AIC is a model selection criterion that identifies the optimal fitted model among competing models for a given data set. Smaller values of AIC indicate a model is closer to the truth. The AIC is represented as:

$$AIC = -2\ln f\left(y\middle|\hat{\theta}_k\right) + 2k$$

where k is the number of estimated parameters in the model, $\text{In} f\left(y\middle|\hat{\theta}_k\right)$ is the maximized value of the likelihood function of the fitted model, $\hat{\theta}$ is the estimated parameter. A key limitation is that it cannot be used to compare models with different sample sizes.

Bayesian Information Criterion (BIC)

BIC is an alternative information criterion that favours smaller models than AIC. It is defined as:

$$BIC = -2\ln f\left(y\middle|\hat{\theta}_k\right) + k\ln n$$

BIC can be used to compare models that are based on different probability distributions. As with the AIC, the optimal model is identified by the minimum value of BIC. A key shortcoming is that it is valid for sample sizes that are larger than the number of parameters in the model, i.e., where there are at least 8 observations.

Chi-Square Statistic

The Chi-square statistic is commonly used as a goodness of fit test to examine differences between observed and expected data that are divided into several bins.

$$X^2 = \sum_{i=1}^{K} \frac{(N_i \; - \; E_{i)}{}^2}{E_i}$$

where K is the number of bins; N_i and E_i are the observed and expected number of samples, respectively, in the *ith* bin. Since this test fails to specific guidelines for choosing the number of bins, @RISK automatically selects and modifies the bin size.

Kolmogorov-Smirnov (K-S) Statistic

K-S is based on the empirical cumulative function, which, assuming a random sample $x_i \ldots x_n$ for a continuous distribution function, is:

$$F_n(x) = \frac{1}{n} * [numberofobservations \leq x]$$

K-S is the vertical difference between F(x) and $F_n(x)$ as:

$$D_n \; = \mathrm{sup}x \; |F_n(x) - F(x)|,$$

where *n* is the total number of data points; $F(x)$ is the fitted cumulative distribution function and $F_n(x)$ is the number of x_i less than x**,** divided by the number of data points. Compared to the Chi-square test, the K-S statistic does not depend on bins and focuses more on the middle of the distribution than the tails.

Anderson-Darling (A-D) Statistic

A-D differs from the K-S test in that it focuses on the differences between the input data and the tails of the fitted distribution. It is represented as:

$$A_n^2 = n\int_{-\infty}^{+\infty} [F_n(x) - F(x)]^2 \lambda(x) f(x) dx$$

where *n* is the total number of data points;

$$\lambda^2 = \frac{1}{F(x)[1 - F(x)]}$$

f(x) is the hypothesized density function; *F(x)* is the hypothesized cumulative distribution function; and $F_n(x)$ equals the number of x_i less than x, divided by the number of data points.

Table B 3: Ranking of Test statistics for Three Best Area yields' distributions[a]

Maize			
	Gamma	InvGauss	Lognorm
Akaike (AIC)	#1(170.36)	#1(170.36)	#3(170.40)
Bayesian (BIC)	#1(170.54)	#2(170.55)	#3(170.58)
Chi-Square Statistic	#1 (0.14)	#1 (0.14)	#1 (0.14)
K-S Statistic	#1(0.09)	#2(0.10)	#2(0.10)
A-D Statistic	#1(0.14)	#2(0.15)	#2(0.15)
Sum of Ranks	**5**	**8**	**11**
Groundnut			
	Pearson5	LogLogistic	InvGauss
Akaike (AIC)	#1 (164.39)	#5(165.15)	#2(164.66)
Bayesian (BIC)	#1(164.57)	#5(165.33)	#2(164.85)
Chi-Square Statistic	#1 (0.14)	#1(0.14)	#4 (1.00)
K-S Statistic	#2(0.12)	#1(0.10)	#5(0.13)
A-D Statistic	#1(0.18)	#1(0.18)	#5(0.21)
Sum of Ranks	**6**	**13**	**18**
Millet			
	LogLogistic	Pearson5	Lognorm
Akaike (AIC)	#1(160.01)	#2(160.15)	#3(160.70)
Bayesian (BIC)	#1(160.19)	#2(160.34)	#3(160.89)
Chi-Square Statistic	#1 (0.14)	#1 (0.14)	#1 (0.14)
K-S Statistic	#1(0.16)	#2(0.18)	#4(0.19)
A-D Statistic	#1(0.30)	#2(0.35)	#4(0.40)
Sum of Ranks	**5**	**9**	**15**

Cowpea			
	Gamma	InvGauss	Lognorm
Akaike (AIC)	#1(171.14)	#2(171.16)	#3(171.19)
Bayesian (BIC)	#1(171.33)	#2(171.35)	#3(171.38)
Chi-Square Statistic	#1 (0.57)	#1 (0.57)	#1 (0.57)
K-S Statistic	#1(0.11)	#3(0.12)	#3(0.12)
A-D Statistic	#1(0.26)	#4(0.29)	#4(0.29)
Sum of Ranks	**5**	**12**	**14**
Sorghum			
	InvGauss	Lognorm	Pearson5
Akaike (AIC)	#1(144.74)	#2(144.75)	#3(144.76)
Bayesian (BIC)	#1(144.92)	#2(144.94)	#2(144.94)
Chi-Square Statistic	#1 (0.57)	#1(0.57)	#1(0.57)
K-S Statistic	#3(0.18)	#3(0.18)	#3(0.18)
A-D Statistic	#1(0.32)	#1(0.32)	#1(0.32)
Sum of Ranks	**7**	**9**	**10**
Rice			
	Weibull	BetaGeneral	Gamma
Akaike (AIC)	#1(169.50)	#3(172.24)	#2(172.15)
Bayesian (BIC)	#1(169.69)	#2(171.75)	#3(172.34)
Chi-Square Statistic	#4 (0.57)	#4 (0.57)	#1 (0.14)
K-S Statistic	#2(0.15)	#1(0.13)	#3(0.21)
A-D Statistic	#2(0.31)	#1(0.27)	#3(0.59)
Sum of Ranks	**10**	**11**	**12**

Notes:

[a] Values in parenthesis are the test statistic for each distribution.

Table B 4: Summary of the Best Distribution used for Area Yield Simulations

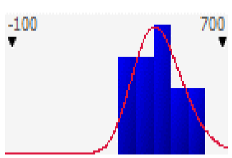
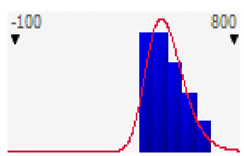
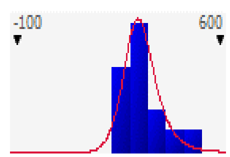
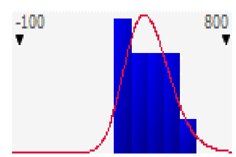
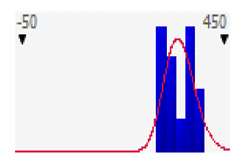
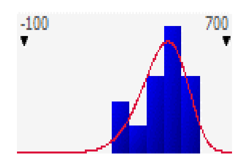
Name	Maize	Groundnut	Millet	Cowpea	Sorghum	Area Rice
Best Fit	Gamma	Pearson5	LogLogistic	Gamma	InvGauss	Weibull
AIC	170.356	164.3876	160.0059	171.142	144.7356	169.4999
Minimum	0	0	0	0	0	0
Maximum	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	455.8045	517.068	327.9736	460.8423	335.1274	443.1016
Mode	438.1538	497.3907	315.471	442.3589	329.4522	463.3891
Median	449.9346	510.3343	322.2712	454.696	333.2319	449.3642
Std. Deviation	89.6953	73.4522	62.6488	92.2925	35.7614	84.4851
Graph						

Table B 5: Ranking of Test statistics for Three Best Farm-level yields' distributions[a]

Maize			
	Gamma	InvGauss	Lognorm
Akaike (AIC)	#1(156.17)	#1(156.17)	#3(156.21)
Bayesian (BIC)	#1(156.36)	#1(156.36)	#3(156.40)
Chi-Square Statistic	#1 (0.14)	#1 (0.14)	#1 (0.14)
K-S Statistic	#1(0.09)	#2(0.10)	#2(0.10)
A-D Statistic	#1(0.14)	#2(0.15)	#2(0.15)
Sum of Ranks	**5**	**7**	**11**
Groundnut			
	Pearson5	LogLogistic	InvGauss
Akaike (AIC)	#1 (147.28)	#5(148.03)	#2(147.55)
Bayesian (BIC)	#1(147.46)	#5(148.22)	#2(147.74)
Chi-Square Statistic	#1 (0.14)	#1(0.14)	#4 (1.00)
K-S Statistic	#2(0.12)	#1(0.10)	#5(0.13)
A-D Statistic	#1(0.18)	#1(0.18)	#5(0.21)
Sum of Ranks	**6**	**13**	**18**
Millet			
	LogLogistic	Pearson5	Lognorm
Akaike (AIC)	#1(137.56)	#2(137.70)	#3(138.26)
Bayesian (BIC)	#1(137.74)	#2(137.89)	#3(138.44)
Chi-Square Statistic	#1 (0.14)	#1 (0.14)	#1 (0.14)
K-S Statistic	#1(0.16)	#2(0.18)	#4(0.19)
A-D Statistic	#1(0.30)	#2(0.35)	#4(0.40)
Sum of Ranks	**5**	**9**	**15**

Cowpea			
	Gamma	InvGauss	Lognorm
Akaike (AIC)	#1(129.67)	#2(129.68)	#3(129.72)
Bayesian (BIC)	#1(129.85)	#2(129.87)	#3(129.90)
Chi-Square Statistic	#1 (0.57)	#1 (0.57)	#1 (0.57)
K-S Statistic	#1(0.11)	#3(0.12)	#3(0.12)
A-D Statistic	#1(0.26)	#4(0.29)	#4(0.29)
Sum of Ranks	**5**	**12**	**14**
Sorghum			
	InvGauss	Lognorm	Pearson5
Akaike (AIC)	#1(118.34)	#2(118.36)	#3(118.37)
Bayesian (BIC)	#1(118.53)	#2(118.55)	#2(118.55)
Chi-Square Statistic	#1 (0.57)	#1(0.57)	#1(0.57)
K-S Statistic	#3(0.18)	#3(0.18)	#3(0.18)
A-D Statistic	#1(0.32)	#1(0.32)	#1(0.32)
Sum of Ranks	**7**	**9**	**10**
Rice			
	Weibull	BetaGeneral	Gamma
Akaike (AIC)	#1(141.93)	#3(144.67)	#2(144.58)
Bayesian (BIC)	#1(142.12)	#2(144.19)	#3(144.77)
Chi-Square Statistic	#4 (0.57)	#4 (0.57)	#1 (0.14)
K-S Statistic	#2(0.15)	#1(0.13)	#3(0.21)
A-D Statistic	#2(0.31)	#1(0.27)	#3(0.59)
Sum of Ranks	**10**	**11**	**12**

Notes:
[a] Values in parenthesis are the test statistic for each distribution.

Table B 6: Summary of the Best Distribution used for Farm Yield Simulations

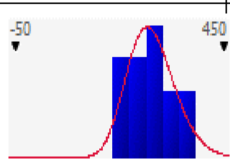
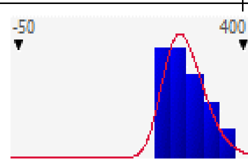
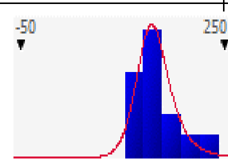
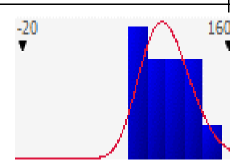
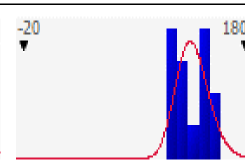
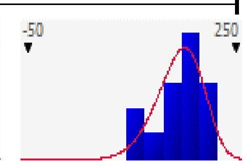
Name	Maize	Groundnut	Millet	Cowpea	Sorghum	Rice
Best Fit	Gamma	Pearson5	LogLogistic	Gamma	InvGauss	Weibull
AIC	156.1706	147.2767	137.5566	129.6659	118.3446	141.9346
Minimum	0	0	0	0	0	0
Maximum	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	274.6355	280.6396	147.1089	104.7699	130.5783	165.5585
Mode	264.0004	269.9597	141.501	100.5678	128.3671	173.1386
Median	271.0987	276.9849	144.5512	103.3726	129.8398	167.8984
Std. Deviation	54.044	39.8663	28.1004	20.9822	13.934	31.5666
Graph						

Table B 7: Correlations between Area, CRI and Farm Yields before Simulations

	A. Maize	A. Groundnut	A. Millet	A. Cowpea	A. Sorghum	A. Rice	F. Maize	F. Groundnut	F. Millet	F. Cowpea	F. Sorghum	F. Rice	CRI
A. Maize	1												
A. Groundnut	0.27	1											
A. Millet	0.30	0.48	1										
A. Cowpea	-0.19	0.14	0.36	1									
A. Sorghum	-0.25	0.15	0.72	0.35	1								
A. Rice	0.29	0.49	0.22	0.31	-0.09	1							
F. Maize	1.00	0.27	0.30	-0.19	-0.25	0.29	1						
F. Groundnut	0.27	1.00	0.48	0.14	0.15	0.49	0.27	1					
F. Millet	0.30	0.48	1.00	0.36	0.72	0.22	0.30	0.48	1				
F. Cowpea	-0.19	0.14	0.36	1.00	0.35	0.31	-0.19	0.14	0.36	1			
F. Sorghum	-0.25	0.15	0.72	0.35	1.00	-0.09	-0.25	0.15	0.72	0.35	1		
F. Rice	0.29	0.49	0.22	0.31	-0.09	1.00	0.29	0.49	0.22	0.31	-0.09	1	
CRI	0.10	0.16	0.09	-0.39	0.02	-0.35	0.10	0.16	0.09	-0.39	0.02	-0.35	1

Table B 8: National Yield Series (2000-2013)

Year	Maize	Groundnut	Millet	Beans	Sorghum	Rice
2000	664.65	404.99	373.48	497.68	541.60	1088.19
2001	593.33	427.55	315.84	501.67	460.35	997.00
2002	665.40	567.96	360.57	578.29	492.62	1103.95
2003	719.30	394.82	377.60	526.10	497.96	969.21
2004	691.13	375.92	346.58	492.84	477.40	943.49
2005	676.43	387.32	434.63	475.63	482.29	1093.42
2006	643.18	447.99	354.86	503.55	462.10	897.66
2007	655.71	363.99	295.77	340.19	339.59	749.97
2008	730.76	550.52	448.26	481.69	534.67	984.46
2009	707.00	628.42	548.69	519.28	570.24	1025.90
2010	778.91	612.66	512.10	507.32	544.90	1134.86
2011	765.12	529.78	420.99	550.88	488.37	966.29
2012	667.00	557.37	421.94	535.12	490.85	1027.00
2013	691.79	501.62	387.23	469.27	449.76	1050.18

Data Source: FAO Database.

Table B 9: National and Area Yields Correlation Matrix

	N. Maize	N. Groundnut	N. Millet	N. Beans	N. Sorghum	N. Rice	A. Maize	A. Groundnut	A. Millet	A. Cowpea	A. Sorghum	A. Rice
N. Maize	1											
N. Groundnut	0.48	1										
N. Millet	0.66	0.75	1									
N. Beans	0.22	0.51	0.35	1								
N. Sorghum	0.46	0.59	0.76	0.68	1							
N. Rice	0.24	0.48	0.59	0.63	0.73	1						
A. Maize	0.28	0.22	0.27	0.39	0.38	0.45	1					
A. Groundnut	0.38	0.75	0.43	0.65	0.53	0.43	0.27	1				
A. Millet	0.42	0.49	0.73	0.09	0.60	0.22	0.30	0.48	1			
A. Cowpea	0.30	0.12	0.11	-0.16	0.05	-0.41	-0.19	0.14	0.36	1		
A. Sorghum	0.36	0.15	0.51	-0.27	0.33	-0.01	-0.25	0.15	0.72	0.35	1	
A. Rice	0.33	0.39	0.28	0.51	0.51	0.36	0.29	0.49	0.29	0.31	-0.09	1

Table B 10: Area and Farm Yields Correlation Matrix Specified in @RISK

	A. Maize	A. Groundnut	A. Millet	A. Cowpea	A. Sorghum	A. Rice	F. Maize	F. Groundnut	F. Millet	F. Cowpea	F. Sorghum	F. Rice
A. Maize	1											
A. Groundnut	0.48	1										
A. Millet	0.66	0.75	1									
A. Cowpea	0.22	0.51	0.35	1								
A. Sorghum	0.46	0.59	0.76	0.68	1							
A. Rice	0.24	0.48	0.59	0.63	0.73	1						
F. Maize	0.82	0.48	0.66	0.22	0.46	0.24	1					
F. Groundnut	0.48	0.82	0.75	0.51	0.59	0.48	0.48	1				
F. Millet	0.66	0.75	0.82	0.35	0.76	0.59	0.66	0.75	1			
F. Cowpea	0.22	0.51	0.35	0.82	0.68	0.63	0.22	0.51	0.35	1		
F. Sorghum	0.46	0.59	0.76	0.68	0.82	0.73	0.46	0.59	0.76	0.68	1	
F. Rice	0.24	0.48	0.59	0.63	0.73	0.82	0.24	0.48	0.59	0.63	0.73	1

Table B 11: @RISK Adjusted Area and Farm Yields Correlation Matrix

	A. Maize	A. Groundnut	A. Millet	A. Cowpea	A. Sorghum	A. Rice	F. Maize	F. Groundnut	F. Millet	F. Cowpea	F. Sorghum	F. Rice
A. Maize	1											
A. Groundnut	0.47	1										
A. Millet	0.64	0.73	1									
A. Cowpea	0.21	0.49	0.34	1								
A. Sorghum	0.45	0.57	0.74	0.66	1							
A. Rice	0.23	0.47	0.57	0.61	0.71	1						
F. Maize	0.80	0.47	0.64	0.21	0.45	0.23	1					
F. Groundnut	0.47	0.80	0.73	0.49	0.57	0.47	0.47	1				
F. Millet	0.64	0.73	0.80	0.34	0.74	0.57	0.64	0.73	1			
F. Cowpea	0.21	0.49	0.34	0.80	0.66	0.61	0.21	0.49	0.34	1		
F. Sorghum	0.45	0.57	0.74	0.66	0.80	0.71	0.45	0.57	0.74	0.66	1	
F. Rice	0.23	0.47	0.57	0.61	0.71	0.80	0.23	0.47	0.57	0.61	0.71	1

B1.2: How @RISK Decides whether a Correlation Matrix is Valid or Not

The basic principle is that if two inputs are each strongly correlated to a third, they must be at least weakly correlated to each other. If the coefficient of A and B is m, and the coefficient of A and C is n, then the coefficient of B and C must be in the range of

$$mn \pm \sqrt{(1-m^2)(1-n^2)}$$

@RISK generalizes this principle for a correlation matrix of any size. If a correlation matrix is created using a full data set, it will be positive semi-definite if there is a linear relationship between any of the variables and positive definite if there is no linear relationship.

@RISK calculates the eigenvalues for the matrix to determine whether it is positive definite (i.e. have all positive eigenvalues) or positive semi-definite (i.e. have eigenvalues greater than or equal to zero and at least one eigenvalue equal to zero).

For @RISK, a “valid” matrix is any matrix that is positive or positive semi-definite, and an “invalid” matrix is any matrix that has at least one negative eigenvalue.

B1.3: How @RISK Adjusts an Invalid Correlation Matrix

Invalid correlation matrix can be adjusted in two ways in @RISK:

1. **Using Adjustment Weight Matrix**

   Users can adjust the matrix on their own or create an adjustment weight matrix to guide @RISK. The adjustment matrix is a square matrix the same size as the correlation matrix, and its name must match the range name for the correlation matrix, with the suffix “Weights”. The adjustment weight values range from 0 to 100. The larger the value, the greater weight @RISK will place on keeping the original correlation coefficient.

2. **No Adjustment Weight Matrix**

Users can also choose not to specify an adjustment weight matrix. In such cases, @RISK follows the steps below to modify the invalid correlation matrix:

a. Find the smallest eigenvalue (E_o)

b. To shift the eigenvalues so that the smallest eigenvalue equals zero, subtract the product of E_o and the identity matrix (I) to the correlation matrix (C).

$$C' = C - E_o I$$

c. Divide the new matrix by $1 - E_o$ so that the diagonal terms equal 1.

$$C'' = \left(\frac{1}{1 - E_o}\right) C'$$

Note: The matrix that @RISK calculates by this method is positive semi-definite, and therefore valid, but in no way is it special or optimal. It's one of many possible valid matrices, and some of the coefficients in it may be quite different from the original coefficients.

We however, used this method in correcting our invalid correlation matrix because of its simplicity and also due to the difficulty in determining appropriate weights to use in the first method.

B1.4: Correlations after @RISK Simulations

Several iterations (10, 20, 30,…, 5000) were simulated to determine the number of iterations that produces the closet correlations to the @RISK adjusted correlations. The 500, 1000 and 5000 iterations simulation produced the correlations closet to the specified ones. We used the 500 iterations simulation to represent 500 states of nature in our GAMS models.

Table B 12: Area and Farm Yields Correlation Matrix at 500 Iterations

	A. Maize	A. Groundnut	A. Millet	A. Cowpea	A. Sorghum	A. Rice	F. Maize	F. Groundnut	F. Millet	F. Cowpea	F. Sorghum	F. Rice
A. Maize	1.00											
A. Groundnut	0.45	1.00										
A. Millet	0.63	0.71	1.00									
A. Cowpea	0.20	0.47	0.30	1.00								
A. Sorghum	0.46	0.58	0.71	0.63	1.00							
A. Rice	0.26	0.48	0.54	0.60	0.70	1.00						
F. Maize	0.82	0.48	0.62	0.21	0.44	0.24	1.00					
F. Groundnut	0.47	0.81	0.76	0.44	0.59	0.47	0.47	1.00				
F. Millet	0.64	0.72	0.80	0.29	0.71	0.56	0.62	0.75	1.00			
F. Cowpea	0.21	0.50	0.32	0.78	0.65	0.57	0.23	0.46	0.29	1.00		
F. Sorghum	0.46	0.58	0.71	0.63	0.78	0.70	0.45	0.60	0.71	0.64	1.00	
F. Rice	0.26	0.50	0.55	0.62	0.71	0.79	0.24	0.49	0.55	0.58	0.68	1.00

Table B 13: Area Series of Real Prices (GHC) from 2009-2014 for Major Crops Considered in the Household Models

Year	Maize	Groundnut	Millet	Cowpea	Sorghum	Rice
2009	0.55	1.12	0.64	0.83	0.76	1.17
2010	0.45	1.19	0.59	0.95	0.65	1.05
2011	0.52	1.75	0.73	1.03	0.73	1.19
2012	0.61	2.07	0.87	1.37	0.84	1.38
2013	0.46	1.83	0.86	1.23	0.75	1.25
2014	0.58	2.09	0.83	1.26	0.85	1.49

Appendix C: GAMS Syntax for Models

This appendix provides the GAMS syntax used for the models developed in this study. The syntax of the calibration process is presented first, followed by the base model and the insurance model.

Appendix C1: Calibration of Base Model

```
$Title                    CALIBRATION MODEL

$inlinecom /* */
$offlisting
$offsymxref offsymlist

Option
   limrow = 10000000,         /*equations listed per block*/
   limcol = 0,                /*variables listed per block" */
   solprint = on,             /* "solver's solution output printed*/
   sysout = off;              /*solver's system output printed*/

Sets
   i state of nature    /1*500/
   d crops           /maize, groundnut, millet, cowpea, sorghum, rice /

Parameters
      lahrs(d)      "labour requirement(hours/acre) for d"
                                  /Maize                248.59
                                   Groundnut            399.50
                                   Millet               238.20
                                   Cowpea               208.20
                                   Sorghum              239.28
                                   Rice                 326.24/

      vc(d)        "variable cost{GHC/acre) for d"
                                  /Maize                38.27
                                   Groundnut            114.56
                                   Millet               30.85
                                   Cowpea               43.68
                                   Sorghum              39.60
                                   Rice                 50.34/

     otuse(d)      "d for other uses(kg)"
                                  /Maize                46.71
```

```
                                        Groundnut            126.58
                                        Millet               39.19
                                        Cowpea               17.11
                                        Sorghum              43.37
                                        Rice                 36.16/

pp(d)      "purchase price(GHC/kg) of d"
                                       /Maize                0.53
                                        Groundnut            1.67
                                        Millet               0.75
                                        Cowpea               1.11
                                        Sorghum              0.76
                                        Rice                 1.26/

phi(d)     "value of consumption-purchase price scaling factor"
                                       /Maize                0.25
                                        Groundnut            0.25
                                        Millet               0.25
                                        Cowpea               0.25
                                        Sorghum              0.25
                                        Rice                 0.25/

gamma(d)   "sale-purchase price scaling factor"
                                       /Maize                0.8
                                        Groundnut            0.8
                                        Millet               0.8
                                        Cowpea               0.8
                                        Sorghum              0.8
                                        Rice                 0.8/;

Table  yld(i,d)     "yield(kg/acre) for d in i"
      Maize     Groundnut   Millet    Cowpea    Sorghum    Rice
1     288.22    333.16      172.14    103.70    149.96     168.61
2     351.68    319.89      176.38    145.94    156.37     202.33
3     258.45    289.08      148.06    80.08     113.93     152.69
4     249.11    322.60      179.31    90.60     139.78     180.61
5     261.18    277.62      157.82    94.61     135.13     154.35
6     301.98    328.03      169.44    119.15    144.51     193.92
7     281.68    301.43      158.97    166.29    151.87     189.52
8     291.46    282.68      153.09    96.64     126.93     147.68
9     319.13    218.14      99.65     93.39     106.63     93.97
10    347.83    375.66      172.83    126.42    139.57     190.02
11    360.95    325.81      163.26    139.00    135.55     203.92
12    337.72    316.85      153.81    123.72    120.79     147.03
13    331.09    271.99      137.05    90.13     112.84     137.89
14    333.53    342.12      189.00    172.42    155.81     215.91
```

15	204.48	233.02	113.36	80.24	115.89	136.45
16	399.51	357.49	203.72	91.85	128.16	176.49
17	271.36	252.22	109.33	127.70	130.82	188.62
18	308.75	262.80	133.77	93.77	127.47	131.62
19	255.15	272.66	133.40	111.58	130.89	172.76
20	348.14	308.58	232.02	104.86	149.35	202.72
21	298.92	285.28	176.04	91.41	162.95	194.69
22	248.71	257.16	93.39	104.77	115.15	115.05
23	231.51	258.26	125.57	115.94	128.43	192.30
24	400.97	282.83	152.74	96.42	123.93	188.61
25	279.47	313.01	125.98	123.83	132.81	104.17
26	352.29	299.77	162.16	109.62	128.98	181.57
27	267.41	250.40	121.29	86.01	123.00	109.76
28	210.54	307.80	163.66	122.55	142.29	209.67
29	211.66	270.95	149.67	117.30	128.66	185.06
30	192.31	273.74	135.60	145.07	139.46	198.45
31	265.32	290.46	162.63	111.06	140.48	191.57
32	231.81	275.21	156.64	77.44	125.68	119.93
33	341.73	308.28	177.05	96.77	138.12	174.75
34	170.58	207.15	126.26	91.64	115.66	167.58
35	335.67	345.67	173.53	125.07	147.49	213.27
36	343.93	256.50	165.10	92.66	129.72	152.35
37	270.38	304.38	142.31	106.82	129.27	157.38
38	391.86	364.51	195.12	131.26	151.38	223.54
39	217.18	287.68	131.69	96.14	124.64	161.58
40	166.56	238.96	113.96	119.34	123.81	197.24
41	242.30	294.78	148.82	101.25	125.65	167.15
42	301.10	302.16	157.97	85.43	126.11	156.55
43	249.50	308.85	143.81	82.67	116.99	180.40
44	250.59	306.74	152.14	82.50	129.86	156.86
45	273.36	224.49	139.29	80.51	122.14	183.41
46	244.71	286.43	150.64	79.28	117.51	186.31
47	284.92	214.79	128.94	94.83	118.23	170.75
48	272.24	289.35	137.69	106.97	125.33	149.19
49	201.26	224.07	121.82	86.59	115.35	126.72
50	281.84	251.35	140.84	101.65	148.31	195.83
51	159.00	212.74	96.79	82.08	118.28	121.98
52	281.05	343.67	201.21	149.00	172.44	233.47
53	296.76	259.59	120.98	102.22	131.51	126.52
54	322.92	277.30	151.01	98.89	136.51	196.62
55	410.97	337.99	209.56	150.72	160.38	199.43
56	189.23	253.15	107.41	95.52	106.01	185.40
57	218.26	240.08	123.88	105.03	116.26	159.13
58	322.67	296.49	164.00	65.28	128.74	130.32
59	207.55	254.60	143.19	121.86	152.44	188.21
60	200.35	238.65	131.43	106.41	143.35	195.77

61	276.42	244.73	145.37	106.00	137.16	159.24
62	205.09	257.74	117.02	114.98	125.07	133.01
63	148.23	236.26	118.80	92.45	117.45	164.23
64	271.41	251.72	134.78	92.58	127.37	169.82
65	277.97	300.42	182.60	78.54	144.98	198.92
66	233.25	266.17	139.73	104.60	137.23	211.76
67	308.01	269.92	159.20	103.19	118.84	175.52
68	258.23	317.74	134.69	105.78	134.97	179.87
69	225.00	261.84	146.16	108.00	131.36	181.93
70	247.46	303.23	141.90	140.78	133.22	182.60
71	260.54	295.40	128.77	103.30	121.11	132.58
72	290.62	259.89	149.72	99.66	140.67	137.82
73	285.97	242.55	148.50	102.70	130.33	170.68
74	300.22	367.14	159.05	126.66	143.61	200.69
75	304.12	257.43	148.69	78.27	139.86	124.05
76	305.03	256.91	140.32	91.33	119.19	140.11
77	234.71	255.72	124.02	88.48	130.00	152.92
78	297.97	258.17	141.35	111.27	128.51	177.86
79	268.91	316.31	150.34	97.13	127.67	166.26
80	279.15	265.99	150.87	79.75	124.85	138.84
81	225.59	266.71	151.48	112.55	132.49	181.45
82	252.41	259.09	158.28	60.34	111.35	115.64
83	218.45	343.08	168.31	84.90	123.39	179.06
84	283.31	265.07	143.60	76.33	108.85	143.09
85	270.84	320.87	215.95	133.62	152.26	196.20
86	220.70	243.40	119.81	79.64	121.78	173.50
87	255.05	346.27	154.72	97.87	122.64	183.10
88	232.91	245.98	131.96	58.15	103.03	96.39
89	237.34	278.66	130.73	86.03	112.12	178.87
90	186.19	234.68	97.84	114.51	133.90	165.36
91	424.49	296.96	220.45	57.17	128.00	175.05
92	339.11	339.31	200.10	115.41	138.63	184.80
93	328.92	283.81	146.53	151.66	146.84	203.46
94	309.70	274.45	165.77	138.72	154.00	200.26
95	341.63	269.18	167.15	106.68	149.02	170.49
96	290.92	245.73	154.44	135.69	151.09	173.86
97	278.19	257.85	151.82	69.28	121.91	131.15
98	198.48	229.81	95.46	112.77	135.08	151.06
99	179.93	254.95	112.47	96.54	116.72	100.64
100	478.32	340.81	239.27	129.12	184.33	189.29
101	277.16	269.79	130.28	90.82	118.52	144.42
102	330.11	259.03	125.34	105.81	127.26	150.46
103	295.41	354.87	182.10	144.08	153.18	208.76
104	278.81	329.72	191.11	95.21	141.76	186.66
105	297.24	263.14	147.74	97.18	134.50	165.65
106	217.73	246.80	129.27	83.87	128.85	146.49

107	299.60	276.35	148.60	88.72	113.81	141.73
108	197.98	203.30	69.00	98.08	105.46	82.44
109	311.31	272.98	143.33	97.70	132.35	165.09
110	183.49	198.43	115.43	99.32	120.86	141.49
111	216.48	215.62	111.38	94.28	114.34	156.63
112	257.12	295.67	140.49	139.97	133.59	163.46
113	316.52	246.34	121.56	147.52	131.70	172.58
114	233.43	288.56	155.55	131.86	146.78	209.04
115	280.35	284.63	153.48	86.33	130.67	119.66
116	224.35	247.90	112.16	115.78	117.92	121.21
117	255.83	334.45	176.81	135.01	141.01	219.29
118	251.93	265.57	121.18	113.23	118.71	147.27
119	222.76	305.45	168.78	115.32	140.66	192.44
120	267.02	230.50	114.82	99.20	120.46	145.66
121	297.90	263.57	153.59	101.83	141.42	199.23
122	202.89	289.50	137.90	116.07	127.51	179.48
123	243.41	284.16	137.67	117.87	148.51	173.89
124	251.59	310.84	145.88	104.01	129.98	164.82
125	265.93	267.00	156.05	91.57	144.28	196.37
126	311.88	411.25	186.35	134.37	139.97	181.06
127	214.17	262.06	135.66	99.89	126.69	194.19
128	302.61	324.87	171.14	130.85	137.76	173.15
129	286.97	268.07	151.76	112.35	132.99	152.09
130	355.49	274.02	186.60	89.30	140.23	177.72
131	253.39	309.62	169.52	141.50	159.34	214.77
132	234.16	233.26	132.33	95.65	121.58	113.68
133	231.07	275.45	104.13	99.42	107.16	119.01
134	196.84	279.79	110.84	73.96	94.90	110.90
135	221.61	259.68	140.91	104.45	135.33	176.57
136	267.82	277.06	149.84	93.19	122.34	137.23
137	246.18	280.46	166.20	97.49	138.81	185.98
138	302.32	250.02	154.93	75.48	123.09	177.18
139	253.83	328.57	175.71	131.50	136.18	163.04
140	290.04	351.67	161.00	121.43	142.10	166.98
141	250.09	303.04	160.20	105.47	124.61	168.71
142	207.11	242.24	122.72	66.39	116.61	151.26
143	214.32	308.19	147.26	113.92	141.86	192.14
144	178.60	231.59	101.33	92.01	96.43	156.94
145	323.61	249.68	142.67	113.38	139.04	164.43
146	325.24	372.40	205.17	124.17	158.93	196.88
147	288.52	275.01	141.66	80.99	119.27	163.63
148	280.89	264.65	145.64	105.63	135.50	190.28
149	214.74	279.91	146.07	96.99	120.12	189.49
150	272.11	278.39	120.42	90.70	112.50	142.00
151	239.43	317.93	158.73	122.11	136.77	204.43
152	286.42	251.12	159.80	120.86	152.71	217.84

153	324.92	311.17	193.46	95.12	138.90	141.36
154	248.11	284.11	126.55	98.95	114.67	114.58
155	359.73	285.38	173.96	103.07	143.05	190.19
156	380.66	294.12	174.13	107.19	141.59	187.59
157	247.23	253.69	126.17	74.66	114.50	171.83
158	415.94	277.47	162.86	115.13	134.28	157.97
159	219.63	288.12	135.04	119.39	126.34	130.59
160	262.48	239.58	146.99	93.12	128.54	181.19
161	239.85	323.71	175.35	102.00	139.61	217.60
162	238.49	275.31	138.16	109.04	123.67	195.38
163	223.12	206.09	88.05	86.21	113.56	90.96
164	293.27	332.46	141.98	95.31	131.53	152.30
165	264.92	237.38	119.65	82.17	107.90	111.15
166	276.81	246.84	129.96	75.64	130.43	134.83
167	243.74	220.71	132.49	68.91	104.84	148.03
168	236.76	236.71	122.03	92.77	111.04	163.91
169	308.38	312.37	193.15	104.39	132.92	166.82
170	315.95	243.74	128.43	96.86	138.00	172.32
171	226.15	332.89	150.84	133.48	127.20	154.82
172	269.95	326.33	161.96	99.10	129.42	135.35
173	309.11	305.05	150.21	101.60	129.20	171.33
174	209.67	217.54	87.27	87.82	109.23	113.43
175	240.95	255.32	140.16	89.74	127.32	118.34
176	304.34	292.64	144.70	111.73	128.89	140.73
177	256.87	245.20	104.65	70.71	108.66	74.10
178	265.73	292.76	142.61	107.58	121.64	160.21
179	191.97	214.02	132.64	106.05	125.77	178.17
180	289.31	272.34	164.21	109.76	129.79	174.32
181	353.45	337.61	175.02	117.74	145.09	194.81
182	295.01	270.27	127.51	95.78	119.76	134.42
183	277.71	320.52	168.29	83.06	128.36	145.01
184	259.39	314.39	162.52	132.13	150.22	237.77
185	297.33	267.94	161.12	130.32	140.16	180.88
186	248.36	266.56	118.32	101.06	119.81	159.47
187	298.29	369.07	170.55	143.13	144.70	191.24
188	173.60	317.14	159.87	108.63	139.16	181.70
189	266.32	286.05	152.52	118.21	128.11	205.68
190	254.28	232.44	102.30	80.97	110.03	125.09
191	285.52	315.20	180.40	106.31	143.50	174.45
192	303.47	403.68	171.42	128.97	134.84	207.83
193	326.84	227.73	110.56	82.48	111.50	72.08
194	191.18	271.80	136.68	105.50	134.67	168.86
195	293.19	311.66	149.14	98.51	131.22	201.16
196	253.06	300.88	136.48	124.85	124.54	138.67
197	274.91	292.00	145.17	99.50	127.82	153.99
198	320.12	314.20	151.17	114.21	133.93	172.79

199	262.63	252.95	146.75	72.85	126.84	120.99
200	269.60	293.40	152.60	108.20	131.89	164.17
201	246.94	235.64	113.14	87.06	111.15	62.33
202	315.49	248.77	135.84	87.92	126.20	165.77
203	223.69	255.46	115.63	79.09	110.07	122.16
204	174.08	210.03	102.57	70.10	100.33	101.58
205	273.95	353.08	198.40	121.59	156.60	216.79
206	254.57	270.22	136.94	95.37	120.20	135.75
207	233.95	273.29	124.16	97.88	125.49	197.63
208	232.68	232.10	132.08	98.42	128.24	133.56
209	273.05	300.16	143.85	101.72	123.03	172.20
210	271.81	298.90	134.08	107.35	122.63	163.07
211	267.96	228.23	125.80	115.50	122.71	162.51
212	333.93	358.78	166.59	140.37	161.95	193.06
213	318.07	297.13	157.74	130.63	150.66	180.22
214	264.60	280.95	141.48	99.78	124.06	189.82
215	241.65	227.86	120.59	123.39	124.03	164.59
216	257.36	230.85	106.91	75.94	104.01	167.52
217	276.06	283.59	136.19	109.87	137.05	190.63
218	253.54	275.85	126.96	181.42	137.97	201.55
219	236.93	322.23	161.27	137.30	142.22	206.55
220	296.44	248.31	135.46	86.77	124.83	171.50
221	339.04	387.20	317.16	103.65	153.70	232.23
222	289.65	286.91	156.96	88.59	127.85	182.79
223	329.57	294.28	179.78	125.19	141.31	189.07
224	294.01	268.98	160.64	102.23	138.31	164.98
225	340.94	380.12	183.95	128.19	141.98	213.41
226	262.11	234.11	106.56	91.21	105.85	118.07
227	286.21	347.17	223.25	114.70	165.37	227.16
228	240.27	276.57	150.55	85.63	117.69	198.13
229	244.86	247.74	132.78	89.64	123.36	140.50
230	236.22	225.82	111.76	92.93	119.65	124.85
231	276.62	205.12	103.24	135.27	130.07	161.54
232	245.13	303.84	133.21	87.61	117.37	176.22
233	195.52	229.30	129.57	83.51	122.32	150.95
234	331.76	327.60	207.72	108.09	148.92	128.54
235	299.40	292.35	164.78	89.90	129.48	156.15
236	262.97	264.77	154.53	94.41	131.43	172.00
237	287.24	298.13	153.26	102.89	119.05	168.08
238	213.17	245.39	109.63	63.88	113.47	133.02
239	329.39	288.42	166.79	113.61	148.25	170.04
240	227.52	237.73	139.54	92.15	121.81	184.63
241	220.91	274.60	137.56	109.70	141.20	141.18
242	301.56	241.47	155.47	94.74	131.09	185.19
243	288.78	227.25	116.69	84.23	120.96	140.36
244	287.66	263.93	143.68	118.01	146.47	187.44

245	377.39	344.56	187.03	132.54	142.98	210.09
246	290.36	339.22	165.05	81.32	126.05	166.67
247	267.09	287.31	145.84	129.50	138.71	182.03
248	264.08	267.71	142.18	124.08	145.15	196.69
249	283.09	301.20	138.07	129.82	132.62	171.55
250	206.48	278.18	144.26	88.90	130.19	135.61
251	312.56	302.74	183.36	112.31	145.71	190.85
252	270.80	300.54	191.97	137.01	161.06	248.33
253	247.63	245.06	127.86	72.79	109.15	85.01
254	266.58	285.96	133.34	88.81	117.04	128.18
255	229.69	278.77	140.69	98.31	133.36	169.13
256	235.18	264.02	127.30	102.03	135.70	154.15
257	278.71	361.80	158.10	127.76	134.77	175.29
258	284.71	311.30	159.99	121.01	143.95	222.54
259	190.18	191.05	90.79	67.87	99.06	111.86
260	274.32	243.96	124.96	76.71	108.04	131.91
261	169.62	188.16	99.23	53.92	115.22	143.94
262	294.37	253.99	131.07	117.49	106.42	145.23
263	358.33	265.14	149.29	78.78	121.24	160.00
264	245.61	248.59	143.42	77.99	118.60	117.58
265	221.26	293.77	159.36	130.21	151.64	201.74
266	228.27	251.85	131.23	78.41	116.47	134.53
267	256.15	239.65	134.22	84.61	140.81	149.82
268	126.68	237.19	112.74	111.69	125.91	162.70
269	318.42	294.65	163.03	93.54	125.30	170.95
270	238.16	252.44	130.92	113.76	136.02	153.18
271	361.86	318.42	188.25	108.58	131.16	193.22
272	317.72	288.86	172.32	100.27	132.59	212.33
273	316.88	280.71	161.79	120.70	136.40	193.60
274	365.69	325.14	211.26	89.19	134.38	126.05
275	185.51	211.53	76.60	100.38	110.47	125.48
276	310.27	316.37	157.49	110.00	139.28	174.84
277	282.70	312.89	167.57	132.96	154.11	198.78
278	250.33	260.46	147.92	100.19	140.42	209.62
279	338.18	296.02	142.82	121.17	123.70	161.16
280	259.84	330.94	161.52	119.64	135.43	193.48
281	252.87	242.99	122.52	84.33	112.91	132.15
282	295.13	341.92	181.36	85.18	131.25	150.36
283	292.67	313.85	170.32	87.42	134.59	182.33
284	312.16	334.98	179.42	94.13	133.27	192.64
285	291.80	312.10	182.49	123.50	143.75	214.08
286	249.81	356.16	194.75	138.37	151.99	203.73
287	212.21	337.26	152.85	119.97	145.95	195.31
288	324.13	394.20	254.95	116.56	150.12	225.55
289	163.31	240.86	125.05	88.06	116.56	165.21
290	235.98	297.79	180.85	114.90	147.20	208.34

291	246.62	303.46	157.17	118.73	145.96	169.57
292	366.83	314.74	146.68	110.85	118.74	112.55
293	304.84	321.90	133.88	161.12	144.80	202.47
294	263.13	278.92	142.28	112.10	124.14	109.07
295	306.21	355.01	201.92	104.63	144.16	190.61
296	196.08	234.32	105.17	85.55	111.91	124.21
297	277.51	261.71	135.31	126.69	137.54	171.08
298	307.52	290.67	157.38	133.03	133.64	159.60
299	328.07	310.41	148.23	111.93	127.07	162.84
300	264.95	291.83	130.07	118.45	136.59	180.70
301	313.59	285.59	155.27	110.76	134.35	153.83
302	332.20	283.44	142.44	102.38	127.95	139.92
303	301.39	271.24	143.11	88.28	122.80	139.56
304	188.39	281.71	122.99	118.54	131.98	188.86
305	317.41	267.21	148.34	98.28	138.36	158.30
306	201.98	290.38	136.80	81.40	118.41	155.89
307	350.60	287.60	156.49	89.03	137.02	185.55
308	283.71	291.53	159.58	107.20	147.93	206.13
309	431.41	298.54	156.29	92.19	126.43	155.68
310	237.94	331.56	141.43	113.89	129.52	159.74
311	345.02	329.87	152.01	134.13	142.56	187.80
312	239.05	262.38	124.46	63.14	104.66	87.73
313	246.29	271.53	126.74	99.99	130.32	150.70
314	255.38	250.72	135.19	114.33	130.48	184.18
315	373.89	306.36	170.13	100.58	150.57	197.36
316	250.80	247.23	156.22	96.02	135.95	182.27
317	357.80	269.45	122.23	131.68	130.97	136.24
318	206.67	269.59	96.28	98.14	113.31	129.49
319	215.36	267.29	127.35	100.47	136.31	163.76
320	222.49	249.58	124.54	100.79	119.08	133.88
321	282.51	218.62	122.81	67.31	118.07	120.53
322	337.18	304.67	185.64	92.33	139.10	160.65
323	219.91	273.53	114.42	112.02	107.58	183.93
324	178.28	242.83	107.75	71.48	108.52	105.80
325	287.90	306.89	146.42	103.48	122.90	155.21
326	405.38	283.08	206.71	134.74	154.69	211.04
327	307.38	261.20	136.34	97.37	115.43	149.75
328	201.91	270.66	138.48	87.19	133.04	151.91
329	199.38	280.50	141.73	129.64	136.96	200.56
330	349.59	299.46	177.63	113.13	146.59	204.29
331	284.51	399.33	234.97	88.22	158.03	155.13
332	289.22	240.52	139.94	65.84	118.94	156.27
333	330.97	360.17	190.10	106.58	140.05	183.77
334	242.94	340.50	130.35	119.72	118.01	144.85
335	259.11	284.88	142.92	114.63	126.96	173.02
336	332.85	289.93	134.98	122.82	129.05	157.52

337	213.60	243.30	137.28	77.62	126.65	137.51
338	176.87	209.23	82.56	90.05	109.65	104.92
339	343.64	274.79	168.57	86.87	123.58	157.10
340	272.80	256.41	126.65	120.20	122.05	183.24
341	242.03	252.47	129.83	103.46	132.14	187.01
342	327.60	291.13	167.34	149.40	157.15	184.61
343	258.96	239.20	130.77	74.24	110.27	175.85
344	270.14	221.09	113.76	101.18	110.65	127.64
345	182.23	247.43	93.05	117.20	124.30	176.15
346	391.03	370.63	139.11	156.88	135.00	179.29
347	257.90	320.35	155.80	137.76	142.63	221.88
348	313.37	335.56	165.34	81.55	135.61	147.37
349	266.05	248.10	137.17	114.12	130.15	162.23
350	325.83	226.80	128.23	68.15	107.24	145.99
351	273.74	262.45	132.30	144.77	140.34	186.06
352	269.32	278.08	134.32	100.69	129.31	151.51
353	231.36	253.44	123.74	108.35	122.25	148.29
354	314.20	282.10	151.60	120.10	141.13	160.94
355	347.12	293.01	189.33	119.01	149.74	161.75
356	228.03	224.81	108.17	77.05	120.04	123.41
357	216.15	219.73	105.72	84.01	117.13	116.41
358	305.76	281.99	157.02	122.37	132.73	179.75
359	326.32	299.11	164.36	139.22	136.14	142.17
360	242.55	251.53	115.87	76.35	111.97	103.63
361	194.77	289.64	115.22	127.48	136.32	200.02
362	241.48	268.49	136.36	113.49	132.43	178.43
363	251.18	352.23	145.55	116.36	124.93	161.35
364	208.82	235.27	119.93	111.43	128.28	145.49
365	252.11	256.03	123.20	93.29	117.87	198.49
366	408.46	429.04	259.36	110.13	155.29	194.46
367	275.31	329.21	140.23	83.24	132.26	153.65
368	220.07	293.94	135.98	120.47	119.93	127.24
369	354.42	279.46	173.37	80.30	142.78	165.90
370	327.10	377.94	213.71	126.25	166.67	223.92
371	306.56	307.38	150.08	102.48	131.60	139.33
372	300.16	260.64	139.37	117.47	133.74	175.64
373	291.35	323.83	169.76	115.64	126.25	170.23
374	229.44	267.45	144.88	61.70	114.18	143.45
375	368.60	365.19	166.07	148.30	157.54	220.13
376	235.71	268.72	137.36	102.54	122.52	167.83
377	217.46	222.45	124.79	86.46	123.16	166.60
378	263.70	223.33	129.47	72.32	120.75	127.79
379	226.87	230.07	118.59	106.17	119.51	146.74
380	228.60	263.42	111.57	97.32	114.73	173.25
381	261.79	301.99	154.05	107.83	138.51	148.86
382	314.79	290.12	144.65	123.04	133.82	146.03

383	222.02	275.73	127.69	93.89	121.35	158.94
384	294.62	274.17	166.54	103.97	138.48	177.09
385	269.22	302.56	131.91	125.88	121.45	176.86
386	307.06	384.04	180.96	142.53	170.98	215.67
387	256.54	244.51	133.57	90.47	113.03	122.68
388	340.29	303.99	177.36	90.43	139.37	175.16
389	156.57	265.36	100.52	73.58	101.38	97.99
390	244.32	271.68	149.55	110.50	144.03	184.44
391	334.77	238.29	138.60	99.57	132.07	128.87
392	205.49	273.35	138.86	69.65	111.70	129.41
393	282.25	235.84	129.64	79.50	114.31	142.45
394	303.01	309.18	195.85	122.74	150.97	185.70
395	226.55	279.62	144.03	127.00	130.71	206.37
396	363.13	276.59	161.57	70.32	122.01	139.03
397	305.39	231.33	131.33	80.78	119.47	95.07
398	293.55	305.74	158.37	87.32	131.76	144.24
399	284.32	276.15	163.82	77.89	129.67	177.60
400	296.20	294.98	155.76	94.93	134.01	176.82
401	186.74	286.23	119.12	136.16	134.59	191.80
402	298.73	261.01	145.14	64.31	115.58	79.02
403	275.57	250.57	151.36	143.05	141.57	212.48
404	232.13	250.04	117.52	104.18	120.31	153.35
405	357.07	291.31	147.68	158.72	142.46	195.03
406	259.91	286.70	156.81	106.53	130.58	199.70
407	292.14	281.19	134.60	124.71	130.78	180.12
408	279.77	319.17	174.32	103.04	133.50	150.06
409	224.87	255.96	138.31	82.85	117.62	98.45
410	235.59	248.93	129.13	123.13	131.83	162.11
411	243.11	297.81	152.34	95.76	124.43	152.74
412	263.38	257.52	155.19	81.89	133.16	178.32
413	386.12	347.88	225.82	128.42	149.43	191.68
414	204.14	263.22	118.11	93.99	123.52	160.32
415	312.94	255.12	144.97	92.96	134.18	166.08
416	354.62	319.43	171.55	116.89	164.89	191.16
417	443.88	318.69	171.94	97.63	137.31	169.76
418	320.98	313.51	148.06	87.71	123.30	160.42
419	240.58	291.00	144.32	85.22	124.72	175.94
420	224.12	272.39	146.90	155.93	159.91	228.82
421	230.44	270.59	123.36	109.38	112.71	143.68
422	275.90	297.53	163.38	107.87	146.22	204.76
423	336.33	241.97	139.63	98.71	122.47	155.41
424	227.10	268.73	127.15	89.38	114.84	158.52
425	320.02	258.47	141.11	76.99	101.69	106.74
426	381.70	306.15	187.71	120.32	137.62	202.13
427	274.43	238.05	110.16	116.21	121.03	184.05
428	371.01	296.30	149.41	136.59	135.26	186.78

429	239.91	334.02	178.41	128.04	145.38	194.01
430	230.02	276.88	132.88	91.00	103.85	116.82
431	258.75	281.56	158.55	83.33	125.24	161.94
432	268.26	282.47	138.66	153.42	136.70	188.35
433	364.00	326.65	213.89	146.68	163.26	230.01
434	311.03	327.25	167.80	152.34	147.70	215.17
435	374.92	349.14	199.32	124.50	158.57	204.99
436	237.64	228.94	128.07	118.13	124.35	108.43
437	260.85	264.23	128.81	108.50	120.66	138.26
438	234.58	281.32	134.40	125.31	126.01	205.34
439	320.55	280.17	144.54	109.22	136.88	155.52
440	248.89	293.21	149.01	122.00	129.14	207.05
441	212.58	231.76	120.72	74.89	102.74	102.74
442	314.39	324.46	160.47	117.04	147.04	182.77
443	349.13	321.64	191.57	101.32	145.57	207.77
444	208.06	253.79	120.24	108.75	129.61	168.49
445	199.48	260.24	117.93	84.62	112.32	123.25
446	321.79	298.39	154.91	112.86	128.73	167.41
447	254.20	212.70	133.71	94.19	117.23	174.10
448	193.97	272.87	117.35	110.36	123.85	151.61
449	274.68	279.16	183.89	112.97	147.46	218.54
450	183.77	219.10	130.55	83.60	126.49	168.29
451	324.39	336.54	160.80	162.35	167.92	197.80
452	378.45	261.27	167.96	107.49	155.43	203.04
453	345.34	299.99	165.60	127.12	144.40	157.75
454	280.52	287.08	140.61	84.12	126.55	178.71
455	394.39	315.89	164.50	100.94	135.87	158.11
456	295.80	288.03	139.10	110.25	137.83	130.00
457	261.28	261.50	116.92	105.12	119.90	149.53
458	251.28	258.66	147.45	128.79	143.25	144.55
459	283.85	201.12	131.66	74.50	116.31	177.99
460	230.65	259.28	123.52	118.83	133.40	148.64
461	260.20	301.59	136.05	135.80	134.13	179.62
462	225.98	236.58	119.31	85.82	113.17	143.30
463	309.42	295.50	184.57	108.87	140.90	187.17
464	300.69	244.25	154.22	91.73	124.22	170.27
465	261.53	246.50	125.73	95.88	113.99	173.69
466	371.87	271.12	154.13	105.24	142.90	160.87
467	272.59	221.46	105.87	96.26	120.55	136.94
468	218.98	264.43	145.46	100.14	127.70	187.29
469	264.23	222.62	141.20	71.30	119.36	163.28
470	384.13	283.25	197.12	107.65	143.38	186.41
471	280.10	226.27	114.63	91.13	125.85	148.37
472	335.43	284.35	150.13	101.46	138.24	177.39
473	319.53	323.07	169.06	111.17	132.78	147.84
474	257.66	310.23	162.36	109.15	137.71	207.41

475	345.83	262.70	147.10	93.67	121.54	136.58
476	364.82	309.80	152.24	105.29	127.59	142.68
477	241.25	225.27	133.10	81.76	115.04	169.45
478	286.66	249.21	138.88	121.39	135.79	192.91
479	388.36	307.28	173.00	125.83	154.51	149.05
480	268.48	252.74	153.14	90.31	137.46	154.55
481	315.39	315.54	153.67	103.82	125.17	158.80
482	211.42	216.18	108.88	73.37	116.02	107.93
483	193.28	235.00	128.05	96.35	121.28	154.72
484	369.17	330.84	178.07	110.59	145.51	169.29
485	281.33	265.71	144.11	89.58	125.05	179.13
486	342.43	268.35	170.91	141.80	153.36	220.91
487	321.90	350.43	184.99	107.06	146.28	200.96
488	285.35	254.30	125.18	75.14	110.94	90.33
489	209.27	266.42	118.94	110.93	127.13	134.20
490	238.70	240.26	108.71	104.23	109.59	158.48
491	292.43	285.10	174.71	116.43	125.59	211.30
492	244.09	296.69	147.46	125.55	148.03	210.66
493	203.58	241.12	116.26	94.49	115.83	166.38
494	245.77	260.11	122.00	109.43	132.18	171.95
495	255.96	277.89	139.93	116.76	126.74	183.58
496	228.96	254.51	116.53	102.85	116.83	146.33
497	303.84	305.29	178.89	112.58	148.68	174.53
498	215.78	241.79	128.55	98.81	125.41	188.02
499	310.46	256.80	146.24	84.96	116.15	168.01
500	210.24	233.69	137.97	72.02	120.40	130.95;

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Scalars
     psi          "risk aversion parameter"                        /0/
     w            "wage rate/hour "                                /0.7/
     totfl        "available family labour(hours}"                 /1656.05/
     tothl         "total hired labour(hours)"                     /2090.38/
     probi        "probability of occurrence for i"                /0.002/
     land         "household land base(acres)"                     /12.7/
     otfexp       "other farm expenses(GHC)"                       /207.698/
     otnfexp      "other non-farm expenses(GHC)"                   /220.188/
     otfinc       "other farm income(GHC)"                         /631.821/
     otnfinc      "other non-farm income(GHC)"                     /597.56/
     maobland     "Observed acres allocated to maize"              /2.513/
     grobland     "Observed acres allocated to groundnut"          /2.814/
     miobland     "Observed acres allocated to millet"             /1.985/
     coobland     "Observed acres allocated to cowpea"             /2.839/
     soobland     "Observed acres allocated to sorghum"            /1.201/
     riobland     "Observed acres allocated to rice"               /0.603/

Variables
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        z1                 "negative exponential objective function"
        sumlanddev         "sum deviation of predicted acres from observed for all crops";

Positive variables
        acre(d)            "acres of production for crop d"
        prout(i,d)         "predicted output (kg)"
        sell(i,d)          "d sold(kg) in i"
        pur(i,d)           "d purchased(kg) in i"
        con(i,d)           "d consumed(kg) in i"
        ps(d)              "selling price(GHC/kg) of d"
        val(d)             "consumption value(GHC/kg) for d"
        hl(d)              "hired labour(hours)allocated to d"
        fl(d)              "family labour(hours) allocated to d"
        tl(d)              "total  labour(hours)for d"

Equations
       OBJ1                "expected utility function (negative exponential)"
        OUTCON             "output constraint"
       LANDCON             "land constraint"
        LABCON             "labour constraint"
        LABCON2            "labour constraint"
        LABCON3            "labour constraint"
        LABCON4            "labour constraint"
        USECON             "use constraint"
        INCEXPCON          "income-expenditure constraint"
        SELLPRICE          "Selling-purchasing prices conversion"
        CONSUMVAL "Consumption value-purchase price conversion";

OBJ1             ..    z1=e=sum(i,probi*(1-exp(-psi*(sum(d,val(d)*con(i,d))))));

OUTCON(i,d)     ..     prout(i,d)=e=yld(i,d)*acre(d);

LANDCON(i)      ..     sum(d,acre(d))=e=11.955;

LABCON(i,d)     ..     lahrs(d)*acre(d)=l=fl(d)+hl(d);

LABCON2(i)      ..     sum(d,fl(d))=l=totfl;

LABCON4(i)      ..     sum(d,hl(d))=l=tothl;

LABCON3(i,d)    ..     tl(d)=e=fl(d)+hl(d);

USECON(i,d)     ..     con(i,d)=e=yld(i,d)*acre(d)+pur(i,d)-sell(i,d)-otuse(d);

INCEXPCON(i)    ..     sum(d,(vc(d)*acre(d)))+sum(d,(hl(d)*w))+
                       sum(d,(pp(d)*pur(i,d)))+OTFEXP+OTNFEXP=l=
```

```
                    sum(d,(ps(d)*sell(i,d)))+OTFINC+OTNFINC;

SELLPRICE(d)   ..   ps(d)=e=gamma(d)*pp(d);

CONSUMVAL(d)  ..   val(d)=e=phi(d)*pp(d);

Model   calibration /all/;

Option   decimals=3;

Option   nlp=GAMSCHK;

calibration.bratio=1.0;

calibration.workspace=330;

calibration.solvelink=%solvelink.CallModule%;

sets
      risk          Risk aversion scenarios                 /R1*R4/
      mascens       Maize consumption value scenarios       /ma1*ma3/
      grscens       Groundnut consumption value scenarios   /gr1*gr3/
      miscens       Millet consumption value scenarios      /mi1*mi3/
      coscens       Cowpea consumption value scenarios      /co1*co3/
      soscens       Sorghum consumption value scenarios     /so1*so3/
      risns         Rice consumption value scenarios        /ri1*ri3/

Parameters    output(*,*,*,*,*,*,*,*,*) Comparative summary

loop(risk,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
          psi=psi+0.004;
                phi("maize")=0;

loop(mascens,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
          phi("maize")=phi("maize")+0.25;
                phi("groundnut")=0.25;

      loop(grscens,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
          phi("groundnut")=phi("groundnut")+0.25;
                phi("millet")=0.25;
```

```
        loop(miscens,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
              phi("millet")=phi("millet")+0.25;
                    phi("cowpea")=0.25;

        loop(coscens,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
              phi("cowpea")=phi("cowpea")+0.25;
               phi("sorghum")=0.25;

        loop(soscens,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
               phi("sorghum")=phi("sorghum")+0.25;
                    phi("rice")=0.25;

        loop(riscens,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
               phi("rice")=phi("rice")+0.25;

Option   nlp=minos;
Solve calibration using nlp maximizing z1;

sumlanddev.l=sqr(acre.l("maize")-maobland)+sqr(acre.l("groundnut")-grobland)+
sqr(acre.l("millet")-miobland)+sqr(acre.l("cowpea")-coobland)+sqr(acre.l("sorghum")-
soobland)+sqr(acre.l("rice")-riobland);

output("Acres
Allocateed",d,risk,mascens,grscens,miscens,coscens,soscens,riscens)=acre.l(d);
output("sum of  squared acres deviation","",risk,mascens,grscens,miscens,coscens,soscens,
riscens)=sumlanddev.l
);
);
);
);
);
);
);
$libinclude xldump output calibration.xlsx sheet1!

Option output: 3:7:1;
Display output;
```

Appendix C2: Base Model

```
$Title                    BASE MODEL

$inlinecom /* */
$offlisting
$offsymxref offsymlist

Option
   limrow = 10000000,         /*equations listed per block*/
   limcol = 0,                /*variables listed per block" */
   solprint = on,             /* "solver's solution output printed*/
   sysout = off;              /*solver's system output printed*/

Sets
   i state of nature    /1*500/
   d crops          /maize, groundnut, millet, cowpea, sorghum, rice /

Parameters
      lahrs(d)      "labour requirement(hours/acre) for d"
                                   /Maize              248.59
                                    Groundnut          399.50
                                    Millet             238.20
                                    Cowpea             208.20
                                    Sorghum            239.28
                                    Rice               326.24/

      vc(d)        "variable cost{GHC/acre) for d"
                                   /Maize              38.27
                                    Groundnut          114.56
                                    Millet             30.85
                                    Cowpea             43.68
                                    Sorghum            39.60
                                    Rice               50.34/

      otuse(d)      "d for other uses(kg)"
                                   /Maize              46.71
                                    Groundnut          126.58
                                    Millet             39.19
                                    Cowpea             17.11
                                    Sorghum            43.37
                                    Rice               36.16/

      pp(d)       "purchase price(GHC/kg) of d"
                                   /Maize              0.53
```

```
                    Groundnut          1.67
                    Millet             0.75
                    Cowpea             1.11
                    Sorghum            0.76
                    Rice               1.26/

phi(d)      "value of consumption-purchase price scaling factor"
                   /Maize              0.5
                    Groundnut          0.5
                    Millet             0.5
                    Cowpea             0.5
                    Sorghum            0.5
                    Rice               0.5/

gamma(d)    "sale-purchase price scaling factor"
                   /Maize              0.8
                    Groundnut          0.8
                    Millet             0.8
                    Cowpea             0.8
                    Sorghum            0.8
                    Rice               0.8/;

*INSERT “Table    yld(i,d)      "yield(kg/acre) for d in i"” in APPENDIX C1 HERE!!!

Scalars
     psi           "risk aversion parameter"                        /0/
     w             "wage rate/hour "                                /0.7/
     totfl         "available family labour(hours}"                 /1656.05/
     tothl          "total hired labour(hours)"                     /2090.38/
     probi         "probability of occurrence for i"                /0.002/
     land          "household land base(acres)"                     /12.7/
     otfexp        "other farm expenses(GHC)"                       /207.698/
     otnfexp       "other non-farm expenses(GHC)"                   /220.188/
     otfinc        "other farm income(GHC)"                         /631.821/
     otnfinc       "other non-farm income(GHC)"                     /597.56/
     maobland      "Observed acres allocated to maize"              /2.513/
     grobland      "Observed acres allocated to groundnut"          /2.814/
     miobland      "Observed acres allocated to millet"             /1.985/
     coobland      "Observed acres allocated to cowpea"             /2.839/
     soobland      "Observed acres allocated to sorghum"            /1.201/
     riobland      "Observed acres allocated to rice"               /0.603/

Variables
      z1           "negative exponential objective function"
      sumlanddev   "sum deviation of predicted acres from observed for all crops";
```

```
Positive variables
        acre(d)         "acres of production for crop d"
        prout(i,d)      "predicted output (kg)"
        sell(i,d)       "d sold(kg) in i"
        pur(i,d)        "d purchased(kg) in i"
        con(i,d)        "d consumed(kg) in i"
        ps(d)           "selling price(GHC/kg) of d"
        val(d)          "consumption value(GHC/kg) for d"
        hl(d)           "hired labour(hours)allocated to d"
        fl(d)           "family labour(hours) allocated to d"
        tl(d)           "total  labour(hours)for d"
        expvalcon       "expected value of consumption";

Equations
       OBJ1             "expected utility function (negative exponential)"
        OUTCON          "output constraint"
       LANDCON          "land constraint"
        LABCON          "labour constraint"
        LABCON2         "labour constraint"
        LABCON3         "labour constraint"
        LABCON4         "labour constraint"
        USECON          "use constraint"
        INCEXPCON       "income-expenditure constraint"
        SELLPRICE       "Selling-purchasing prices conversion"
        CONSUMVAL       "Consumption value-purchase price conversion";


OBJ1            ..      z1=e=sum(i,probi*(1-exp(-psi*(sum(d,val(d)*con(i,d))))));

OUTCON(i,d)     ..       prout(i,d)=e=yld(i,d)*acre(d);

LANDCON(i)      ..       sum(d,acre(d))=e=11.955;

LABCON(i,d)     ..       lahrs(d)*acre(d)=l=fl(d)+hl(d);

LABCON2(i)      ..       sum(d,fl(d))=l=totfl;

LABCON4(i)      ..       sum(d,hl(d))=l=tothl;

LABCON3(i,d)    ..       tl(d)=e=fl(d)+hl(d);

USECON(i,d)     ..       con(i,d)=e=yld(i,d)*acre(d)+pur(i,d)-sell(i,d)-otuse(d);

INCEXPCON(i)    ..       sum(d,(vc(d)*acre(d)))+sum(d,(hl(d)*w))+
                        sum(d,(pp(d)*pur(i,d)))+OTFEXP+OTNFEXP=l=
```

```
                    sum(d,(ps(d)*sell(i,d)))+OTFINC+OTNFINC;

SELLPRICE(d)    ..     ps(d)=e=gamma(d)*pp(d);

CONSUMVAL(d)  ..    val(d)=e=phi(d)*pp(d);

Model    diversification /all/;

Option   decimals=3;

Option   nlp=GAMSCHK;

diversification.bratio=1.0;

Set scenarios /R1*R4/

Parameters
        Output (*,*,*) Comparative summary
        Riskaver(scenarios) Risk aversion scenarios    /R1 0.008
                                                        R2 0.012
                                                        R3 0.016
                                                        R4 0.020/;

loop(scenarios,
option clear=z1,clear=acre,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=val;
        psi=riskaver(scenarios);

Option   nlp=minos;
Solve diversification using nlp maximizing z1;

expvalcon.l=sum((i,d),con.l(i,d)*val.l(d))*0.002;

output('Risk Parameter','',scenarios)=PSI;
output('Acreage Allocation',d,scenarios)=acre.l(d);
output('Objective Value','',scenarios)=Z1.l;
output('Expected Value of Consumption','',scenarios)=expvalcon.l;
);

Display output;
```

Appendix C3: Insurance Model

```
$Title                  INSURANCE MODEL

$inlinecom /* */
$offlisting
$offsymxref offsymlist

Option
   limrow = 10000000,         /*equations listed per block*/
   limcol = 0,                /*variables listed per block" */
   solprint = on,             /* "solver's solution output printed*/
   sysout = off;              /*solver's system output printed*/

Sets
   i state of nature    /1*500/
   d crops              /maize, groundnut, millet, cowpea, sorghum, rice /

Parameters
      lahrs(d)          "labour requirement(hours/acre) for d"
                                  /Maize           248.59
                                   Groundnut       399.50
                                   Millet          238.20
                                   Cowpea          208.20
                                   Sorghum         239.28
                                   Rice            326.24/

      vc(d)             "variable cost{GHC/acre) for d"
                                  /Maize           38.27
                                   Groundnut       114.56
                                   Millet          30.85
                                   Cowpea          43.68
                                   Sorghum         39.60
                                   Rice            50.34/

      otuse(d)          "d for other uses(kg)"
                                  /Maize           46.71
                                   Groundnut       126.58
                                   Millet          39.19
                                   Cowpea          17.11
                                   Sorghum         43.37
                                   Rice            36.16/

      pp(d)                   "purchase price(GHC/kg) of d"
                                  /Maize           0.53
                                   Groundnut       1.67
```

Millet 0.75
Cowpea 1.11
Sorghum 0.76
Rice 1.26/

phi(d) "value of consumption-purchase price scaling factor"
/Maize 0.5
Groundnut 0.5
Millet 0.5
Cowpea 0.5
Sorghum 0.5
Rice 0.5/

gamma(d) "sale-purchase price scaling factor"
/Maize 0.8
Groundnut 0.8
Millet 0.8
Cowpea 0.8
Sorghum 0.8
Rice 0.8/

EL(d) "Expected loss(Kg)"

avgyld(d) "Average Area Yiels"

yc(d) "Critical Yield"

yldif(i,d) "Difference between Observed Area and Critical yields";

*INSERT "Table yld(i,d) "yield(kg/acre) for d in i"" in APPENDIX C1 HERE!!!

Table obsareayld(i,d) Observed area yields

	Maize	Groundnut	Millet	Cowpea	Sorghum	Rice
1	550.11	595.24	396.53	588.79	360.44	512.44
2	611.40	551.88	407.86	553.91	382.86	624.24
3	393.69	526.89	336.69	366.92	344.67	399.84
4	472.38	533.26	371.52	479.25	359.17	529.94
5	465.37	509.45	317.69	364.00	307.57	418.45
6	425.01	764.07	397.49	516.14	343.61	482.58
7	448.07	628.19	317.07	633.27	368.62	482.17
8	434.85	603.74	332.06	483.87	350.57	334.01
9	519.16	477.03	246.74	475.18	289.59	220.34
10	580.50	842.38	439.88	508.21	356.04	410.29
11	601.94	594.76	414.67	460.07	366.47	536.90
12	540.27	582.41	299.89	522.67	342.91	370.06
13	546.67	491.98	310.86	348.47	290.30	377.55

14	613.09	638.09	359.26	628.32	384.45	541.58
15	294.47	406.66	279.66	360.96	316.17	357.00
16	527.40	626.39	393.31	380.71	337.28	446.80
17	426.20	389.24	304.88	556.36	350.02	521.70
18	448.31	479.38	330.57	436.29	329.70	412.46
19	309.88	556.75	293.70	583.70	336.81	430.24
20	536.67	691.23	392.35	498.17	368.46	549.58
21	456.51	503.40	404.56	464.68	346.93	575.35
22	422.84	487.38	276.43	449.39	280.56	279.13
23	318.01	420.47	288.88	496.32	355.16	492.49
24	547.19	513.88	326.87	448.07	308.17	487.43
25	465.96	536.49	336.49	423.34	302.99	367.97
26	494.13	558.79	315.02	524.55	342.49	417.85
27	381.22	495.23	306.27	459.05	315.23	350.27
28	392.87	510.24	321.87	504.02	353.19	596.65
29	395.55	493.68	289.69	532.32	366.91	589.03
30	359.72	589.80	299.18	671.07	363.98	489.95
31	473.95	602.88	394.71	472.43	365.04	554.06
32	402.12	497.79	303.93	346.04	315.00	304.58
33	504.54	634.57	402.72	456.55	352.98	497.36
34	307.88	453.12	240.55	354.86	312.73	458.29
35	524.77	637.03	389.48	714.18	379.75	511.58
36	589.26	517.27	305.90	500.89	339.76	475.23
37	432.61	569.11	323.23	477.80	314.08	399.15
38	533.20	641.81	425.52	742.99	438.89	524.62
39	387.79	481.28	331.21	466.61	335.31	508.09
40	301.44	504.46	257.20	565.82	322.11	521.20
41	374.87	543.54	278.53	493.04	312.31	436.68
42	561.09	562.36	365.50	394.23	308.89	469.57
43	504.08	502.79	348.01	378.50	315.48	418.83
44	379.38	518.43	309.72	392.59	288.82	329.43
45	411.20	437.10	270.12	377.04	298.59	454.99
46	391.68	514.07	335.19	344.52	312.87	447.96
47	531.04	468.44	319.95	491.28	381.04	471.59
48	518.57	478.60	317.80	410.13	325.75	348.92
49	432.07	378.73	245.75	363.38	314.41	365.48
50	472.44	507.19	361.41	564.50	345.82	557.85
51	298.01	369.08	230.72	361.55	282.45	423.78
52	479.30	552.44	402.28	787.76	451.49	615.32
53	475.30	441.45	297.38	526.16	323.22	342.44
54	606.65	494.34	377.51	484.99	350.70	500.11
55	725.14	577.95	424.51	555.52	401.65	590.64
56	328.24	442.26	257.60	404.24	295.42	411.52
57	392.45	477.76	263.04	468.18	330.75	435.29
58	573.73	467.12	363.02	316.26	298.72	370.69
59	279.19	475.34	341.55	417.62	360.65	540.13

60	384.04	440.55	294.46	531.41	336.91	519.02
61	434.34	434.01	298.30	389.91	334.51	455.74
62	429.83	493.99	287.16	459.73	318.17	394.25
63	348.69	461.61	214.53	499.93	298.04	431.50
64	450.23	471.82	299.80	505.95	328.41	410.20
65	488.48	548.10	382.10	474.61	340.41	495.67
66	331.93	485.40	301.93	513.59	316.87	573.88
67	566.28	485.25	312.41	339.70	324.48	512.08
68	475.22	515.49	343.49	502.78	307.82	439.40
69	444.41	490.48	299.31	428.09	347.44	328.65
70	385.47	587.02	297.25	557.98	331.97	494.15
71	430.02	510.54	308.65	403.06	292.16	421.59
72	440.73	435.79	311.99	398.57	340.00	392.82
73	571.72	468.24	304.24	427.46	336.50	461.71
74	403.32	630.71	420.75	528.09	355.70	499.76
75	481.12	374.31	315.71	368.90	327.49	388.42
76	505.38	488.89	326.74	370.81	331.00	404.89
77	439.56	471.47	337.37	364.65	291.94	455.44
78	502.90	505.91	324.75	552.90	363.79	516.80
79	365.96	583.16	334.49	425.91	295.75	542.28
80	446.91	458.59	350.81	331.67	354.93	306.44
81	425.44	505.18	293.07	428.34	346.25	399.40
82	446.42	484.79	293.31	255.49	302.58	281.57
83	420.55	580.06	322.04	457.23	329.31	375.15
84	488.85	506.42	307.79	376.47	327.26	301.64
85	518.28	682.27	361.19	616.09	413.36	578.22
86	381.92	443.93	290.52	507.50	312.47	469.53
87	435.80	517.60	320.49	443.43	317.67	436.33
88	428.01	452.22	261.77	275.35	272.12	213.54
89	378.97	417.07	262.10	441.03	301.39	451.02
90	351.29	470.31	304.54	420.31	304.05	327.13
91	542.79	573.11	406.69	311.77	317.40	478.69
92	600.18	576.43	354.33	525.53	372.24	528.45
93	507.01	572.19	400.35	602.29	405.42	534.78
94	636.31	585.12	373.12	681.74	383.39	605.51
95	548.90	559.46	380.77	509.61	366.70	506.76
96	461.14	466.57	256.32	631.41	352.51	501.99
97	458.59	488.63	323.90	320.33	303.90	424.49
98	377.07	409.28	288.03	520.16	325.06	436.92
99	337.41	448.55	242.35	432.65	290.72	374.31
100	681.37	591.95	542.90	579.07	430.87	548.23
101	360.36	488.05	314.14	333.62	299.35	391.42
102	538.75	469.04	351.68	431.23	333.57	419.07
103	476.67	725.15	427.86	592.26	386.66	561.68
104	469.89	586.77	370.87	528.53	368.16	516.15
105	487.06	519.08	362.47	449.71	362.11	414.30

106	418.08	387.73	295.00	359.90	312.00	379.67
107	481.27	507.75	253.98	435.82	297.71	345.18
108	284.82	436.32	177.07	530.23	258.73	247.74
109	507.77	492.27	384.05	433.13	354.68	484.94
110	448.77	405.34	226.90	405.25	307.33	381.50
111	357.14	384.89	258.17	375.59	316.78	451.91
112	494.77	609.71	330.84	515.49	336.17	466.48
113	445.31	560.13	328.81	545.16	356.29	456.65
114	321.43	522.24	357.38	499.27	388.80	566.93
115	455.07	558.55	359.99	402.21	339.37	393.38
116	394.74	433.01	226.49	429.24	287.73	333.39
117	491.12	635.29	385.08	636.11	420.35	545.85
118	353.85	443.54	231.66	565.10	329.88	335.12
119	462.26	469.51	326.13	538.65	393.34	537.04
120	414.16	422.81	282.67	442.23	313.65	488.86
121	516.10	539.00	406.00	501.52	373.47	563.73
122	343.91	488.38	296.48	411.33	326.12	457.09
123	417.84	567.87	326.44	613.88	322.94	472.29
124	401.53	591.15	345.52	424.14	319.74	396.62
125	438.86	479.53	414.18	413.06	371.83	538.07
126	515.70	665.56	443.12	494.67	402.65	471.86
127	382.47	516.99	311.46	477.02	323.56	535.07
128	529.67	668.45	348.99	612.14	371.02	556.04
129	510.70	479.08	310.10	521.25	357.80	564.28
130	569.45	565.86	390.11	433.65	362.74	486.27
131	443.96	562.67	369.06	527.43	361.89	580.68
132	363.50	441.71	237.32	409.34	316.53	372.24
133	404.85	457.62	222.98	441.48	255.80	323.55
134	315.21	541.96	267.93	289.71	263.04	150.59
135	341.61	556.13	305.54	550.99	334.78	544.20
136	362.34	485.93	272.70	444.58	334.98	347.40
137	423.75	525.64	360.88	381.29	357.30	428.19
138	537.60	481.63	349.74	340.46	332.50	387.72
139	484.59	706.21	345.26	485.88	365.12	421.92
140	459.18	618.78	371.91	532.69	343.03	463.52
141	386.61	524.68	375.57	335.80	371.72	486.96
142	369.11	427.36	298.50	352.01	296.01	341.49
143	413.46	534.37	372.26	430.15	347.97	432.39
144	264.36	426.37	156.06	407.48	273.44	291.76
145	531.41	447.49	319.20	386.17	331.20	385.58
146	503.71	657.29	501.68	471.04	391.31	497.02
147	615.39	546.63	348.65	347.41	285.96	303.18
148	511.38	511.43	358.35	401.36	331.32	519.93
149	412.85	535.57	328.23	410.99	338.87	499.20
150	444.68	499.98	323.83	397.67	305.72	353.80
151	339.58	662.79	364.64	489.11	351.63	562.32

152	453.27	489.57	316.49	535.87	349.33	536.11
153	571.43	554.28	374.27	382.49	357.58	453.60
154	403.66	508.19	328.09	362.41	328.86	403.89
155	468.52	598.45	379.01	462.71	351.36	477.85
156	686.62	523.62	384.41	497.11	361.23	489.37
157	440.54	495.66	369.95	330.78	330.34	294.72
158	666.56	484.20	347.28	466.18	367.31	444.92
159	432.91	527.56	275.72	445.34	289.77	475.60
160	461.83	512.65	321.23	425.35	345.53	459.30
161	368.33	605.08	394.18	516.86	384.96	509.03
162	452.58	589.52	298.15	625.27	337.46	439.60
163	379.70	404.27	224.13	392.51	280.02	241.05
164	560.25	486.63	370.66	464.96	317.94	464.84
165	410.08	457.24	247.02	393.99	283.59	366.64
166	411.66	464.86	366.09	273.13	292.87	351.96
167	414.82	418.09	263.45	357.71	330.86	363.15
168	410.54	414.94	259.66	377.59	319.52	315.99
169	469.03	530.18	342.70	408.38	384.24	474.48
170	395.67	470.77	325.85	492.10	325.56	443.39
171	342.38	618.00	333.40	479.89	369.03	458.01
172	490.55	538.38	331.55	379.33	320.17	339.86
173	558.03	504.65	337.96	504.77	338.06	468.55
174	348.13	414.45	199.09	390.81	248.17	298.75
175	367.22	523.37	315.59	336.09	299.76	437.87
176	445.53	523.03	332.70	488.67	352.06	473.31
177	437.29	429.71	260.44	438.15	286.15	193.73
178	372.20	537.66	315.40	469.15	341.81	506.28
179	387.02	440.25	241.46	476.21	346.79	448.38
180	493.69	554.87	332.94	463.23	365.43	508.71
181	500.98	600.67	430.33	491.67	381.39	454.70
182	447.46	462.98	313.95	393.41	309.80	440.27
183	522.07	616.53	395.90	353.72	318.64	429.31
184	576.06	568.07	383.52	623.24	378.77	510.54
185	471.14	526.19	324.36	497.44	377.22	491.62
186	355.60	461.93	267.20	468.10	298.22	336.37
187	545.48	585.82	352.11	562.06	352.79	526.44
188	321.95	555.39	300.19	540.03	348.86	483.61
189	460.27	480.55	302.90	453.70	340.19	504.36
190	336.78	350.80	253.83	405.75	310.43	367.47
191	591.16	584.69	381.75	483.08	359.34	482.92
192	436.78	678.21	463.41	541.28	393.01	570.49
193	521.11	446.52	272.22	396.20	292.63	270.86
194	407.14	529.58	329.29	440.07	325.29	493.58
195	506.67	560.77	476.54	546.40	404.01	539.45
196	491.92	582.16	322.38	460.33	333.19	344.09
197	396.38	536.27	288.40	582.72	320.88	496.60

198	507.91	571.29	367.84	477.79	343.35	454.30
199	513.39	454.03	331.20	341.88	323.44	376.90
200	621.09	483.61	339.64	519.02	374.85	438.98
201	442.46	431.84	236.47	355.80	270.90	284.52
202	456.98	457.92	291.57	434.92	303.57	362.35
203	389.41	497.25	304.30	407.33	305.55	373.54
204	276.26	422.10	217.19	305.59	273.72	307.87
205	535.79	625.06	417.86	575.11	379.29	586.18
206	477.80	438.92	287.63	396.86	324.32	376.02
207	360.68	472.88	311.92	517.50	321.00	494.64
208	397.49	450.12	285.39	429.80	338.75	456.18
209	514.48	538.46	334.60	404.43	308.41	423.46
210	464.28	519.52	314.37	485.54	321.62	381.95
211	398.02	437.95	286.88	382.79	342.68	490.23
212	520.27	639.75	457.14	650.43	372.83	585.30
213	583.79	499.56	376.65	524.19	376.75	480.70
214	459.43	514.51	302.51	438.30	296.86	464.08
215	454.50	496.23	256.64	479.55	310.77	416.92
216	383.25	390.72	238.50	417.36	278.95	286.43
217	481.97	475.66	350.42	678.41	378.17	522.03
218	329.83	505.53	278.80	665.21	375.30	493.69
219	332.33	542.51	331.88	537.84	374.45	556.98
220	362.65	489.31	318.84	387.88	309.34	422.44
221	646.45	686.52	570.88	513.87	408.88	551.51
222	400.18	472.22	327.32	385.45	330.44	433.56
223	433.64	533.73	320.78	452.97	357.11	481.71
224	470.19	498.90	327.63	415.04	341.07	458.97
225	489.25	599.70	416.78	511.02	376.14	561.00
226	429.25	463.49	264.79	313.70	271.53	237.11
227	517.26	570.02	464.57	534.96	423.59	543.41
228	393.35	491.40	306.57	443.93	334.31	517.92
229	450.78	476.01	284.70	416.59	302.17	392.36
230	343.11	464.67	277.82	365.77	294.19	369.34
231	352.99	393.40	212.81	617.49	332.09	476.68
232	384.72	497.46	335.03	435.34	326.29	429.75
233	326.59	429.10	271.97	365.06	314.62	498.64
234	598.20	595.88	366.44	456.19	358.39	465.72
235	547.91	550.14	316.26	475.47	310.25	509.33
236	487.34	524.18	306.79	391.10	304.23	419.54
237	465.69	645.30	330.17	395.62	318.36	324.35
238	316.46	407.66	280.10	379.76	283.93	318.99
239	563.45	516.24	386.80	474.29	375.64	502.75
240	404.97	537.19	295.38	488.28	338.47	479.50
241	391.45	477.44	344.62	473.76	370.13	412.12
242	596.06	444.08	300.77	442.46	341.01	457.56
243	425.80	438.67	265.13	464.40	288.94	360.75

244	421.23	503.95	321.11	512.97	337.60	437.59
245	608.81	674.16	474.46	604.18	424.06	595.68
246	457.26	591.77	358.01	447.36	313.32	446.91
247	488.05	557.55	300.58	576.27	322.86	514.48
248	370.60	512.97	314.63	596.42	353.44	550.40
249	463.19	577.04	343.07	555.03	345.14	500.97
250	419.73	498.13	291.14	446.32	313.56	383.81
251	567.91	545.11	368.62	436.57	355.33	496.32
252	491.47	575.75	432.64	595.63	465.41	701.10
253	419.50	492.78	253.23	322.99	265.21	355.97
254	426.82	469.03	309.35	445.75	328.78	433.11
255	460.56	483.05	344.88	356.20	319.01	397.58
256	390.50	421.49	292.42	495.43	333.99	408.29
257	421.88	621.84	378.32	502.06	355.91	505.97
258	462.91	532.32	333.56	706.86	358.20	569.30
259	273.16	399.76	201.60	285.90	251.60	407.17
260	415.60	469.91	286.25	292.33	274.99	395.30
261	286.04	346.29	195.02	240.78	237.76	383.45
262	453.80	449.69	205.44	381.37	287.24	401.64
263	538.90	503.19	338.12	400.72	322.62	377.92
264	407.57	494.98	297.69	368.97	327.58	356.59
265	355.20	549.85	318.74	609.84	370.40	531.43
266	430.89	408.86	313.48	329.56	341.98	272.78
267	486.40	459.84	335.63	448.39	331.56	296.88
268	254.08	401.35	219.18	402.71	297.28	479.02
269	585.89	474.96	324.47	461.33	349.19	459.63
270	376.12	480.70	319.47	483.57	359.84	442.02
271	603.95	647.68	403.71	471.95	389.67	461.24
272	562.54	542.89	433.34	408.14	388.40	529.33
273	484.11	520.60	329.65	507.04	369.52	488.06
274	595.27	626.04	365.40	406.29	350.23	384.95
275	289.00	415.86	229.25	421.86	294.54	355.11
276	519.94	561.46	373.32	584.95	353.94	581.36
277	492.67	604.62	410.09	653.24	415.94	553.05
278	592.46	520.91	353.11	493.69	327.05	533.55
279	568.34	549.04	358.92	444.67	351.04	449.96
280	471.77	578.40	339.14	542.43	353.63	491.31
281	417.20	413.31	286.11	334.60	306.66	389.28
282	582.71	615.16	511.36	423.86	396.18	445.33
283	541.16	537.00	387.90	446.91	348.65	501.61
284	522.34	698.62	413.20	421.28	329.44	462.49
285	435.25	546.27	367.26	496.08	397.29	495.10
286	496.59	588.81	359.63	573.90	389.94	571.89
287	378.13	533.06	375.93	412.12	329.57	505.09
288	574.20	743.25	561.03	473.40	396.68	636.35
289	299.80	459.29	248.63	425.64	309.08	484.59

290	449.32	597.05	352.89	567.41	380.56	566.35
291	433.48	508.76	301.54	620.71	353.82	473.79
292	701.09	577.17	338.68	470.72	340.76	290.98
293	554.93	612.23	337.66	702.20	324.57	460.25
294	451.24	547.26	291.93	422.41	315.54	449.22
295	469.42	565.15	368.33	518.50	364.53	558.32
296	350.68	411.73	251.00	373.11	297.55	257.46
297	470.83	479.89	294.32	533.54	344.24	389.96
298	540.95	514.86	317.50	468.67	358.89	467.27
299	525.09	606.95	345.97	467.37	321.74	408.85
300	389.69	500.67	305.79	569.13	318.10	476.85
301	500.34	528.27	321.57	455.00	336.37	415.45
302	587.65	579.15	340.29	511.37	309.99	487.58
303	514.80	552.82	336.13	397.87	309.53	386.83
304	349.50	424.65	276.10	578.71	341.55	480.41
305	532.17	483.94	357.56	368.08	327.88	417.47
306	406.41	425.50	280.48	399.00	311.70	342.70
307	563.86	453.51	398.25	367.61	340.64	440.80
308	449.91	516.75	360.42	490.14	343.81	509.98
309	617.79	549.21	377.18	400.14	315.82	362.92
310	388.56	532.50	339.31	451.35	336.10	407.90
311	576.64	632.96	420.37	580.87	356.75	515.49
312	409.60	435.02	259.21	262.94	265.51	177.59
313	437.91	526.97	332.50	416.24	301.81	359.87
314	399.00	466.26	266.70	521.97	328.20	426.54
315	795.30	540.08	429.48	541.64	349.61	525.67
316	439.94	539.35	308.22	534.17	351.23	503.92
317	482.82	482.61	308.91	481.53	319.30	364.71
318	396.74	446.53	298.86	422.97	305.30	349.28
319	372.02	455.34	324.94	465.44	339.69	435.69
320	399.41	460.33	251.31	458.79	314.88	390.56
321	475.98	399.28	312.83	294.71	300.84	310.24
322	495.55	613.80	349.42	472.49	326.51	528.07
323	441.85	455.19	270.63	452.71	311.30	427.81
324	311.30	394.89	235.16	319.71	269.39	299.94
325	501.89	556.50	378.71	384.17	347.32	412.98
326	674.78	649.69	422.96	510.54	400.63	530.91
327	530.24	515.91	284.01	450.32	307.10	396.45
328	390.09	511.79	351.96	519.39	359.76	492.98
329	303.34	570.43	290.80	530.77	326.37	548.76
330	641.32	656.09	408.72	509.55	352.31	503.18
331	427.09	650.34	460.50	420.95	357.84	490.69
332	415.98	447.11	325.32	321.99	294.79	507.26
333	627.31	629.99	445.82	487.36	375.78	545.25
334	436.36	511.40	323.44	454.21	337.80	346.98
335	422.22	521.81	288.31	503.66	330.08	426.18

336	479.67	545.27	310.21	572.56	324.72	438.60
337	376.83	445.21	274.46	314.92	277.17	319.47
338	243.90	419.67	239.58	324.64	275.20	331.74
339	542.31	535.07	374.88	388.88	367.63	470.05
340	384.64	462.35	242.78	560.46	319.11	462.03
341	351.88	574.16	355.69	500.00	343.21	510.93
342	635.28	562.04	400.72	571.59	408.31	542.73
343	386.04	428.72	286.76	338.84	306.91	397.83
344	367.02	395.69	234.16	369.66	301.54	432.77
345	311.76	494.72	273.09	451.00	283.22	311.06
346	498.66	601.80	341.78	732.88	338.17	529.05
347	466.61	599.89	389.02	605.93	385.91	567.60
348	466.96	540.55	369.46	434.08	322.47	371.40
349	463.77	478.30	283.67	506.25	339.15	450.38
350	485.92	439.67	268.76	350.75	285.50	314.65
351	365.55	528.50	329.99	568.39	370.72	540.36
352	454.22	545.78	346.21	386.91	293.14	480.07
353	394.13	493.35	268.52	424.65	303.22	312.26
354	489.88	529.61	295.12	514.71	324.10	317.35
355	556.95	587.76	356.22	438.76	363.47	425.82
356	428.38	378.03	260.15	410.32	282.05	425.22
357	325.28	364.46	187.20	470.21	284.57	359.12
358	534.96	543.96	281.11	551.57	326.80	460.95
359	579.46	519.94	343.75	412.63	373.92	443.87
360	305.19	410.50	243.72	396.40	288.42	246.55
361	370.15	467.52	319.85	529.72	317.50	517.15
362	375.57	515.16	335.98	451.56	341.79	532.82
363	404.04	573.86	284.35	558.70	300.44	471.15
364	373.58	520.20	292.22	419.22	306.32	445.68
365	374.12	473.37	320.29	494.20	348.01	464.10
366	650.61	716.52	851.50	546.13	398.27	583.88
367	478.47	531.51	391.10	439.63	305.04	363.95
368	368.65	565.35	291.47	480.67	348.50	388.61
369	516.56	491.20	382.58	341.16	319.87	411.08
370	551.84	733.81	498.15	607.46	381.53	533.70
371	406.20	621.12	316.19	552.28	320.30	394.37
372	480.16	503.75	313.20	490.55	332.60	498.09
373	512.67	677.18	350.18	403.76	333.76	413.36
374	412.18	473.75	328.65	236.59	285.08	321.48
375	525.86	563.19	487.01	644.79	405.96	573.41
376	418.52	552.16	310.51	431.95	310.61	467.47
377	364.72	451.08	262.86	430.75	303.38	414.95
378	552.91	412.71	265.62	454.41	311.55	276.18
379	330.01	444.82	221.42	426.46	295.05	373.20
380	292.48	507.85	281.60	385.15	276.47	375.90
381	430.74	530.42	347.59	498.45	360.14	472.76

382	451.50	526.10	285.17	559.28	335.64	339.65
383	325.80	449.05	289.32	391.69	304.67	452.45
384	501.45	597.57	344.44	436.91	344.38	398.34
385	455.90	524.29	353.76	502.19	377.40	444.28
386	555.93	659.37	522.90	597.71	387.16	518.16
387	409.13	486.95	273.43	354.47	308.74	357.93
388	555.00	583.94	367.05	476.40	334.18	441.28
389	226.72	431.05	244.74	302.23	261.88	409.50
390	533.83	465.75	395.43	415.49	372.60	547.61
391	428.74	434.55	303.53	350.39	322.34	326.13
392	399.89	518.27	307.45	377.94	304.43	478.00
393	414.58	442.93	290.08	301.02	291.21	386.40
394	495.21	623.37	325.69	561.83	362.36	466.99
395	408.89	547.70	279.23	619.48	347.02	485.45
396	606.18	451.52	343.84	337.24	323.82	404.50
397	427.42	430.54	271.34	298.60	281.10	353.47
398	534.52	566.70	364.43	409.00	328.55	288.54
399	458.42	456.75	363.93	328.97	339.28	484.04
400	509.86	502.25	385.74	359.11	335.47	442.24
401	347.56	557.75	322.54	641.81	351.94	527.08
402	544.25	437.48	279.86	346.74	296.18	227.29
403	422.86	501.56	333.87	539.48	409.85	546.55
404	431.53	474.61	277.99	418.65	296.64	361.28
405	559.74	522.40	354.55	659.14	416.75	476.25
406	467.70	575.19	351.05	492.76	354.22	520.31
407	478.79	499.24	292.89	570.22	327.99	465.30
408	502.31	580.55	346.58	372.68	332.25	434.78
409	398.32	501.95	294.07	284.23	287.90	405.77
410	424.64	471.06	276.90	523.58	344.65	440.44
411	452.82	566.84	337.03	387.22	320.52	473.71
412	464.56	459.95	309.26	384.72	311.02	427.20
413	656.61	701.85	449.23	516.22	411.26	522.92
414	320.08	455.80	282.96	489.49	321.35	421.09
415	442.06	481.98	355.29	394.84	345.71	443.04
416	497.88	572.74	436.96	549.18	371.28	514.06
417	733.51	544.34	450.51	406.53	347.80	477.21
418	545.15	496.61	318.08	462.32	306.15	391.49
419	509.10	527.87	340.77	431.73	316.33	382.58
420	373.15	498.47	340.11	587.86	394.89	538.42
421	388.26	513.22	269.35	429.11	308.57	379.91
422	446.36	490.07	338.38	482.33	329.09	604.41
423	593.35	451.88	311.68	415.77	338.43	428.73
424	364.52	509.20	313.67	413.94	321.13	469.09
425	472.95	594.12	283.32	352.52	279.31	336.80
426	697.19	548.56	391.66	420.62	369.31	515.30
427	438.68	482.17	248.01	600.07	291.64	481.10

428	528.98	559.78	353.87	548.54	361.60	501.18
429	346.33	652.04	357.04	547.57	382.93	519.29
430	416.70	500.31	270.97	342.95	300.54	345.91
431	477.33	539.77	363.66	327.59	313.80	522.43
432	467.37	521.31	318.36	537.22	363.38	526.04
433	663.23	670.93	484.44	637.43	427.92	612.61
434	477.00	564.39	342.27	688.98	399.50	532.32
435	508.99	608.16	471.50	505.11	379.61	619.44
436	474.57	474.25	250.23	401.80	318.83	351.39
437	438.22	541.61	302.80	486.65	337.05	403.16
438	340.74	512.21	310.96	544.02	360.98	492.02
439	412.42	518.85	362.81	455.31	358.74	431.71
440	334.56	610.95	347.72	526.44	367.71	559.13
441	345.43	458.90	232.91	307.94	266.95	384.73
442	623.03	525.20	388.14	576.88	365.62	505.40
443	645.04	495.87	441.94	373.90	366.02	524.56
444	377.45	418.91	281.38	520.64	345.28	420.75
445	338.71	461.34	275.44	356.96	302.51	267.81
446	423.44	581.07	356.49	452.11	356.48	466.04
447	380.35	463.86	301.38	326.38	344.96	442.67
448	335.28	460.92	295.64	455.65	335.74	416.10
449	513.31	501.05	346.78	563.70	400.50	600.62
450	314.12	432.39	255.59	344.69	293.93	413.96
451	499.36	644.14	435.47	649.19	382.29	555.33
452	624.32	463.95	453.27	427.15	394.56	503.75
453	585.42	619.60	342.21	550.19	335.11	488.75
454	400.58	445.60	303.30	418.27	293.70	434.26
455	565.09	606.70	410.75	442.85	346.13	401.35
456	408.41	490.60	305.26	484.34	317.04	400.39
457	354.49	472.83	296.98	399.71	305.82	402.38
458	457.61	506.31	312.59	447.58	348.38	513.71
459	455.37	397.49	269.88	349.54	300.17	462.87
460	358.82	492.46	329.07	413.61	341.33	420.22
461	420.69	528.94	296.08	660.64	350.44	460.35
462	418.88	403.01	264.11	304.80	291.05	251.90
463	496.63	550.54	386.61	375.16	377.98	447.37
464	497.45	535.39	355.04	310.18	333.28	453.43
465	443.31	507.07	267.57	480.90	299.67	474.92
466	526.79	531.92	340.73	463.55	320.64	407.51
467	357.87	433.41	296.31	360.10	313.06	264.61
468	407.98	476.87	301.17	487.08	361.30	416.27
469	473.80	425.74	285.68	371.68	321.92	423.07
470	630.46	543.23	373.96	448.96	386.12	406.58
471	461.66	448.06	274.79	458.28	281.42	378.73
472	482.49	501.27	327.75	512.32	326.96	451.62
473	523.51	553.80	323.02	389.56	315.97	395.60

474	441.23	612.84	348.40	536.57	344.01	513.00
475	493.21	486.14	307.54	383.10	332.91	338.44
476	550.77	531.02	352.52	437.53	331.80	434.00
477	356.44	454.34	261.21	434.50	325.87	452.98
478	511.53	483.16	334.05	587.33	390.86	449.48
479	577.96	609.61	411.93	466.77	363.01	405.17
480	499.45	427.62	302.23	461.73	342.32	485.81
481	505.94	511.04	308.37	478.62	323.87	431.03
482	323.64	382.48	208.62	374.54	268.34	322.03
483	333.60	456.31	266.31	371.20	311.83	470.57
484	523.84	568.84	419.27	440.63	364.36	424.75
485	442.88	541.19	380.25	388.17	346.44	468.28
486	485.49	571.07	341.15	600.98	373.85	594.06
487	451.82	593.37	361.95	590.73	349.76	577.13
488	528.08	420.64	274.97	318.64	277.59	262.35
489	382.97	423.85	277.16	419.79	307.70	428.83
490	402.89	509.77	251.98	414.18	278.11	330.11
491	484.90	534.04	307.01	543.33	387.91	523.58
492	401.16	551.21	399.34	592.95	392.31	552.65
493	361.75	450.39	254.73	457.67	299.02	498.94
494	405.70	487.65	289.44	508.85	301.04	402.52
495	416.43	553.51	316.94	469.99	333.84	448.72
496	345.24	466.90	249.43	581.56	332.79	380.56
497	553.35	563.87	379.89	440.36	354.37	483.19
498	435.64	465.16	273.89	482.20	314.23	451.22
499	483.38	476.53	282.29	460.85	325.11	446.36
500	371.04	452.57	281.95	280.10	286.55	368.80;

```
Scalars
     psi          "risk aversion parameter"                /0/
     w            "wage rate/hour "                        /0.7/
     totfl        "available family labour(hours}"         /1656.05/
     tothl        "total hired labour(hours)"              /2090.38/
     probi        "probability of occurrence for i"        /0.002/
     land         "household land base(acres)"             /12.7/
     otfexp       "other farm expenses(GHC)"               /207.698/
     otnfexp      "other non-farm expenses(GHC)"           /220.188/
     otfinc       "other farm income(GHC)"                 /631.821/
     otnfinc      "other non-farm income(GHC)"             /597.56/
     theta        "subsidization factor"                   /1/
     lambda       "coverage level"                         /0.7/
     beta         "Scale"                                  /1/
     zigma        "Premium load"                           /0.1/
```

```
Variables
      z1                "negative exponential objective function"
      sumlanddev        "sum deviation of predicted acres from observed for all crops";

Positive variables
      acreunins(d)      "Uninsured Acres of d"
      acreins(d)        "Insured Acres of d"
      prout(i,d)        "predicted output (kg)"
      sell(i,d)         "d sold(kg) in i"
      pur(i,d)          "d purchased(kg) in i"
      con(i,d)          "d consumed(kg) in i"
      ps(d)             "selling price(GHC/kg) of d"
      val(d)            "consumption value(GHC/kg) for d"
      p(d)              "pre-determined selling price of d"
      totval            "predicted output value"
      totindem(i)       "Total indemnity"
      totprem           "Total premium"
      hl(d)             "hired labour(hours)allocated to d"
      fl(d)             "family labour(hours) allocated to d"
      tl(d)             "total  labour(hours)for d"
      expvalcon         "expected value of consumption";

Equations
      OBJ1              "expected utility function(negative exponential)"
      OUTCON            "output constraint"
      LANDCON           "land constraint"
      LABCON            "labour constraint"
      LABCON2           "labour constraint"
      LABCON3           "labour constraint"
      LABCON4           "labour constraint"
      USECON            "use constraint"
      PREM              "Premium Payment"
      INDEM             "Indemnity Equation"
      INDEMPRICE        "Pre-determined prices of crops for indemnity"
      INCEXPCON         "income-expenditure constraint"
      SELLPRICE         "Selling-purchasing prices conversion"
      CONSUMVAL         "Consumption value-purchase price conversion";

avgyld(d)=sum(i,obsareayld(i,d)/card(i));

yc(d)=avgyld(d)*lambda;

yldif(i,d)=(yc(d)-obsareayld(i,d))$(yc(d) gt obsareayld(i,d));

EL(d)=probi*sum(i,yldif(i,d));
```

```
OBJ1          ..      z1=e=sum(i,probi*(1-exp(-psi*(sum(d,val(d)*con(i,d))))));

OUTCON(i,d)    ..     prout(i,d)=e=(yld(i,d)*acreunins(d))+(yld(i,d)*acreins(d));

LANDCON(i)     ..     sum(d,acreunins(d)+acreins(d))=e=11.955;

LABCON(i,d)    ..     (lahrs(d)*acreunins(d))+(lahrs(d)*acreins(d))=l=fl(d)+hl(d);

LABCON2(i)     ..     sum(d,fl(d))=l=totfl;

LABCON4(i)     ..     sum(d,hl(d))=l=tothl;

LABCON3(i,d)   ..      tl(d)=e=fl(d)+hl(d);

USECON(i,d)    ..     con(i,d)=e=prout(i,d)+pur(i,d)-sell(i,d)-otuse(d);

INCEXPCON(i)   ..           sum(d,vc(d)*(acreins(d)+acreunins(d)))+sum(d,hl(d)*w)+
                            sum(d,(pp(d)*pur(i,d)))+totprem+OTFEXP+OTNFEXP=l=
                            sum(d,(ps(d)*sell(i,d)))+totindem(i)+OTFINC+OTNFINC;

SELLPRICE(d)   ..    ps(d)=e=gamma(d)*pp(d);

CONSUMVAL(d)  ..  val(d)=e=phi(d)*pp(d);

INDEMPRICE(d) ..  p(d)=e=ps(d);

PREM(i)        ..     totprem=e=(1-theta)*(sum(d,p(d)*EL(d)*acreins(d))*(1+zigma));

INDEM(i)    ..        totindem(i)=e=sum(d,p(d)*yldif(i,d)*acreins(d));


Model    insurance /all/;

Option   decimals=3;

Option   nlp=GAMSCHK;

insurance.bratio=1.0;

Set
      riskscen        Risk aversion scenarios            /R1*R4/
      coveragescen    Coverage scenarios                 /C1*C4/
      scalescen       Scale scenarios                    /SC1*SC4/
      subsidyscen     Subsidy scenarios                  /SUB1*SUB5/
```

```
Parameters
        Output (*,*,*,*,*,*)       Comparative summary
        Riskaver(riskscen)                 Risk aversion scenarios          /R1 0.008
                                                                             R2 0.012
                                                                             R3 0.016
                                                                             R4 0.020/

        Coverage(coveragescen)             Coverage scenarios               /C1  0.70
                                                                             C2  0.80
                                                                             C3  0.90
                                                                             C4  1.00/

        Scale(scalescen)                   Scale scenarios                  /SC1 0.90
                                                                             SC2 1.10
                                                                             SC3 1.30
                                                                             SC4 1.50/

        Subsidy(subsidyscen)               Subsidy scenarios                /SUB1 0.2
                                                                             SUB2 0.4
                                                                             SUB3 0.6
                                                                             SUB4 0.8
                                                                             SUB5 1.0/

loop(riskscen,
option
clear=z1,clear=acreunins,clear=acreins,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=p,clear=val,clear=totprem,clear=totindem;
        psi=riskaver(riskscen);

loop(coveragescen,
option
clear=z1,clear=acreunins,clear=acreins,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=p,clear=val,clear=totprem,clear=totindem;
        lambda=Coverage(coveragescen);

loop(scalescen,
option
clear=z1,clear=acreunins,clear=acreins,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=p,clear=val,clear=totprem,clear=totindem;
        beta=Scale(scalescen);

loop(subsidyscen,
option
clear=z1,clear=acreunins,clear=acreins,clear=hl,clear=fl,clear=tl,clear=prout,clear=sell,
clear=pur,clear=con,clear=ps,clear=p,clear=val,clear=totprem,clear=totindem;
        theta=Subsidy(subsidyscen);
```

```
Option   nlp=minos;
Solve insurance using nlp maximizing z1;
expvalcon.l=sum((i,d),con.l(i,d)*val.l(d))*0.002;

output('Uninsured Acreage Allocation',d,riskscen,coveragescen,scalescen,subsidyscen)=
acreunins.l(d);
output(e'Insured Acreage Allocation',d,riskscen,coveragescen,scalescen,subsidyscen)=
acreins.l(d);
output('Objective Value','',riskscen,coveragescen,scalescen,subsidyscen)=Z1.l;
output('Expected Value of Consumption','',riskscen,coveragescen,scalescen,subsidyscen)=
expvalcon.l
);
);
);
);

$libinclude xldump output insurance1.xlsx sheet1!

Display output;
```