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Risk management and its implications on household incomes

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Risk Management and its Implications on Household Incomes

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Abstract

The subject of risk in agricultural production is very pertinent and touches on various aspects such as investments, food security, income levels of farmers, and market stability. Unmanaged, risks can have profound impacts on the agricultural sector and at the same time severely hamper long-term economic growth and poverty reduction efforts. Furthermore, risk management by farm households are multifarious with each having different cost and benefit implications. Using empirical data from a nationally representative farm household survey in Senegal, we evaluated the effect of different risk management strategies employed by farm households on agriculture income and dispersions around incomes. We achieve this by employing a Multinomial Endogenous Switching Regression model and a Moment-Based Approach. We find mix results of the impact of risk management on agriculture incomes. The use of risk mitigation and transfer significantly reduces agriculture incomes while risk coping strategies significantly increases agriculture incomes. Risk mitigation strategies were observed to be associated with opportunity costs relating to income loss and likely inefficient resource allocations. On the contrary, the reduced agricultural incomes observed with the use of risk transfer might be related moral hazard problems such that insurance policy holders do not take care or expend less effort in their production activities. We also find that risk management strategies significantly reduce dispersions around agriculture incomes with risk transfer producing the largest effect. Furthermore, the effect of risk transfer strategies on dispersions around agriculture incomes is reduced when combine with other strategies. For the other risk management strategies, we find that when used in combinations, the dispersion reduction effect is greatly enhanced.

Keywords: Risk management, strategies, dispersion, multinomial, mitigation, transfer, coping

Introduction

As pervasive and permanent fixtures of agricultural landscapes, risks are costly and if unchecked breeds uncertainty, stifle agricultural investments (D'Alessandro *et al.*, 2015) and impose ex ante barriers to the use of technologies, which in turn affect agricultural productivity and economic growth (Binswanger and Sillers, 1983; Barnett *et al.*, 2008; Miller, 2008; Di Falco and Chavas, 2009; Kouamé, 2010; Dercon and Christiaensen, 2011; Demeke *et al.*, 2016; Poole, 2017; Amare *et al.*, 2018). Agricultural price risks increases food prices and reduce the accessibility of food and this has a substantial impact on household nutrition, health, survival and resource management (D'Alessandro *et al.*, 2015; Demeke *et al.*, 2016). The incidence of risks also has important spill-over effects on other rural households and businesses (Anderson, 2001). For instance, destroyed crops and livestock reduce employment opportunities, with serious implications for the landless rural poor in developing countries. By lowering farm outputs, risks can also reduce turnover for agricultural merchants and agro-processors (Pannell and Nordblom, 1998).

Agricultural risks are also the principal cause of transient food insecurity and disruption to agricultural supply chains (World Bank, 2016). At the same time, risks faced by farmers are many, specific and vary in terms of climate, agricultural system of production and country (Anderson, 2001; Jaffee *et al.*, 2010). Yield volatility and price volatility are by far the two most important risk faced by farmers which are projected to rise due to climate change. Additionally, agricultural risks potentially limits access to finance, increases the likelihood of farmers defaulting on loans and this restrains agriculture productivity (Yaron *et al.*, 1997; Demeke *et al.*, 2016). Particularly in developing regions of the world, smallholder producers are often exposed to a variety of biological and climatic risk factors that can negatively affect household income, wealth, as well as tremendous variability in output and input prices.

As a leading sector in the economy of Senegal, agriculture is highly vulnerable to natural disasters and to the effects of climate change. In Senegal, agriculture is predominantly rain-fed, with more than 95% of the total cropped area depending on rain-fed systems, and most farmers practicing subsistence agriculture (Khouma *et al.*, 2013). Like most countries in the Sahel region, Senegal's agricultural sector faces highly variable rainfall and is highly vulnerable to the effects of climate change. Furthermore, climate in Senegal is particularly characterized by high temperatures and low, highly variable annual precipitation with numerous observations indicating that risks associated with agricultural activity will grow in terms of diversity, size and frequency. Based on an analysis of available quantitative and qualitative data, D'Alessandro *et al.*, (2015) identified drought, locusts, price volatility, crop pest and diseases as the most important risks facing Senegal's agricultural sector. Specifically, weather related factors that relates to moisture stress caused either by erratic rainfall, early cessation of rains, delayed onset of rains, or extended drought are particularly prominent. Despite these identified risk events occurring in isolation, multiple and overlapping shocks are observed to have far greater impacts and higher associated losses (D'Alessandro *et al.*, 2015).

In fact more than 40% of the variation in crop yields in Senegal can be ascribed to the variation in annual rainfall amounts (D'Alessandro *et al.*, 2015). Furthermore, a macro level analysis and estimates of the indicative value of losses, due to agricultural risks for 11 major crops between the period of 1980 to 2012 by D'Alessandro *et al.*, (2015) shows that total losses from production risks in Senegal amounted to 4.82 million MT. In monetary equivalent, this is about

US$1.38 billion, or about US$41.7 million per year, corresponding to about 3.9% of agricultural GDP on an average annual basis. The analysis further showed that the highest crop losses coincided with major shocks to agricultural production. D'Alessandro *et al.,* (2015) further observed that although the average annual impact of shocks on GDP is relatively modest, actual impacts when they occur potentially results in losses of the order of 10 to 20% of the agricultural sector GDP. Further analysis also shows that Senegalese agriculture is subjected to losses exceeding 10% of gross production value in one out of every five or six years on average due to unmanaged risks. The most significant cause of loss in Senegal is due to drought/erratic rainfall, and this accounts for approximately 50% of crop yield reductions, followed by pests and diseases, especially locusts, which accounts for about 25% of crop yield losses. In addition maize production exhibits the highest level of vulnerability in terms of frequency of risk, whereas groundnuts production incurs the highest losses, accounting for nearly 45% of aggregate losses (D'Alessandro *et al.,* 2015).

Adverse weather patterns, in addition to limiting the ability and motivation of farm households to invest in agricultural technology and wealth-increasing assets, are particularly detrimental to farm households' yields and outputs and this result in significant income losses and negative impacts on farmers' livelihoods, consumption and food security (Demeke *et al.*, 2016; Obiri and Driver, 2017). In Senegal D'Alessandro *et al.*, (2015) argues that a major limiting factor to the adoption of productivity enhancing technologies is due to the widespread reluctance among the millions of smallholder farmers to assume risks associated with increased productivity. With only a limited capacity to manage production related risks, highly vulnerable farmers choose to limit their exposure by limiting their investment outlays. This is particularly the case because once farm households have invested a bulk of the required resources into production, there is effectively no way back when risks to production occur. Therefore, farm households in their risk aversion strategy will choose the planting of low-investment, reward, and risk planting combinations (Hao, 2010) for example, thereby reducing the possibility to increase investment. Furthermore, by causing fluctuations in income and consumption, risks usually imply relatively high levels of transient poverty (Kouamé, 2010). This observation has been observed to contributes to the poverty trap experienced by rural people in many developing countries (World Bank, 2001; World Bank, 2005b; Barnett *et al.*, 2008; Demeke *et al.*, 2016; World Bank, 2016; Birthal and Hazrana, 2019). Failure of farm households to cope with income risk is not only reflected in household consumption fluctuations but also on nutrition, health and education and this contribute to inefficient and sub-optimal intra-household resource allocations (Anderson, 2001; Dercon, 2002). For example, in India Rosenzweig and Binswanger (1993) found that the loss in efficiency associated with risk mitigation was considerably higher among poorer farmers. Similarly, studies by Morduch (1995), and Kurosaki and Fafchamps (2002) also find considerable efficiency losses associated with risk mitigation.

If unmanaged, risks can have a profound impact on the agricultural sector performance and this can severely hamper long-term economic growth and poverty reduction efforts. Additionally, unmanaged risks could potentially result in a vicious sequence of shock–partial recovery–shocks, which can undermine natural and capital resources and threaten the transition from subsistence to commercial agriculture (Cusmano, 2013; Demeke *et al.*, 2016; World Bank, 2016). Hence, mitigation of agricultural risk has been increasingly focused on reducing the exposure and increasing the resilience of production systems and livelihoods to adverse

impacts (World Bank, 2016). Putting in place effective risk management measures can help mitigate adverse impacts on agricultural supply chains and the livelihoods they support. However, it is virtually impossible to address all risks at once. Thus, it is necessary to prioritize interventions based on which risks occur most frequently and which cause the greatest financial losses (D'Alessandro *et al.*, 2015).

With limited access to credit or insurance markets and resources, farm households most often have challenges managing the myriad risks they face. At the same time, social and institutional mechanisms for coping with risk exposure are typically quite limited in low-income countries, especially among the rural poor (World Bank, 2005a; Devereux and Guenther, 2007; Barnett *et al.*, 2008). Hence farm households heavily rely on a range of traditional risk management strategies to avoid or minimize losses but these are mostly incomplete, suboptimal and mitigate only a small part of overall risk (Siegel and Alwang, 1999; Dercon, 2002; Alderman, 2008; Barnett *et al.*, 2008; Deressa *et al.*, 2010; Kouamé, 2010). Because risks faced by farmers are both numerous, complex and interconnected, they vary in their levels of frequency and severity, and have profound short-term and long-term impacts on both income and livelihoods and therefore a singular blueprint for risk management is not feasible. Hence many farm households combine the use of many different strategies and tools to manage agricultural risk. As a result, the risk management portfolio of farm households is complex in nature (Meraner and Finger, 2017).

Farm households have a number of options available to manage farm risk but broadly speaking, mitigation strategies employed by various farm household may include; accepting the risk, avoiding or eliminating the risk, transferring the risk to another party or controlling the risk. Farm households therefore use these risk management tools simultaneously or in combinations to deal with agricultural risks (Harwood *et al.*, 1999; Makki *et al.*, 2001; Flaten *et al.*, 2005; Velandia *et al.*, 2009; Ullah and Shivakoti, 2014; Ullah *et al.*, 2015; World Bank, 2016). In most cases they are assumed to select a combination of risk management strategies that, for example maximize expected net returns subject to the degree of risk they are willing to accept (Harwood *et al.*, 1999; Tomek and Peterson, 2001). Empirical evidence suggest that risk management approaches in which multiple approaches are considered simultaneously, appears to be more efficient than single approaches (Huirne *et al.*, 2007). Despite the existence of many risk-spreading strategies and tools available to farm households, these are not always widely available or prove ineffective for poor farm households and are also not without associated costs. In fact the empirical literature (see Zimmerman and Carter, 2003; Barnett *et al.*, 2008; Kahan, 2008; Deressa *et al.*, 2010; World Bank, 2016) tend to suggest that there is an implied risk cost to all risk management strategies employed by farm households. These implied risk cost or premium can either the explicit or the opportunity cost of undertaking the strategy.

At the same time several alternatives for mitigating risk have been reported in the empirical literature, yet most of these empirical studies have focused on the adoption of one or two management strategies at most (see Dercon and Christiaensen, 2011; Gong *et al.*, 2016; Saqib *et al.*, 2016). But how effective[1] are these risk management strategies farm households employ in managing risk, and how large are the benefits? The available empirical evidence is

[1] The overall effectiveness of a risk management strategy typically requires the evaluation of trade-offs between expected returns and the associated costs (actual or opportunity costs). Effectiveness of a risk management strategy therefore calls for a balanced of costs against the achieved reduction or returns (dispersion around incomes). In this paper we only evaluate the effectiveness of risk management strategies from the returns perspective. Cost effectiveness is beyond the scope of this study. We use the associated standard deviation of households' agriculture incomes as proxy indicators for the return's effectiveness of a risk management strategies.

inadequate to provide definitive answers. A few studies have evaluated the effectiveness or impact of some of these risk management strategies and tools on a case by case basis. For instance Birthal and Hazrana (2019) used a panel of district-level data from India to evaluate the effectiveness of crop diversification in mitigating harmful effects of climatic shocks on the performance of agriculture by estimating a dynamic generalized method of moments model with lags of dependent and independent variables as instruments. They found that crop diversification was an important ex ante adaptation measure to climatic shocks and they estimated the marginal effects of diversification under moderate and severe climatic shocks to be 1.73 and 2.19, respectively. They also observed that in the long-run, the marginal effects improve considerably to 4.96 under moderate shocks and to 6.35 under severe shocks. Howard and D'Antonio (1984) also used a theoretical mathematical optimization model investigate the hedging effectiveness of optimal holding of future contracts. They find that hedging effectiveness depends exclusively on the correlation between the returns of the spot and the futures and the risk-return relative. Kimura *et al.*, (2010) shows that diversification as a risk management strategy is a very effective strategy to reduce revenue risk. They find that it lowers the coefficient of variation of revenue under 6 crop allocation by an average of 12% in Germany, 29% in the UK, 29% in Estonia, 35% in the Netherlands and 33% in Australia. Furthermore, Kimura *et al.*, (2010) found that the marginal impact of price-hedging through forward contract on income variability increased the certainty equivalent of income by 1.3% and 2.2% in Australia and UK, respectively.

Li and Vukina, (1996) finds that dual hedge in price and yield futures in the presence of price and yield risks reduces the variance of farm revenue by hedging in both markets rather than just using the price futures. Dhuyvetter and Kastens (1997) also used simulated revenue to examine the combinations of crop insurance alternatives (catastrophic insurance, multi-peril crop insurance, and crop revenue coverage) as they relate to expected income and income variability. They find that multi-peril crop insurance and crop revenue coverage resulted in the least income variability, measured by both standard deviation and minimum revenue. Heifner and Coble (1997) employed numerical integration to approximate crop revenue distributions when optimal futures and options hedges are coupled with or without crop insurance. They find that combinations of crop insurance and forward pricing are much more effective than either alone in reducing risks. Berg (2002) also investigated farm level impacts of multiple peril yield and revenue insurance in an expected value-variance framework using a stochastic simulation approach with numerical optimisation. He finds that multiple peril crop insurance significantly reduces the variability of income. In a most recent study, Vigani and Kathage (2019) used a multinomial endogenous switching regression model to estimate the impacts of different risk management strategies and portfolios under varying levels of risk on total factor productivity using survey data from French and Hungarian farms. They found that the impacts can be positive or negative, depending on the risk management strategies adopted, the structure of the farming system, and the probability of risks. Breen *et al.*, (2013) have also used multi-criteria analysis approach to evaluate various risk management tools and polices. In their approach they summarized the strengths and weaknesses of various market and government risk management related tools and policies and then ranked them accordingly. The criteria upon which they evaluated the various risk management tools and policies included acceptability, effectiveness, operationality and cost. Despite being useful, their approach is subjective and not backed by any empirical evidence.

Among the most fundamental and complex decisions that farm households have to make, is the choice among probability functions of income stemming from different risk management strategies. Hence an optimal risk management decisions of farm households often rely on sound analysis of the entire portfolio of policies available to them. Concurrently, the aim of agricultural risk management is to find risk-efficient combination of tools and instruments that reduces the variability of household farm incomes. Motivated by the solid and growing literature on risk management techniques, this paper seeks to answer the question; which optimal risk management strategies allow households to maximize their objectives in terms of expected income and variability of income? We are therefore interested in investigating how effective the various strategies and mechanisms employed by farm households to deal with risk are. More importantly we seek to explore their impacts in terms of stabilizing and reducing the variability or dispersions around agriculture incomes. We therefore attempt to determine the "best" tools, in terms of stabilizing farm households' agriculture incomes by employing a multinomial endogenous switching regression that accounts for selectivity bias and a moment-based approach to determine the impacts of the various risk management strategies on agriculture incomes and it's dispersions in a multinomial framework. Although our paper is not the first to investigate the effectiveness of risk management strategies, to the best of our knowledge, it is the first to analyse the causal impact of various risk management typologies in a multinomial framework[2]. This approach is unique and interesting because it allows us to evaluate and compare risk management strategies across the different typologies.

This study is also important for several reasons. First it highlights the need for a more targeted and systematic approach to agricultural risk management. Because good risk management decisions depend on accurate information, hence evaluating the effectiveness of different strategies and tools helps farm households to refine their decisions and select optimum set of strategies when faced with risky situations. This is particularly important because fluctuations in farm incomes, due to risks may present difficult welfare problems for farmers. Optimal risk management tools also have implications for rural growth and poverty reduction. Furthermore, since both national governments and donor organizations face budget constraints and opportunity costs related to using scarce resources to develop risk management programs, identifying optimal risk management strategies provides useful information for the design of appropriate risk management policies by policymakers. The rest of the paper is organized as follows. Section 2 formally presents relevant works on risk management in the empirical literature. In Section 3, the conceptual framework, econometric specification, and the survey and data used is described. In Section 4, we present the empirical results and discussions and finally, Section 5 offers conclusion and policy implications.

[2] A few studies have also used the multinomial endogenous switching regression (MESR) model to study the impact of some risk adaptation strategies. In a recent study, Vigani and Kathage (2019) employed the MESR model to estimate the impacts of different risk management strategies and portfolios under varying levels of risk on total factor productivity using panel data from French and Hungarian farms. Kassie *et al.,* (2015) used the MESR model together with a moment-based approach just like this current study to investigate the impact of sustainable intensification practices (crop diversification and minimum tillage) on farm households' food security, downside risk and the cost of risk in Malawi. Di Falco and Veronesi (2013) have also used multinomial endogenous switching regression model to analyze the impact of different adaptation strategies on crop net revenues in the Nile Basin of Ethiopia. Their focus was on agronomic practices such as soil conservation, changing crop varieties, water strategies and various other strategies.

2.0 Literature review

A large number of literature exists on the subject of risk and risk management in agriculture with variations in the understanding and use of the terminology. In the context of this study, agriculture risks are seen as shocks (e.g. climatic shocks – drought, erratic rainfall, flooding; biological shocks – pest and disease outbreaks; and price volatility for inputs and outputs) experienced by farm households. There are three important channels through which these shocks impact farm households; first they influence households' decisions to adopt productivity-enhancing inputs and impose ex ante barriers to their use (Di Falco and Chavas, 2009; Dercon and Christiaensen, 2011; Amare *et al.*, 2018). Secondly, they reinforce changes in production portfolio towards farm enterprises that are less-vulnerable to shocks, but at the same time may also be less remunerative compared to others (Birthal and Hazrana, 2019). Thirdly, they cause potential deviation between expected and real outcomes (Schaffnit-Chatterjee, 2010; Obiri and Driver, 2017). While this deviation may either be positive or negative, a negative outcome has greater importance from a practical point of view. Several research (see Newbery and Stiglitz, 1981; Harwood *et al.*, 1999; Fafchamps, 2000; Poole, 2017) have shown that farm households are not particularly concerned with uncertainty relating to agricultural output and prices, but rather to variability of their incomes. This is because economic well-being is affected not only by the level of income but also its fluctuations. Hence from the perspective of farm households, risk can reduce welfare in several important ways.

Risk management involves choosing among alternatives to reduce the effects of risk and this typically requires the evaluation of trade-offs between changes in risk, expected returns, and other variables (Harwood *et al.*, 1999). Because risks in agriculture is a continuum, different instruments (risk management strategies and tools) are best suited to address different these risks. The empirical literature describes risk management based on different taxonomies or typologies. These include; *risk mitigation/reduction, risk transfer, and risk coping* (Walker and Jodha, 1986; Singla and Sagar, 2012; Barnett *et al.*, 2008; D'Alessandro *et al.*, 2015; Demeke *et al.*, 2016; World Bank, 2016; Edema *et al.*, 2017; Gessesse and Zerihun, 2017). *Reduction, mitigation and coping* (Siegel and Alwang, 1999; Holzmann and Jørgensen, 2001; OECD, 2009). Risk reduction strategies are those meant to reduce or minimize the likelihood of the occurrence of an uncertain event which would negatively affect welfare. Risk mitigation strategies on the other hand do not only moderate the likelihood of risk occurrence but also offsets any welfare losses following realization of the event. Such strategies are therefore taken prior to the realization of a risky event to lower the probability of a risky event.

Strategies under this typology have been found to be particularly useful for risks that occur with relatively high frequency but with lower impact intensity. Risk transfer strategies encompasses tools or mechanisms that transfer the potential financial consequences of particular risks from one party to a willing third party, usually for a fee or premium. Such transfer strategies are useful for risks that occur with relatively low frequency but with medium loss probabilities. Risk coping strategies involves tools to deal with an event once it has occurred. They seek to help farm households to better absorb and recover from the impacts of a risk and are appropriate for very low frequency but with very high loss probabilities. Risk management could also be based on *sources of risk in farming* such as production, marketing, financial, institutional, and human and personal risk management tools (Baquet *et al.*, 1997; Musser and Patrick, 2002; Kahan, 2008; Aditto *et al.*, 2012; Crane *et al.*, 2013; Obiri and Driver, 2017).

Furthermore, risk management can be based on a matrix of *informal, formal, ex ante and ex post risk management strategies* (World Bank, 2001b; Lilleor *et al.*, 2005; World Bank, 2005b) or *Ex ante tools and ex post tools* (Chetaille *et al.*, 2011). Here, informal strategies are those practiced at the micro or farm level by farmers, whereas formal strategies are institutional and driven by national governments. *Ex* ante or *ex* post typology focuses on the point at which the reaction to risk takes place. In particular, *ex* ante strategies are those taken before the realization of a risky event to lower the probability of a risky event. In the nutshell, *ex* ante measures are synonymous with the risk reduction/mitigation and transfer strategies described earlier and are used when there is an anticipation of variation farm income. *Ex* post strategies are those taken after a risk event has occurred and are synonymous to risk coping strategies. They are used in response to the variation of farm income. Another risk management typology described in the empirical literature is *risk prevention and treatment* (Chetaille *et al.*, 2011). Here risk prevention strategies are meant to either reduce the probability of loss or to reduce the impact of the loss (or both). Because prevention strategies are not enough or applicable in every case, risk treatment strategies are meant to limit the negative impacts of risk on income and there are three subcategories of risk treatment which are; assumption, transfer and safety nets.

Miller *et al.*, (2004) also classifies risk management strategies into *avoidance, reduction, assumption/ retention and transfer*. Risk avoidance as a strategy involves structuring farm enterprises so that certain types of risk are non-existent. Risk assumption/retention strategies are basically employed because not all risks are transferable hence risk assumption/retention involves retaining or accepting risks with the objective that assuming such increased risk helps to maintain control and/or enhance overall profitability. Alderman and Paxson (1994) have also classified risk management into *risk management strategies and risk coping strategies*. Where risk management strategies involve actions to reduce the variability of income.

For the sake of brevity, risk management actions can be implemented at both the micro and macro-level. Micro-level actions are undertaken by farm households, with the goal of risk management decisions to protect assets and improve resiliency and these actions are the focus of the current study. On the other hand, macro-level actions are those implemented at a national level with various risk management strategies being incorporated into sectorial growth and investment and policy decisions. Farm households employ different risk management strategies and tools under the various typologies described earlier and the literature documents a vast number of these strategies used to offset the adverse effects of risk and income shortfalls. Some of these include choosing to produce lower risk outputs (Rosenzweig and Binswanger, 1993; Bardhan *et al.*, 2000; Dercon, 2005; Carter and Barrett, 2006; Barnett *et al.*, 2008; Kahan, 2008), employing risk reducing inputs or technologies (Holzmann and Jørgensen, 2001; World Bank, 2005b; Barnett *et al.*, 2008; Kahan, 2008; Schaffnit-Chatterjee, 2010; Chetaille *et al.*, 2011; Breen *et al.*, 2013; Obiri and Driver, 2017), informal risk-sharing arrangements such as share tenancy contracts, traditional money-lending, and risk sharing within extended family and other community networks (Zeuli, 1999; Anderson, 2001; Barnett *et al.*, 2008; Kahan, 2008), and diversifying income sources through multiple farm enterprises or off-farm activities (Mishra and Goodwin, 1997; Harwood *et al.*, 1999; Adger *et al.*, 2003; Benin *et al.*, 2004; Mishra and El-Osta, 2002; Kijima *et al.*, 2006; Matsumoto *et al.*, 2006; Barnett *et al.*, 2008; Di Falco and Chavas, 2009; Deressa *et al.*, 2010; Di Falco *et al.*, 2010; Tangermann, 2011; Bezabih and Sarr, 2012; Bezabih and Di Falco, 2012; Ullah and Shivakoti, 2014; Obiri and Driver, 2017; Birthal and Hazrana, 2019). Others include formal insurance such as index-based

insurance products (Wang *et al.*, 1998; Martin *et al.*, 2001; Turvey, 2001; Vedenov and Barnett, 2004; Barnett *et al.*, 2005; World Bank, 2005a,b; Deng et al., 2007a,b; Huirne *et al.*, 2007; Barnett *et al.*, 2008; Kahan, 2008; Velandia *et al.*, 2009; Enjolras *et al.*, 2012; D'Alessandro *et al.*, 2015; Wang *et al.*, 2016; World Bank, 2016; Obiri and Driver, 2017; Poole, 2017), informal insurance such as dependence on relatives and neighbours for material and moral support (World Bank, 2005a,b, 2016), agronomic practices such as conservation farming practices, mulching, sustainable land management etc. (World Bank, 2016; Baiyeri and Aba, 2017; Obiri and Driver, 2017), production and market (sales) contracts (Makus *et al.*, 1990; Harwood *et al.*, 1999; World Bank, 2005b; Kahan, 2008; Breen *et al.*, 2013), and household coping strategies such as labour market participation, reduced consumption, sales of assets etc. (Rosenzweig and Wolpin, 1993; Fafchamps, 1999; Dixon *et al.*, 2001; Skees *et al.*, 2002; Belay *et al.*, 2005; Devereux and Guenther, 2007; Kahan, 2008; Deressa *et al.*, 2010; Demeke *et al.*, 2016; World Bank, 2016).

Even though the strategies outlined above are very important for risk and vulnerability reduction, there is an implied risk premium or cost for all of these risk management strategies which can be very high (Rosenzweig and Binswanger, 1993; Morduch, 1995; Zimmerman and Carter, 2003; Deressa *et al.*, 2010; World Bank, 2016). For instance, the implied risk premium for self-insurance strategies employed by farm households such as diversification, producing lower risk outputs, or employing risk reducing inputs or technologies is either the explicit or the opportunity cost of undertaking the strategy. According to Kahan (2008), the cost could be expressed by the amount of resources tied up in order for a farm household to manage their risks more effectively. Such implied costs are easy to identify in some instances, while in others, the cost is less recognisable. At the same time, some of these risk management strategies can potentially generate adverse external effects. Dercon (1996), Skees *et al.*, (2002) and Barrett and Swallow (2006) for instance observed pecuniary externalities in the case of distress asset sales following covariate shocks. For example, mass selling of livestock during a major shock such as drought can drive livestock prices down in situations where covariate risks have impacts across large regions, hence bringing no increase income gains for households. Furthermore, some authors (see Rosenzweig and Binswanger, 1993; Zimmerman and Carter, 2003) also tend to suggest the occurrence of such impacts even in the case of localized adverse shocks if markets for the asset are not spatially integrated. As pointed out earlier, traditional or household-level risk-management strategies are mostly ineffective (Skees *et al.*, 2002; World Bank, 2005a) because they only achieve partial risk coverage at a very high cost and are in some cases localized and limited in scope. In addition, informal risk transfer measures such as socially constructed reciprocity obligations within various social networks, semi-formal microfinance, rotating savings and credit marginalize the most vulnerable and have high hidden costs (World Bank, 2001a,b, 2005a,b). Empirical evidence (see Platteau, 1997; Jalan and Ravallion, 1999; Santos and Barrett, 2006) also suggest that access to these informal risk transfer measures are positively related to social factors such as existing wealth, meaning this can prevent reciprocity obligations and hence the poorest of the poor have little to gain from such arrangements. At the same time, such arrangements are fragile, inequitable and untimely and can leave individuals exposed to risk while at the same time creating a dependency that has dire consequences (Carter, 1997; World Bank, 2005a). Since covariate agriculture shocks often affect entire regions, local mutual insurance schemes can break-down (Hazell, 1992; Dercon, 1996, 2002; Anderson, 2001; Skees *et al.*, 2002; Rosenzweig and Binswanger, 1993; Townsend, 1994; Zimmerman and Carter, 2003).

Also, some empirical studies (see Rosenzweig and Binswanger, 1993; Morduch, 1995; Kurosaki and Fafchamps, 2002) have found considerable efficiency losses associated with risk mitigation, typically due to lack of specialization due to the need for farmers to make trade-offs between income variability and profitability. Skees *et al.*, (2002) also observed that ex post risk management strategies involving coping measures such as reduced consumption and sales of assets are costly. Some authors (see Bhandari *et al.*, 2007; Barnett *et al.*, 2008; Amare *et al.*, 2018) suggest that farm households that use risk coping mechanisms are unable to recover the loss of assets *ex* post the shock. Hence, liquidating productive assets may also not be a viable risk management option for the poorest of the poor (Barnett *et al.*, 2008) with empirical evidence (see Zimmerman and Carter, 2003; Kazianga and Udry, 2006) suggesting that extremely poor households recognize the danger of such sales of assets and thus choose to waive consumption (e.g. reduced expenditures on school fees, health care, and food consumption) rather than further liquidating assets. This can reduce in the nutshell the value of human assets, further presenting not only a barrier to poverty alleviation, but also reinforces poverty (Hoddinott and Kinsey, 2001; Dercon and Hoddinott, 2003; Thomas *et al.*, 2004; Hoddinott, 2006; Kouamé, 2010). The World Bank (2005b) also observed that the need of households to smooth consumption against idiosyncratic and correlated shocks which they do through coping strategies, comes at a serious cost in terms of production efficiency and reduced profits, thus lowering the overall level of household consumption.

Diversification as a risk management strategy can hinder development since gains are possible when households specialize (Skees *et al.*, 2002). Furthermore, diversification may not actually spread certain types of risk, in particular, weather events that cause widespread losses. Implying that when covariate risks occurs, it may impact a variety of sources of income such own farm, agricultural labour, and non-farm income hence diversification may not necessarily be an effective strategy (Skees *et al.*, 2002). Furthermore, diversification could imply farmers shift the share of land use under high value crops such as cash and permanent crops and this reallocation can have a detrimental effect on agriculture income. Furthermore, diversification can lower the yields of cash crops relative to staple crops, and potentially increase the level of staple crops planted. This is because farmers devote a larger share of land to safer, traditional varieties or staple crops than to riskier high-yielding varieties or value crops (Morduch, 1995; Salazar-Espinoza *et al.*, 2015). In the nutshell farmers tend to use resources sub-optimally leading to less productivity on average than other strategies that farmers could have followed if risk could be ignored for instance (Anderson, 2001). Other studies (see Purdy *et al.*, 1997; Barry *et al.*, 2001; Poon and Weersink, 2011) have also shown that farm enterprise diversity does not always lower farm income volatility, suggesting that encouraging a wider mix of enterprises is not always an effective strategy to reduce fluctuations in farm income. In a study of the effects of multiple enterprises on reducing risk for Saskatchewan farmers, Schoney *et al.*, (1994) observed that slight risk reduction was obtained by diversifying beyond two or three crop portfolios. In addition, the aforementioned authors observed that, despite several crops typically having a risk-reducing effect on the portfolio, these benefits were typically offset by the lower gross incomes linked with such levels of diversification.

Index-based insurance products in agriculture serves two main purposes, reducing vulnerability by compensating producers for the economic losses suffered from insured events and increasing productivity through increased investment by securing credit in case of loan default due to insurable events (Barnett *et al.*, 2008; Kouamé, 2010; D'Alessandro *et al.*, 2015).

However, despite index-based insurance products being a powerful ex ante instrument to address risk before it materializes, one significant limitation is the existence of basis risk (Miranda and Vedenov, 2001; World Bank, 2005b; Barnett *et al.*, 2008; Hazell *et al.*, 2010; Jensen and Barrett, 2017; Jensen *et al.*, 2018). With basis risk, it is possible for a farm household to experience a loss and yet not receive a payment. Concurrently, it is also possible that the household will not experience a loss and yet receive a payment. Basis risk occurs because the index upon which the insurance is developed is not perfectly correlated with farm-level losses (Barnett *et al.*, 2008). The effectiveness of index-based insurance as a risk management tool is therefore dependent on how positively farm-level losses are correlated with the underlying index (World Bank, 2005b).

In using a field experiment in Mali, Elabed and Carter (2015) show that behavioural factors related to basis risk affected insurance demand and showed that farmers disliked the uncertainty of insurance payments with this behavioural reaction generating a drop-in insurance demand from approximately 60% to 35% when compound-risk aversion (the aversion to original uncertainty of shocks and uncertainty of insurance payments or basis risk) was taken into consideration. Similarly, studies by Jensen *et al.*, (2018) and Clarke (2016) shows that basis risk deter insurance purchase. Even though several studies (see Wang *et al.*, 1998; Black *et al.*, 1999; Martin *et al.*, 2001; Turvey, 2001; Vedenov and Barnett, 2004; Barnett *et al.*, 2005; Deng *et al.*, 2007) having empirically examined the effectiveness of index-based insurance products with mixed results, Barnett *et al.*, (2008) argues that they can be highly effective risk management tool if basis risk is relatively small and ineffective if basis risk is large. Furthermore, agricultural insurance is often characterized by high administrative costs, due, in part, to the risk classification and monitoring, data acquisition needed to establish accurate premium rates and conducting claims adjustments (World Bank, 2005b). Some studies have also found contradictory impacts of insurance.

For example, Giné and Yang (2009) finds index insurance contracts to significantly reduce investment in a new agricultural opportunity. De Nicola (2015) finds that in cases where single, low-technology options are available, insurance tends to reduce total input investments, and it weakens farmers' precautionary motives to overinvest. Farrin and Murray (2014) reports of a negative effect of insurance on wealth, as in good years farmers pay a premium but do not receive an indemnity payment. Giné *et al.*, (2010) also observed that index-insurance products could only improve welfare if other risk-sharing mechanisms employed by households are insufficient. Dercon *et al.*, (2014) argues that index-insurance is particularly beneficial to groups that are able to hedge idiosyncratic risks in an informal manner. Some insurance schemes have also been observed to reduce the use of production diversification, or reduces and even eliminate the demand for other formal risk hedging/transfer products (Schaffnit-Chatterjee, 2010). Supplementary to risk management strategies employed by farm households, public risk-management strategies targeting farm households also have limitation in terms of coverage, weak institutional linkages among stakeholders who deal with risk management, poor early warning mechanisms, and dependence on foreign sources (World Bank, 2005a; Devereux and Guenther, 2007).

3.0 Conceptual framework

The conceptual framework used in this study is based on farm households' decisions to adopt risk management strategies that help them to offset the adverse effects of risk and income shortfalls. At the farm household level, risk management strategies are basically aimed at enhancing expected return while reducing volatility. Following Kim and Chavas (2003); Koundouri *et al.*, (2006) and Mukasa (2018) we model farm households' choice of agricultural risk management tools in an expected utility framework. Just like farm households having to make production decisions before climatic and other risks are realized, the adoption of risk management strategies follows a situation where farm households are uncertain about the outcome of their decisions. Therefore, the adoption of risk management strategies is related to uncertain prospect, which one can reduce to a probability distribution over a domain of possible payoffs. Hence, decision-making by farm households therefore boils down to a choice between different possible probability distributions of returns, herein agricultural incomes.

We therefore assume that each risk management strategies are associated with certain probability distribution of agriculture incomes which is directly unknown to the farm households. Farm households are confronted with a situation where they must choose from among a set of risk management strategies that maximizes their subjective expected returns. Households select from a finite set of risk management strategies (mitigation, transfer, and coping) to maximize[3] the impact of risk management strategy on their income. More importantly as shown in figure 1, adoption of the various risk management practices is associated with different effects, herein dispersions around the means of agriculture income. From figure 1a, if we assume that agriculture incomes follow a normal distribution and π is the mean or average household agriculture income, then an adopted risk management strategy can; a) reduce the dispersion or variation around π (i.e. the areas between τ_1 and τ_2) or b) increase the dispersion or variation around π (i.e. the areas between φ_1 and φ_2). In the same fashion, risk management strategies could have different effects on the skewness distribution of household incomes (figure 1b). It could lead to a) negative skewness distribution (i.e. φ_1) or b) positive skewness distribution (i.e. φ_2).

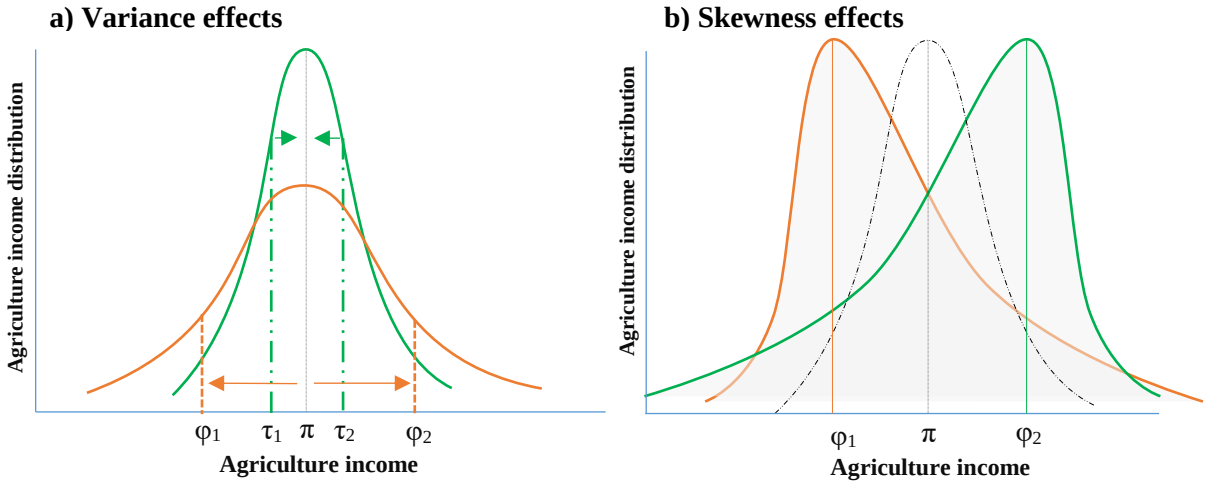

Figure 1: Dispersion effect of risk management strategies on incomes

[3] In this context we assume farm households select risk instruments that maximizes agriculture incomes but minimizes dispersions around of incomes.

Furthermore, adoption decisions on these risk management strategies are made without knowing which outcomes may result from such decisions, hence farm household decision making occurs under uncertainty. The risk management strategies in this finite set are also mutually exclusive, therefore the choice of one implies rejection of the others. We assume that a farm household decisions are based on whether or not to adopt any, some, or all of the risk management strategies, j available to them ($j = 1,...., M$).

In light of this, we assume that farm households will choose risk management strategies that will result in the highest expected utility. Households will maximize their expected utility $E[u(k)] = \int k\, f(k)u(k)$, where $u(k)$ is a real-valued function representing the utility obtained from a risk management strategy k, and $f(k)$ is the probability density function of k.

3.1 Empirical strategy

In a multiple risk management strategies adoption setting, farm households' simultaneous use[4] of these strategies (risk mitigation, transfer, and coping) leads to eight[5] (2^3) possible combinations (portfolio) of strategies that farm households could choose from (Table 1). Because of the simultaneous use of these strategies, failing to account for the fact that farm households can adopt several risk management strategies simultaneously, can lead to biased estimates as the overall effect of adoption is not necessarily equal to the sum of the effects of adopting each strategy separately (Wu and Babcock, 1998). Farm households' decisions to adopt these combinations of strategies may not also be random and they may endogenously self-select into adoption or non-adoption. Therefore, decisions are likely to be influenced systematically both by observed and unobservable characteristics that may be correlated with the outcomes of interest herein agriculture income and standard deviation of agriculture income. Such unobservable characteristics may include for example the innate managerial and technical abilities of the farmers in understanding and using risk management strategies or the types of social networks formed by farmers that are not captured, such as the kind of neighbours the farmer communicates with and whether such neighbours have adopted the risk management strategy. Inability to therefore capture these unobservable characteristics may lead to selection bias.

Table 1: Risk management portfolios available to farm households

Risk Management Portfolio	Portfolio ID	Risk mitigation	Risk transfer	Risk coping	Frequency (%)
Base category - no strategy	RMP0	×	×	×	5.38
Risk mitigation	RMP1	✓			59.13
Risk transfer	RMP2		✓		0.83
Risk coping	RMP3			✓	19.07
Risk mitigation + transfer	RMP4	✓	✓		1.56
Risk mitigation + coping	RMP5	✓		✓	13.08
Risk mitigation + transfer + coping	RMP6	✓	✓	✓	0.24
Risk transfer + coping	RMP7		✓	✓	0.70

[4] Empirical evidence suggests that farm households use a combination or a portfolio of risk management strategies to deal with adverse effects of risk. These have already been discussed at length in the literature review section. We provide the individual strategies before the aggregation into the three risk management typologies in Appendix A1.

[5] Due to fewer observations risk management portfolio RMP6 was dropped. We observed 13 observations under this risk management portfolio.

Hence, to disentangle the pure effects of adoption, we model the farm households' choice of risk management portfolio and the impacts of adoption in a multinomial endogenous switching regression framework. This approach is a selection-bias correction methodology based on the multinomial logit selection model developed by Bourguignon *et al.*, (2007). This approach allows us to firstly, obtain both consistent and efficient estimates of the selection process and a reasonable correction for the outcome equations, even with violations of the axiom of the independence of irrelevant alternatives (IIA). Secondly, it allows us to evaluate both individual risk management strategies and combined strategies (portfolios), while capturing the interactions between the choices of alternative portfolios. Estimation of the multinomial endogenous switching regression occurs simultaneously in two steps. In the first stage, farm households' choices of risk management portfolios are modelled using a multinomial logit selection model, while recognizing the inter-relationships among the portfolios. The respective parameters are also estimated and then used to calculate the selection-bias correction (or selectivity) terms.

In the second stage, the selection-bias correction terms together with the probability of each risk management portfolio being chosen are incorporated into as covariates to estimate the impacts of portfolios on agriculture income and the standard deviation of agriculture incomes using ordinary least squares (OLS). Following the studies of Di Falco and Veronesi (2013); Kassie *et al.*, (2015); Teklewold *et al.*, (2017) and Vigani and Kathage (2019) we describe the empirical econometric approach used in the study below.

Stage I: Multinomial Adoption Selection Model

Farm households are assumed to maximize their expected revenues by using a portfolio of risk management strategies. Let Y^*_{ij} be the latent variable that captures the expected net revenues from the use of a risk management portfolio *j (j=1……..M)* with respect to implementing any other portfolio *k*. We specify the latent variable as

$$Y^*_{ij} = X_i\varpi + \varepsilon_{ij} \qquad [1]$$

Equation [1] includes a deterministic component ($X_i\varpi$), and an idiosyncratic unobserved stochastic component ε_{ij}. The deterministic component is a latent variable determined by observed household characteristics such as age, gender, education of the household head, farm household size, asset ownership, plot, soil fertility and climatic characteristics (e.g. mean rainfall and temperature). While the unobserved stochastic component captures all the variables that are relevant to the farm household's decision maker but are unknown to the researcher such as skills or motivation. The utility obtained by farm households from choosing among the risk management portfolios is not directly observable, but the adoption decision is observable. A farm household *i* will choose a risk management portfolio *j* if it provides expected returns greater than any other portfolio if:

$$Y_i \begin{cases} 1 \text{ iff } Y_{i1}^* > \max_{k \neq 1}(Y_{ik}^*) \text{ or } \varepsilon_{i1} < 0, \\ \vdots \qquad \vdots \qquad\qquad \vdots \qquad \text{for all } k \neq j. \\ M \text{ iff } Y_{iM}^* > \max_{k \neq M}(Y_{ik}^*) \text{ or } \varepsilon_{iM} < 0, \end{cases} \qquad [2]$$

The formulation in equation [2] implies that the *i*th farm household will adopt a risk management portfolio *j* to maximize their expected benefit if it provides greater expected utility than any other risk management portfolio $k \neq j$, i.e. if $\varepsilon_{ij} = \max_{k \neq 1}(Y_{ik}^*) < 0$. It is assumed that the covariate vector X_i in equation [1] is uncorrelated with the idiosyncratic unobserved stochastic component ε_{ij}, i.e. $E(\varepsilon_{ij} \mid X_i) = 0$. Under the assumption that ε_{ij} is identically and independently Gumbel distributed, the probability of the *i*th farm household with characteristics *X* choosing the *j*th risk management portfolio can therefore be specified by a multinomial logit model (McFadden, 1974) as:

$$P_{ij} = P(\varepsilon_{ij} < 0 | X_i) = \frac{\exp(X_i \varpi_j)}{\sum_{k=1}^{M} \exp(X_i \varpi_k)}. \qquad [3]$$

The parameter estimates of the latent variable model can be estimated by maximum likelihood estimation. In our specification, the base category, non-adoption of any risk management portfolio (see Table 1), is denoted as $j = 1$. In the remaining portfolios ($j = 2, \ldots, 7$), at least one portfolio is used by a farm household.

Stage II: Multinomial Endogenous Switching Regression Model

In the second stage, we estimate a multinomial endogenous switching regression model to investigate the impact of each risk management portfolio on agriculture income and the standard deviation of agriculture incomes by applying the Bourguignon *et al.*, (2007) selection bias correction model. Our model implies that farm households face a total of *M* regimes (one regime per risk management portfolio, where $j = 1$ is the reference category "base or non-adapting category"). We assume that the vector of outcome variables is a linear function of explanatory variables. Hence, the stochastic function to evaluate agriculture income and the standard deviation of agriculture incomes implications of each risk management portfolio for each regime *j* is given as:

$$\text{Regime 1: } Q_{i1} = Z_i\beta_1 + \alpha_{i1}\overline{Z}_{i1} + \mu_{i1} \text{ if } A_i = 1 \qquad [4a]$$
$$\vdots \qquad\qquad \vdots \qquad\qquad , \qquad\qquad \vdots$$
$$\text{Regime M: } Q_{iM} = Z_i\beta_M + \alpha_{iM}\overline{Z}_{iM} + \mu_{iM} \text{ if } A_i = M \qquad [4m]$$

where Q_{ij} is the outcome variable of farm household *i* in regime *j*, (j = 1, …. , *M*), and Z_i represents a vector of inputs, and farm household head and household's characteristics, asset ownership, soil fertility and climatic characteristics (e.g. mean rainfall and temperature) included in X_i. β and α represents the corresponding vector of coefficients to be estimated. μ_{ij} represents the unobserved stochastic component, which verifies $E(\mu_{ij} \mid Z_i, X_i) = 0$ and $V(\mu_{ij} \mid Z_i, X_i) = \sigma^2_j$. In addition, to overcome the possible correlation of farm-invariant unobserved

heterogeneity with observed covariates, we employed the approach of Mundlak (1978) and Wooldridge (2018) which has also been used by Di Falco (2014), Kassie *et al.*, (2015), Teklewold *et al.*, (2017) and Vigani and Kathage (2019)[6]. Controlling for unobserved heterogeneity, is particularly important to help address farm or plot-specific unobservables as they may contain useful missing information regarding land quality (Kassie *et al.*, 2015) for instance. Concurrently, if farm households obtain private information about unobservable effects such as how good the soil is on the plot or some shocks, they will adjust their factor input decisions accordingly (Fafchamps, 1993; Levinsohn and Petrin, 2003; Assunção and Braido, 2007). Hence, this approach allows us to exploit crop and farm household-level information to deal with the issue of farm household's unobservable characteristics such as their skills (human capital). Furthermore, crop-level information can potentially control for farm specific effects. We exploit crop-level information and include the mean of crop varying $\overline{Z}$ explanatory variables, which include land holding, fertilizer quantity and seed quantity to deal with the issue of unobserved heterogeneity. According to Teklewold *et al.*, (2013), a Wald test of the null hypothesis that the vectors α are jointly equal to zero is required to indicate the relevance of crop-specific heterogeneity.

For each sample observation, Q_{ij} is observed if and only if one among the M dependent regimes is observed. When estimating an ordinary least squares (OLS) model, the outcomes of interest, agriculture income and the standard deviation of agriculture income equations [4a]–[4m] are estimated separately. However, if the error terms of equation [1], ε_{ij} are correlated with the error terms μ_{ij} of the outcome model [4a] – [4m], then the expected values of μ_{ij} conditional on the sample selection are nonzero i.e., corr(ε_{ij}, μ_{ij}) $\neq 0$, and the OLS estimates will be biased and inconsistent. To correct for the potential inconsistency, we employ the multinomial endogenous switching regression model by Bourguignon *et al.*, (2007), which takes into account the correlation between the error terms ε_{ij} from the multinomial logit model estimated in the first stage and the error terms from each outcome equation μ_{ij}. Bourguignon *et al.*, (2007) show that consistent estimates of β and α in the outcome equations [4a]–[4m] can be obtained by estimating the following selection bias-corrected agriculture income and the standard deviation of agriculture income equations:

$$\begin{aligned} &\text{Regime 1:} \quad Q_{i1} = Z_i\beta_1 + \alpha_{i1}\overline{Z}_{i1} + \sigma_1\tau_{i1} + v_{i1} \text{ if } A_i = 1 && [5a] \\ &\quad\vdots \qquad\qquad\qquad \vdots \qquad\qquad\qquad\qquad , \qquad\qquad \vdots \\ &\text{Regime M:} \quad Q_{iM} = Z_i\beta_M + \alpha_{iM}\overline{Z}_{iM} + \sigma_M\tau_{iM} + v_{iM} \text{ if } A_i = M && [5m] \end{aligned}$$

where, v is the error term with an expected value of zero, σ is the covariance between ε_{ij} and μ_{ij}, τ is the inverse Mills ratio computed from the estimated probabilities in equation [3] as follows:

$$\tau_i = \sum_{k\neq j}^{j} \rho_j \left[\frac{\hat{P}_{ki}\ln(\hat{P}_{ki})}{1-\hat{P}_{ki}} + \ln\left(\hat{P}_{ji}\right)\right]; \rho$$

where $\hat{P}$ represents the probability that farm household i chooses risk management portfolio j as defined in equation [3], ρ_j is the correlation between ε_{ij} and μ_{ij}. The specification in equation

[6] In most of these studies, plot-variant variables were used to control for unobserved heterogeneity but due to the lack of plot-level data we use an alternative approach by using crop and farm household-variant variables since household produce multiple crops and we have crop-level data. In addition, we include the mean of crop-variant production cost because in our data we observed some cost related to the use of lubricants, pesticides, electricity and fuel and not the physical quantities of these inputs. A Wald test of the joint significance of mean of crop-variant production cost and the other crop variant variables in our model was significant, hence giving a justification for the inclusion.

[5a – 5m] implies that the number of selection correction (bias) terms in each equation is equal to the number of multinomial logit choices M.

The specified model allows us to identify not only the direction of the bias related to the allocation of farm households in a specific portfolio, but also which choice among any two alternative portfolios these bias stems from. For example, a positive bias correction coefficient related to alternative *j* selection equation in the alternative *k* outcome (e.g. agriculture income) equation highlights higher agriculture incomes of farm households who chose alternative *k* compared to farm households taken at random, due to the allocation of farm households with worse unobserved skills out of alternative *k* into the alternative *j*. In the nutshell, for each portfolio-based outcome estimation, a negative (positive) selectivity coefficient related to any of the alternative portfolio indicates lower outcomes than those of randomly chosen farm households on account of the allocation of farm households with better (worse) unobserved characteristics out of the given portfolio and into the respective alternative risk management portfolio.

Estimating the standard deviation of agriculture incomes

Ideally in estimating dispersions around agriculture income, panel or longitudinal data will be the most appropriate to observe risk management strategies and dispersions around agriculture incomes over time. But since we only have cross sectional data for this study, we employ an alternative approach to observe dispersions around agriculture incomes. In line with previous studies (see Kim and Chavas, 2003; Koundouri *et al.*, 2006; Di Falco *et al.*, 2007; Di Falco and Chavas, 2009; and Kassie *et al.*, 2015; Mukasa, 2018), the estimation strategy for the standard deviation of agriculture income consisted of computing moments of the income function. The moment-based approach has been widely used in the literature as an indicators of risk exposure. Furthermore, the central moment moments around the mean is widely considered as a proxy for downside risk or the probability of losses. According to Antle (1983), maximization of the expected utility of profit $E[U(\pi)]$ is equal to the maximization of the relevant moments of the risk exposure (e) distribution conditional on inputs use. To proceed with the estimation process, we first estimated each regime net agriculture income function and then used the residuals to compute the simple moments (variance and skewness) for each farm household. The mean equation of agriculture income is estimated as follows:

$$R_{V_{ij}} = H_i\phi_1 + \gamma_{i1}\overline{H}_{i1} + \Psi_{i1} \qquad [6]$$

where $R_{V_{ij}}$ is the mean agriculture income of farm household i in regime j, H_i is a vector of variables assumed to influence the mean agriculture income functions; $\overline{H}_i$ is a vector of inputs used that may shift the farm production, these includes fertilizer, seed and labour use, land size, soil fertility etc.; and Ψ denotes error terms distributed with mean zero $E(\Psi_{ij}) = 0$. ϕ and γ are vectors of parameters to be estimated and associated with H and $\overline{H}$, respectively. If we assume that the independent variables in equation [6] are exogenous, then we can consistently estimate

equation [6] by using OLS[7]. The first moment of agriculture income is then estimated as follows:

$$f(H_i, \phi_i, \gamma_i, \overline{H}_i) \equiv E\left[R_{V\,ij}(H_i, \overline{H}_i, e)\right] \quad [7]$$

The higher moments of agriculture income can be written as follows:

$$E\left[R_{V\,ij}(H_i, \overline{H}_i, e) - f(H_i, \phi_i, \gamma_i, \overline{H}_i)^k | H\right] = f_k(H_i, \phi_i, \gamma_i, \overline{H}_{ik}) \text{ where } k = 1,2,3 \quad [8]$$

where $k = 1$ is the mean agriculture income functions, $k = 2$ and $k = 3$ are the second (variance) and third (skewness) central moments of agriculture income functions under each risk management portfolio respectively. The standard deviation[8] of agriculture incomes is then estimated as the squared root of second central moment (variance) of agriculture incomes. We then use the estimated standard deviation of agriculture income functions as dependent variables in equations [5a] – [5m] to estimate the impact of the adoption of each risk management portfolio on dispersions around agriculture income.

While the variables X_i in equation [1] and Z_i in equation [5a] – [5m] are allowed to overlap, proper identification requires at least one variable (instrument) in X_i that does not appear in Z_i. However, finding true instruments in empirical work is sometimes challenging, or even impossible (Kassie *et al.*, 2015; Ng'ombe *et al.*, 2017). Therefore, the selection equation [1] is estimated based on all explanatory variables specified in the outcome equations plus at least one or more instruments. Following Di Falco and Veronesi (2013), we establish the admissibility of the selected instruments by performing a simple falsification test: the selected or valid instrument (s) is required to significantly influence a farm household's choice of risk management portfolio but have no significant effect on outcomes (i.e. agriculture income and standard deviation of agriculture incomes). We also followed Stock *et al.*, (2002) and examined the strength of the instruments based on the F-statistic. In this study, we employ membership of a farmer-based organization[9], insurance needs and knowledge as identifying instruments. As shown by Antle (1983) the error terms in equations [5a] – [5m] are likely to exhibit heteroscedasticity, hence following Bourguignon *et al.*, (2007), we bootstrapped the standard errors to deal with heteroscedasticity in the second stage.

Estimation of the treatment and counterfactual effects

The adoption of risk management strategies by farm households could result in positive welfare outcomes for households. However, estimating such outcomes in observational studies such as this one is important because of the difficulty of observing the counterfactual outcomes. In cases where experimental data are involved or available through randomized control trials for instance, information on the counterfactual situation would normally be provided, and as such, the problem of causal inference can easily be resolved (Miguel and Kremer, 2004). The challenge of impact evaluation using observational data is to estimate the counterfactual

[7] We employed four different specification; linear, log-linear, linear-log and quadratic for the mean agriculture income equation. By observing the AIC and BIC with each specification, we settled for the log-linear specification because it produced the smallest values for AIC and BIC.
[8] It must be noted that the standard deviation estimated here are nothing other than the residual standard deviation. Most of the literature have used variance, skewness and kurtosis extensively, however this does not meet the interest of our paper, hence we transformed the second central moment (variance) into standard deviations. This is more advantageous because standard deviation is expressed in the same units as agriculture, hence making it more intuitive and informative.
[9] Vigani and Kathage (2019) in their study used membership of a farmer's union as instrument.

outcome, which is the outcome of interest when farm households that adopted a particular risk management portfolio could have gained had they not adopted that portfolio. Di Falco (2014), argues that in the absence of a self-selection problem, it would be appropriate to assign to farm households that adopted a counterfactual outcome of interest equal to the average outcome of interest of non-adopters with the same observable characteristics. However, unobserved heterogeneity in the propensity to choose a risk management portfolio also affects the outcome of interest and creates a selection bias in the outcome of interest equation (i.e. [5a] – [5m]) that cannot be ignored. The Multinomial Endogenous Switching Regression framework however can be used to examine average treatment effects (ATT) by comparing expected outcomes of adopters with and without adoption. Following Bourguignon *et al.*, (2007), we first derive the conditional expected outcome of interest (agriculture income and standard deviation of agriculture income) of farm households that adopted, which in our study means $j = 2$……..M ($j = 1$ is the reference category "non-adoption") from equation [5a] – [5m], as

$$E(Q_{i2}|A_i = 2) = Z_{i2}\beta_2 + \alpha_{i2}\overline{Z}_{i2} + \sigma_2\tau_{i2} \quad [9a]$$
$$\vdots \quad . \quad \vdots$$
$$E(Q_{iM}|A_i = M) = Z_{iM}\beta_M + \alpha_{iM}\overline{Z}_{iM} + \sigma_M\tau_{iM} \quad [9m]$$

Then, we obtain the expected outcome of interest of farm households that adopted risk management portfolio j in the counterfactual hypothetical case that they did not adopt ($j = 1$) as

$$E(Q_{i1}|A_i = 2) = Z_{i2}\beta_1 + \alpha_1\overline{Z}_{i2} + \sigma_{i1}\tau_{i2} \quad [10a]$$
$$\vdots \quad . \quad \vdots$$
$$E(Q_{i1}|A_i = M) = Z_{iM}\beta_M + \alpha_{iM}\overline{Z}_{iM} + \sigma_{iM}\tau_{i1} \quad [10m]$$

Equations [9a] – [9m] represent the actual expected outcomes of interest (agriculture income and standard deviation of agriculture income) actually observed in the sample for adopting farm households, while equations [10a] – [10m] are their respective counterfactual expected outcomes of interest. The use of these conditional expectations allows us to calculate the average treatment effects (ATT) – i.e. the treatment effect for treated farm households, which is the difference between equations [9a] and [10a] or [9m] and [10m] as an example.

Method for addressing potential endogeneity

An issue that needs to be addressed in estimating equation [1] is the potential endogeneity problem that may arise. It is therefore important to account for any potential reverse causality between the adoption decision of risk management strategies and the outcomes of interest. A potential source of endogeneity identified in the empirical literature comes from the risk attitude of a farmer. The risk profile or risk perception of a farmer may influence the choice of risk management strategy. Risk management strategies employed by a farmer can potentially correlate to his or her risk profile or risk perception. Studies by Pennings and Leuthold (2000), Miyata (2003), Sherrick *et al.*, (2004), Wik *et al.*, (2004), Pennings *et al.*, (2008), Kouamé (2010), Dercon and Christiaensen (2011), Theuvsen (2013), Ullah and Shivakoti (2014), Ullah

et al., (2015), Meraner and Finger (2017), and Asravor (2019) all show that farmers' risk attitudes are positively correlated with the choice of risk management strategy. Since some of the risk management strategies employed by farmers are technologies and management practices based, farm households having access to agricultural extension agents might be encouraged to adopt these strategies. At the same time, farm households adopting these risk management strategies may potentially attract more visits by extension staff than non-adopters.

Thus, risk attitude and extension variables may be jointly determined with the decision of farm households choosing to adopt risk management strategies. Hence, we follow previously studies (see Abdulai and Huffman, 2015; and Ma and Abdulai, 2016), and control for potential endogeneity of the variables using the control function approach[10] (Wooldridge, 2015). Due to the dichotomous nature of both variables, we employed a logit regression specification of the potential endogenous variable (i.e. risk attitude and extension) as a function of all other variables used in selection equation[11] (i.e. equation [1]) in addition to instrumental variables in the first-stage estimation, such as:

$$S_i = X_{ij}\tau + G_{ij}\gamma + \epsilon_{ij} \quad [11]$$

where S_i is vector of the observed potential endogenous variables, X is as described previously in equation [1], G_{ij} is a vector of instrumental variables and ϵ_{ij} is the random error term. To ensure identification in the estimation of the adoption specification, some of the variables included in the first-stage estimation in equation [11] are excluded from the adoption equation in [1]. Just as previously explained, the employed instruments should strongly influence the given potential endogenous variables (i.e. risk attitude and extension) but not the choice of the risk management strategies. For the purpose of our study, two variables included as instruments in equation [11] are storage technology used by farm household which is expected to influence risk attitude but not expected to influence the choice of risk management strategies, and the need for support and type of support needed, which is expected to influence extension access but not the choice of risk management strategies. In addition, it is also worth noting here that the instrumental variable(s) used here is expected to not correlate with the other instrumental variables used for the multinomial endogenous switching regression model identification[12]. We incorporated both potential endogenous variables and the estimated residuals[13] predicted from equation [11] in the selection equation [1] to account for endogeneity as follows:

$$U_{ij}^{*} = X_{ij}\beta + S_i\vartheta + R_{ij}\alpha + \omega_{ij} \quad [12]$$

where X_{ij} is as defined previously, S_i is a vector of the observed potential endogenous variables (risk attitude and extension access), and R_{ij} is a vector of the "generalized residuals" terms from the first-stage regressions of the endogenous variables in equation [11]. The endogenous variables become appropriately exogenous in a second-stage estimation equation by adding appropriate "generalized residuals" since they serve as the control function. As suggested by Wooldridge (2015), the approach leads to robust, regression-based Hausman test for

[10] This is also known as a two-stage residual inclusion model in the empirical literature (see Gibson *et al.*, 2010; Terza, 2017; Harris and Kessler, 2019)
[11] Results of the control function are not provided but are available on request
[12] In appendix A1, we provide results of the correlation of instruments and our outcomes of interest
[13] Wooldridge (2015, Pp. 427 – 428) proposes estimating a "generalized residuals" which uses the inverse Mills ratio (the ratio of the standard normal density, ϕ, divided by the standard normal cumulative distribution function, Φ) to compute the "generalized residuals".

endogeneity of the suspected variables. If the coefficient of the residual term is statistically significant, it shows that endogeneity was indeed present and also well controlled for in the model (Gibson *et al.*, 2010; Ricker-Gilbert *et al*., 2011; Amankwah et *al.*, 2016; Harris and Kessler, 2019; Katengeza *et al.*, 2019; Ogutu *et al.*, 2019). Furthermore, Wooldridge (2015) observed that if the coefficient on the estimated generalized residual are statistically significant, there is a need to adjust the standard errors for the two-step estimation by bootstrapping.

The empirical specification

The specification of our empirical model is based on economic theory, empirical studies on risk management strategies adoption (Goodwin *et al.*, 2004; McNamara and Weiss, 2005; Finocchio and Esposti, 2008; Tavernier and Onyango, 2008; Ashfaq *et al.*, 2008; Velandia *et al.*, 2009; Deressa *et al.*, 2010; Poon and Weersink, 2011; Dadzie and Acquah, 2012; Enjolras *et al.*, 2012; Amanor-Boadu, 2013; Bowman and Zilberman, 2013; Bryan *et al.*, 2013; Nienaber and Slavič, 2013; Bartolini *et al.*, 2014; Ullah and Shivakoti, 2014; Huang *et al.*, 2015; Ullah *et al.*, 2015; Meraner and Finger, 2017; Asravor, 2019; Vigani and Kathage, 2019) and factors affecting the variability of farm incomes (Pope and Prescott, 1980; Dunn and Williams, 2000; Schurle and Tholstrup, 1987, 1989; Purdy *et al.*, 1997; Barry *et al.*, 2001; Poon and Weersink, 2011; Enjolras *et al.*, 2012). Following this literature, we summarized variables that are hypothesized to affect risk management strategies adoption decisions, agriculture income and standard deviation of agriculture income.

These are *farm household characteristics* (age, gender, education of household head, household size, labour use, income transfers/remittances, risk attitude, nature of farm work, household welfare index(HWI)[14], membership of farmer-based organizations, access to credit, subsidies, and irrigation use), *farm characteristics* (size of land holding, number of crops grown, share of land under cash crops, and soil quality[15]), *risk indicators* (risk count, loss count, mean annual rainfall and temperature from 2000 to 2015[16] and the standard deviation of rainfall and temperature from 2000 to 2015), *access to information* (access to extension and market information), and *location variables* (distance to major road and market). In addition, mean land holding, fertilizer, seed quantities used and production cost were included as control for unobserved heterogeneity. Table 2 presents the definition of the variables used in the analysis. The summary statistics of variables across the various risk management strategies and the pooled data is presented in Table A4 of appendix A3.

[14] We computed a household welfare index which is proxy for household wealth using principal component analysis (PCA) based on farm household access to basic amenities such as water, electricity, toilet, the type of roof, wall and floor material, and the number of sleeping rooms in the household.
[15] For soil quality, we computed a soil quality index using publicly available data from International Soil Reference and Information Centre (ISRIC – World Soil Information). We describe the computation of this index in appendix A6.
[16] Rainfall and temperature datasets used are from the Climate Hazards Center of the University of California, Santa Barbara.

Table 2: Variables definition and summary statistics

Name	Variable description
Outcome variables	
Agriculture income	Log[17] of agriculture (crop and livestock) income in CFA
Std. agriculture income	Standard deviation of log of agriculture income in CFA
Farm household characteristics	
Age	Age of household head in years
Gender	=1 if household is male-headed
Education	=1 if household head has formal education
HH size	Number of people residing in the household
Total labour	Total labour used by household
Risk attitude	=1 if risk taking
Nature of work	=1 if farm work is done on part-time basis
Transfers	=1 if household receives cash remittances
Subsidy	=1 if access to subsidies
Credit access	=1 if access to credit
Irrigation	=1 if farmer uses irrigation
HWI	Household welfare index
Agriculture income share	Agricultural income share (%) in total household income
Nonfarm income	Total nonfarm income (CFA)
Farm characteristics	
Land holding	Total land area farmed by household (ha)
Crop portfolio	Number of crops cultivated by household
Cash crop	Share of land under cash crops (%)
SQI	Soil quality index
Risk indicators	
Std. Rainfall	Standard deviation of rainfall (2000 – 2015)
Rainfall	Mean annual rainfall in mm (2000 – 2015)
Std. Temperature	Standard deviation of temperature (2000 – 2015)
Temperature	Mean annual temperature in °C (2000 – 2015)
Risk count	Number of production risks faced by household
Loss count	Number of risk related losses experienced by household
Access to information	
Extension access	=1 if accessed extension service
Market information	=1 if accessed market information
Location variables	
Road	Log of distance to the nearest road (km)
Market	Log of distance to the nearest market (km)
Mundlak Fixed Effects	
Mean land holding	Mean land (ha) allocation across all crops grown
Mean fertilizer quantity	Mean fertilizer (kg) use across all crops grown
Mean seed quantity	Mean seed (kg) use across all crops grown
Mean production cost	Mean production cost (FCFA) across all crops grown
Instrumental variables	
Membership	=1 if member of farmer-based organization
Insurance needs	=1 if farmer has specific insurance needs
Insurance knowledge	=1 if farmer has ever heard of farm insurance
Storage technology	=1 if household use metal silos
Support needs	=1 if farmer has support needs
Type support needs	=1 if training on good farming practices is needed

[17] The logarithm of variables used in the analysis were to the base 10.

3.2 Study area and data

As a West African country, Senegal is a country within the Sahel region. The country has six agro-ecological zones, based on biophysical and socioeconomic criteria and these are; Niayes, Senegal River Valley, Sylvo-pastoral Zone, Groundnut Basin, Eastern Senegal and Casamance. These agro-ecological zones have unimodal rainfall, hence they are characterized by varying levels of rainfall and temperature with conditions that gradually become increasingly dry moving north from Senegal's high rainfall southern regions to its northern arid zones. The length of the rainy season differs from one year to the next and from one region to the other. With more than 95% of the total cropped area depending on rain-fed and less than 1% of agricultural land under irrigation, the growing season in Senegal strongly correlates to the rainy season. The strong dependence of crop production on rainfall results in highly variable production, as both rainfall amounts and the onset and cessation of the rains are subject to marked space-time variability and temporal changes (D'Alessandro *et al.*, 2015).The main crops cultivated in Senegal by smallholders are groundnuts and millet, which together account for almost 75% of the planted area. Maize, rice sorghum, cowpeas, and cotton make up about 25% and less than 1% is sown to other crops, including vegetables (D'Alessandro *et al.*, 2015).

The data used in the study comes from a farm household survey as part of the larger Senegalese "Projet d'appui aux politiques agricoles (PAPA)" or the Agricultural Policy Support Project. The farm household survey was conducted from between April and May 2017 across all the 14 administrative regions of Senegal and all the departments with the exception of the departments of Dakar, Pikine and Guédiawaye. A total of 42 agricultural departments were included in the survey. The survey was targeted towards cereals, horticultural crops, and fruit and vegetable producers. The survey design was a two-stage, nationally based random survey that included rural census districts as the primary units and farm households as the secondary units. The method consisted of first dividing the statistical population (i.e. agricultural households) in the primary units so that each of them is unambiguously related to a well-defined primary unit. Then samples were drawn in two stages. In the first stage, a sample of rural census districts was drawn and in the second stage, a sample of agricultural households was selected at the level of each primary unit. In rural census districts where rainfed agriculture was practice and localized crops were grown such as Senegal River Valley and Niayes Market Gardening Zone, a stratification of the rural census districts was done before agricultural households were selected. Data collected include information on household demographic characteristics, plot and land holdings, agricultural equipment ownership, crop production for the 2016/2017 growing season, credit, inputs use and cost, family and hired labour, sales volumes and process. Others included household consumption, access to amenities, non-farm and livestock revenue, remittance, agricultural insurance, risks and adaptation strategies, perception on subsidized fertilizer, seeds and agricultural equipment, and membership of farmer-based organizations.

4.0 Empirical Results

In this section we first investigate factors driving the adoption of the various risk management strategies in isolation or combination. Secondly, we present the economic implications associated with each risk management portfolio on household agriculture incomes and the standard deviation of agriculture. We do not however discuss results of the econometric

estimation of agriculture income and the standard deviation[18] of agriculture income model. Related results are however provided in appendix A4 and A5. The selectivity correction terms (rmp0 to rmp7) in Table A5 and A6 are significant in some of the risk management portfolio equations. This indicates the presence of sample selectivity effects and using OLS would have produced biased and inconsistent estimates. Thus, accounting for selectivity effects using the Multinomial Endogenous Switching Regression model was appropriate.

Table 3 shows the results of the multinomial logit model for the different risk management portfolios. We find that the multinomial logit model fits the data well, the Wald test is highly significant, hence rejecting the null hypothesis that all the regression coefficients are jointly equal to zero. Furthermore, the test for joint significance of instruments across the different risk management portfolios are highly significant. The results from the control-function specification indicate that the correction for endogeneity in the model was necessary. We find the coefficient of the risk residual term to be statistically significant in four of the risk management portfolios, implying the presence of endogeneity of risk attitude.

Drivers of Risk Management Strategies

The relative probability of adopting risk mitigation *(RMP1)* is strongly negative and statistically significant for farmers' characteristics; education of household head, risk attitude, nature of work, wealth and the share of agriculture income in total household income. This suggest that household heads with formal education, risk taking farmers, working part-time on the farm, wealthier households and having higher shares of agriculture incomes in total household income are less likely to adopt risk mitigation as a risk management strategy. Conversely, we fine the number of crops grown, number of risk and losses experienced, insurance needs and insurance knowledge to be strongly positive and statistically significant for the adoption of risk mitigation. The effect of membership of farmer-based organizations is negative and statistically significant.

We find that the probability of adopting risk transfer *(RMP2)* is statistically significant for farmers' characteristics; education of household head and credit access. Hence a household head having formal education, and having access to credit are more likely to adopt risk transfer as a risk management strategy. The number of losses experienced by a household is positive and statistically significant for the adoption of risk transfer. The probability of adopting risk coping *(RMP3)* is positive and statistically significant for total labour used, nature of work and credit access. Risk attitude and wealth are positive and statistically significant for adopting risk coping strategies. The number of crops grown, soil fertility, number of risks experienced, distance to major road, insurance needs and knowledge are positive and statistically significant for the adoption of risk coping. On the contrary, membership of famer-based organizations is negative and statistically significant for the adoption of risk coping.

[18] Due to space, we do not show results for the moment of agriculture income for each regime. However, the results are available upon request

With respect to the combination of strategies, we find that risk mitigation and transfer *(RMP4)* adoption is positive and statistically significant for age of the household head, credit access and irrigation use. Risk attitude is however negative and statistically significant for the adoption of risk mitigation and transfer. Furthermore, membership of farmer-based organizations and insurance needs are positive and statistically significant for adoption. An increase in the standard deviation of temperature is associated with a less likely adoption risk mitigation and transfer as a risk management strategy.

The relative probability of adopting risk mitigation and coping *(RMP5)* is strongly negative and statistically significant for education level of household head, risk attitude, wealth and the share of agriculture income in total household income. However, farm household characteristics related to total labour, nature of work and subsidy access is strongly positive and statistically significant for adopting risk mitigation and coping portfolio. Furthermore, the number of crop commodities grown, the number of risk and losses experienced, and insurance needs and knowledge are positive and statistically significant for the adoption of risk mitigation and coping. On the contrary, membership of famer-based organizations is negative and statistically significant for adoption.

Lastly, the relative probability of risk transfer and coping *(RMP7)* adoption is strongly positive and statistically significant for irrigation use, the number of losses experienced and insurance needs. In summary, we find that the probability to adopt the six risk management portfolios is largely driven risk attitude, the number of losses experienced, membership of farmer-based organizations and insurance needs.

Table 3: Parameter estimates of risk management portfolios adoption, Multinomial Logit Selection Model

	RMP1		RMP2		RMP3		RMP4		RMP5		RMP7	
Variable	**Coef.**	**Std.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Age	0.005	0.005	-0.008	0.027	-0.003	0.006	0.029*	0.016	-0.001	0.006	0.009	0.023
Gender	-0.073	0.235	1.631	9.063	0.395	0.271	0.512	1.780	0.232	0.302	-0.860	3.562
Education	-0.254*	0.141	1.571*	0.811	-0.207	0.154	-0.082	0.384	-0.377**	0.172	0.169	0.528
HH size	0.004	0.017	0.123	0.093	0.022	0.018	0.031	0.043	-0.001	0.019	0.040	0.070
Total labour	0.034	0.022	-0.011	0.131	0.045*	0.025	-0.016	0.084	0.059**	0.024	-0.045	0.128
Risk attitude	-2.193***	0.603	0.027	6.363	-2.699***	0.644	-3.980**	1.808	-2.762***	0.721	-0.635	5.321
Nature of work	0.385**	0.154	-0.120	0.785	0.851***	0.166	0.624	0.419	0.774***	0.181	0.866	0.614
Transfer	-0.145	0.242	-1.382	1.341	-0.133	0.260	-1.259	2.530	0.339	0.281	0.106	4.890
Subsidy	0.331	0.248	2.023	2.337	0.310	0.263	0.536	0.873	1.085***	0.291	1.205	1.439
Credit access	0.505	0.434	1.658*	0.899	0.822*	0.455	1.849***	0.621	0.278	0.503	1.562	0.948
Irrigation	0.295	0.202	1.574	0.993	0.048	0.225	1.387***	0.533	-0.046	0.257	1.366*	0.819
HWI	-0.098**	0.047	0.247	0.252	-0.126***	0.048	0.143	0.121	-0.161***	0.057	-0.062	0.182
Agriculture income share	-1.157**	0.446	21.636	342.226	-0.334	0.471	0.954	1.626	-1.367***	0.475	1.623	75.046
Land holding	0.009	0.019	0.020	0.057	0.016	0.019	0.011	0.026	0.006	0.020	0.021	0.073
Crop portfolio	0.265**	0.105	0.729	0.525	0.568***	0.114	0.408	0.294	0.439***	0.123	0.070	0.626
Cash crop	0.083	0.329	-2.189	61.390	0.142	0.339	-0.890	1.203	0.612	0.377	0.153	1.583
SQI	0.904	0.972	3.644	4.687	3.148***	1.047	0.925	2.530	-0.171	1.157	-0.629	4.454
Std. Rainfall	-0.002	0.002	-0.001	0.009	-0.001	0.002	-0.001	0.005	0.000	0.002	0.005	0.006
Std. Temperature	0.025	0.110	0.080	0.531	0.057	0.120	-0.493*	0.295	0.104	0.130	-0.170	0.395
Risk count	0.293***	0.105	-2.720	12.268	0.310***	0.110	0.271	0.176	0.647***	0.110	0.068	0.286
Loss count	0.265**	0.122	1.134**	0.474	0.145	0.133	0.160	0.238	0.574***	0.133	0.583**	0.290
Extension access	-0.102	0.449	1.625	2.197	0.085	0.508	1.952	1.211	-0.577	0.547	-0.937	1.763

Notes: The base category is farm households that did not adopt any of the risk management portfolios (i.e. RMP0). RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping. ***, **, * represent 1%, 5%, and 10% significance level, respectively. Reported standard errors are the bootstrapped standard errors.

Table 3: Parameter estimates of risk management portfolios adoption, Multinomial Logit Selection Model (*continued*)

	RMP1		RMP2		RMP3		RMP4		RMP5		RMP7	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Market information	-0.141	0.136	0.183	0.635	-0.167	0.146	0.142	0.328	-0.072	0.160	-0.457	0.509
Road	-0.070	0.095	0.435	0.559	0.169*	0.102	0.093	0.208	-0.137	0.108	-0.204	0.348
Market	0.191	0.157	0.725	1.008	-0.129	0.161	-0.009	0.464	0.049	0.179	0.261	0.514
Membership	-0.701***	0.229	-1.013	1.079	-0.987***	0.265	1.313**	0.631	-0.820***	0.301	-0.314	0.947
Insurance needs	0.638***	0.152	-0.234	0.686	1.054***	0.169	2.144***	0.410	0.538***	0.183	16.396***	1.675
Insurance knowledge	0.317*	0.184	-1.517	0.982	0.488**	0.194	3.606	5.293	0.987***	0.208	3.830	7.520
Resid risk attitude	0.636**	0.324	1.044	2.075	1.129***	0.343	1.600	0.996	0.841**	0.386	1.109	2.066
Resid extension access	0.053	0.228	-0.888	1.557	-0.054	0.254	-0.360	0.631	0.258	0.264	0.693	0.916
Constant	1.578	1.019	-37.709	347.077	-2.035*	1.090	-9.970	6.559	-1.518	1.160	-24.724	76.623
Joint sig Instruments ($\chi 2$) in agriculture income equation	34.83***		2.46		68.37***		30.94***		50.49***		96.8***	
Wald test, $\chi 2$ (180)	1367.86***											
N	3048		43		1004		81		693		37	

Notes: The base category is farm households that did not adopt any of the risk management portfolios (i.e. RMP0). RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping. ***, **, * represent 1%, 5%, and 10% significance level, respectively. Reported standard errors are the bootstrapped standard errors.

Economic Implications of Risk Management Strategies

The objective of this paper, is to identify which optimal risk management strategies allow households to maximize their objectives in terms of expected income and variability of income. In this section, we therefore attempt to determine the "best" tools, in terms of stabilizing farm households' agriculture incomes. The economic implications of adopting each risk management portfolio on farm households' agricultural incomes and the standard deviation of income measured in terms of the average treatment effects (ATT) for the treated farm households are presented in Table 4 and 5 respectively. After controlling for the effects of several covariates and the selection bias stemming from both unobserved and observed factors on household agriculture incomes, the adoption of some of the risk management portfolios is associated with significant positive incomes. For some risk management strategies, the observed effects are negative.

Regarding the adoption of single risk management strategies, we find that the adoption of risk coping strategies provides higher agriculture incomes compared to a counterfactual case where farm households did not adopt risk coping as a risk management measure. This is not surprising because risk coping strategies rely largely on the sale of assets. By using risk coping as a strategy, farm households obtain about 39% more agriculture income and this effect is statistically significant at 1%. Risk coping might be an effective strategy to smooth household consumption in the short-run. However in the long-run, poorer households might be unable to recover the loss of productive assets *ex* post the shock (Bhandari *et al.*, 2007; Barnett *et al.*, 2008; Amare *et al.*, 2018), which might partly be due to the cost in terms of production efficiency and reduced profits (World Bank, 2005b).

Table 4: Impact on agriculture income by risk management strategy

Portfolio	Actual agriculture income	Counterfactual agriculture income - If households did not adopt	ATT	Change (%)
Risk mitigation	5.337(0.007)	5.358(0.008)	-0.021**(0.011)	-4.72
Risk transfer	6.125(0.097)	6.580(0.122)	-0.455***(0.156)	-64.92
Risk coping	5.564(0.011)	5.421(0.015)	0.142***(0.019)	38.68
Risk mitigation + transfer	5.762(0.054)	5.856(0.055)	-0.094(0.077)	-19.46
Risk mitigation + coping	5.566(0.010)	5.429(0.016)	0.137***(0.019)	37.09
Risk transfer + coping	5.875(0.094)	5.884(0.213)	-0.009(0.233)	-2.05

Notes: Standard errors are in parentheses. ***, ** represent 1% and 5% significance level, respectively. The change expressed in percentage in terms of treatment effect was computed using the formula $100(10^{ATT} - 1)$.

The adoption of risk mitigation and risk transfer leads to lower agriculture income compared to the counterfactual case of non-adoption. The effect is particularly statistically significant at 5% for households that adopted risk mitigation as a risk management strategy. The effect is also statistically significant (1%) for households that adopted risk transfer as a risk management strategy. This implies that by using risk mitigation and transfer as a risk management strategy, farm households obtain about 5% and 65% lower agriculture incomes compared to the counterfactual case. The result is rather surprising, because risk transfer, herein insurance use,

should allow farm households to use more of productive inputs such as organic fertilizer, improved or high yielding varieties of crops. Nonetheless, the result might be explained by some findings reported in the empirical literature. For instance, in the US, Smith and Goodwin (1996) found that fertilizer and chemical use among Kansas wheat producers tended to be negatively correlated with insurance purchases. They found that, producers who purchased insurance use less inputs than those producers that did not buy insurance. Similarly, Giné and Yang (2009) and De Nicola (2015) finds insurance contracts to significantly reduce total input and investments in new agricultural opportunities. In Hungary, Spörri *et al.*, (2012) also found a negative impact of insurance on farm profit, labour and land productivity in arable farms. Furthermore, some risk transfer products have been found to reduce the use of complementary risk management strategies such as diversification (Schaffnit-Chatterjee, 2010). This crowding out effect could potentially have cascading effects which might be reflected in incomes. Although we observed from the data (see Table A4 in appendix) that aside land use, risk transferring households use higher levels of fertilizer, seeds and hired labour use per hectare compare to farm households using the other risk management strategies, behavioural changes of insurance policy holders in terms of effort devoted towards their farming activities might explain the findings. As shown in previous studies (see Horowitz and Lichtenberg, 1993; Smith and Goodwin, 1996; Goodwin *et al.*, 2004; Goodwin, 2001) insurance use leads to moral hazard problems and farmers with insurance are likely not going to take care in their production activities compared to a situation without insurance.

Reduction of cultivated areas and orientation to non-agricultural activities consists of about 55% of risk mitigation strategies (see Table A1 in appendix). Intuitively, there is an opportunity cost related effect to the use of these strategies. The use of these strategies causes losses in agriculture income. Furthermore, production or agricultural diversification in particular could lead to shifts or reallocation of resources (land) for high value crops and staple crops and this can have a negative effect on agriculture income, when a household income is largely dependent on the sale of high value crops and yields for high value crops are lower relative to staple crops (Morduch, 1995; Salazar-Espinoza *et al.*, 2015). Evidently, we find that farm households using mitigation strategies allocate about 50.3% of their cultivated lands towards staple crops production and only about 26.8% towards cash crops. As argued by Skees *et al.*, (2002) and Larochelle and Alwang (2013) diversification can also hinder important gains that can be obtain from specialization. Other results also suggests that diversification is beneficial up to a certain threshold only (Schoney *et al.*, 1994). Also, by renting out land, there is an opportunity cost related to the farm household using the land for a profitable agriculture enterprise.

Results of the combined adoption of risk management strategies shows the farm households adopting risk mitigation with coping, significantly obtain higher agriculture incomes (37% more) compared to the counterfactual case they did not adopt this combination. Though not statistically significant, we find that farm households adopting risk mitigation with risk transfer earn lower agriculture incomes compared to the counterfactual case of not adopting. Furthermore, we find that households adopting risk transfer with coping earn lower agriculture incomes compared to the counterfactual case. However, the observed effect is not significant. The effect of risk management on agriculture income shows that the use of risk coping as a

strategy in isolation or a combination of risk mitigation and coping significantly leads to about 38% more agriculture incomes than any other strategy in isolation or in combination.

Results of the effect of risk management on dispersions around agriculture incomes for farm households is presented in Table 5. Managing production risks either through single strategies or in combinations in effect helps to reduce dispersions around agriculture incomes. By using risk mitigation as a risk management strategy, farm households reduce dispersions around agriculture incomes by about 11% and this effect is statistically significant at 1%. Transferring risks allow farm households to reduce dispersions around agriculture by about 99% compared to the counterfactual case of not transferring. The effect is statistically significant at 1%. Risk coping measures employed by farm households significantly reduces dispersions around agriculture incomes by about 20% compared to the counterfactual case of not employing risk coping measures. Farm households that use risk mitigation in combination with risk transfer are able to reduce dispersions around agriculture incomes by about 39% compared to a counterfactual case of not using this combination. We also find that households using risk mitigation and coping in combination reduce dispersions around agriculture income by about 17% and the effect is statistically significant at 1%. Concurrently, the use of risk transfer and coping in combination reduces dispersions around agriculture incomes by about 50% with the effect being statistically significant at 1%.

Table 5: Dispersions impact on agriculture income by risk management strategy

Portfolio	Actual standard deviation of agriculture income	Counterfactual standard deviation of agriculture income - If households did not adopt	ATT	Change (%)
Risk mitigation	0.345(0.002)	0.391(0.004)	-0.047***(0.004)	11.43
Risk transfer	0.177(0.022)	0.475(0.026)	-0.298***(0.034)	98.61
Risk coping	0.283(0.003)	0.363(0.006)	-0.080***(0.007)	20.23
Risk mitigation + transfer	0.298(0.018)	0.441(0.018)	-0.143***(0.025)	39.00
Risk mitigation + coping	0.273(0.003)	0.342(0.007)	-0.069***(0.008)	17.22
Risk transfer + coping	0.203(0.026)	0.379(0.030)	-0.176***(0.040)	49.97

Notes: Standard errors are in parentheses. *** represent 1% significance level. The change expressed in percentage in terms of treatment effect was computed using the formula $100(10^{ATT} - 1)$.

Risk transfer strategies appear to be very effective in reducing dispersions around agriculture incomes when used in isolation, compared to when combined with other strategies. When risk transfer is considered as the main risk management strategy used by a farm household, combining it with risk mitigation, leads to a dispersion reduction effect on agriculture income by only 39%. In parallel, the use of risk transfer in combination with risk coping measures reduce dispersions around agriculture incomes by about 50%. Contrarily, if risk mitigation is considered as the main risk management strategy, it is observed to not be as effective as when combined with other risk management strategies. In combination with risk transfer, the dispersion reduction effect is about 40% compare with 11% when used in isolation. Similarly,

the dispersion reduction effect when used in combination with coping strategies is about 17%. Likewise, the effect of risk coping is observed to be stronger when combined with risk transfer strategies compared with risk mitigation strategies. When used as the main risk management strategy, the dispersion reduction effect of risk coping on agriculture income is only 20% but in combination with risk transfer this is about 50%.

5.0 Conclusion and policy implications

This study sought to investigate how effective the various risk management strategies employed by farm households to deal with risk are and to identify which optimal risk management strategies allow households to maximize their objectives in terms of expected income and variability of income. We employed a multinomial endogenous switching regression that accounts for selectivity bias and a moment-based approach to determine the impacts of the various risk management strategies on agriculture incomes and its dispersions around agriculture incomes in a multinomial framework. We find mixed results of the impact of risk management on agriculture incomes. More specifically, we find a positive impact of risk coping strategies on farm household agriculture incomes. Risk management through risk mitigation strategies appears to erode net agriculture incomes because these strategies are preliminarily related to opportunity cost of farm incomes and suboptimal allocation of productive resources. We find that when risk mitigation strategies are implemented in combination with risk coping strategies, the net impact is significantly higher, allowing farm households to gain more agriculture incomes.

Interestingly, we find that the adoption of risk transfer as a risk management strategy leads to significantly lower agriculture incomes compared to the counterfactual case of non-adoption. Although the result is rather baffling, we are of the view that some underlying factors might explain the observed outcome. Firstly, the presence the use of insurance may relate to moral hazard problems, with insurance policy holders not taking care or expending effort in their production activities. Secondly, the use of risk transfer might crowd out the use of other risk management strategies which might have complementary effects or benefits on agriculture incomes. Aside the adoption of risk mitigation and coping in combination, we find no statistical evidence that more comprehensive risk management strategies lead to higher agriculture incomes. We find that the adoption of risk mitigation with transfer, and risk transfer with coping leads to lower agriculture incomes compared to the counterfactual case of non-adoption of these combinations.

We find that the adoption of risk management strategies by farm households are effective in reducing the dispersions around agriculture incomes. Risk transfer has the highest observed effect on reducing dispersions around agriculture income. The use of risk transfer reduces dispersions around agriculture incomes by about 99%. More specifically, we find that adopting risk transfer in combination with other strategies lowers the dispersion reduction effect relative to using only risk transfer as a management strategy. On the contrary we find that if risk management strategies other than risk transfer is considered as the main risk management strategy employed by a household, combination with other strategies generally improves the dispersion reduction effectiveness compared to being used in isolation.

Our findings have some important policy implication. First, there is a need for a more targeted and systematic approach to agricultural risk management. Of particular relevance is the need for several kinds of implementation instruments such agricultural investments and technical assistance that can amplify the benefits of some of the risk management strategies employed by households. Investments related to the provision of climate information for example can be beneficial in helping farmers select the right crop commodities to produce for a particular season and at what time within the season to sow for instance. At the same time, empowering farmer's management of climate risks will require the adoption of context-suitable agricultural practices such as conservation agriculture, sustainable land management practices etc. and technologies which are important low-cost risk mitigation strategies such as improved and drought resistant varieties of crops. This will require the provision of information and technical assistance to farmers in the use and implementation of these practices.

Risk transfer products such as index-based insurance should be widely promoted to farm household since they appear to better manage production risks. However, to achieved this there is a need to overcome some socioeconomic and institutional barriers to the adoption of risk transfer products. There is a need to improve better access to credit and offer comprehensive information on how insurance works. This is because we find credit access and information about insurance to be positively correlated with the adoption of risk management strategies. Most importantly, there is the need for better insurance product designs that highly correlates indemnification with losses experienced by farmers. Although we observed that farm households using risk transfer as a risk management strategy come from all but one of the 14 administrative regions of Senegal involved in the survey, coverage is still very low. There is therefore the need to scale up the product to more farm households. This can be done through the use of farmer-based organizations for instance, since they are important in influencing the use of risk management strategies. Additionally, offering index insurance products through farmer-based organizations can lower related administrative costs.

In conclusion, there are some important caveats to be considered for this study. Due to lack of panel or longitudinal datasets, the study relied solely on cross-sectional data. Hence the analysis used in this paper is a static one and also neglects the dynamic behaviour of production systems. Also, the effectiveness of the various risk managements strategies might have both temporal and spatial dimensions which is not evaluated in this study. Some of the studied risk management strategies can be effective in the short run, while others might deliver payoffs in the long run. Hence, having access to data with a long-time dimension on various production systems, agriculture incomes and risk management strategies employed by farm households would allow for the investigation of all these dimensions and provide a better comparison between the various risk management strategies. Such data would be needed to provide more robust evidence on the implication of risk management on important household welfare outcomes. Furthermore, since we clustered the various risk management strategies into three broad typologies, we failed to evaluate their individual impacts. Because production conditions and the scope of risk management strategies are heterogeneous across farms, focusing on aggregate effects as we did in this study may obscure individual strategy specific effects for instance.

Appendix A1

Table A1: Risk management strategies employed by farm households

Risk management strategies	Frequency	%
Risk mitigation		
Diversify agricultural activities	2095	39%
Reduce the area under cultivation	1074	20%
Orientation to non-agricultural activities	1610	30%
Rent land to others	122	2%
Risk transfer		
Subscribe to agricultural insurance	177	3%
Risk coping		
Sell grain stocks	483	9%
Sell property	462	9%
Sale of animals	1062	20%
Exchange/swap clothes or jewels for food	79	1%
Total	**5312**	**100%**

Table A2: Correlation test of instrumental variables

	Std. agric income	Log agric income	Membership of FBO	Insurance needs	Insurance knowledge	Storage technology	Type of support needs	Need for support
Std. agric income	1							
Log agric income	-0.2001	1						
Membership of FBO	0.0033	0.1131	1					
Insurance needs	-0.0375	0.1246	0.1274	1				
Insurance knowledge	0.0019	0.1472	0.1900	0.2841	1			
Storage technology	-0.0632	0.0525	-0.0512	-0.0546	-0.0303	1		
Type of support needs	-0.0472	0.0592	0.1074	0.1152	0.0815	0.0057	1	
Need for support	-0.0359	0.0669	0.0995	0.2191	0.1424	0.0212	0.5872	1

Appendix A2

Table A3: Test of the validity of the instrument (falsification test) on non-adopters

	No risk management		Log of agriculture income		Std. of agriculture income	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std.**
Age	-0.005	0.005	-0.003	0.003	0.002	0.002
Gender	0.073	0.242	0.404***	0.118	-0.082	0.080
Education	0.254*	0.141	0.037	0.070	0.008	0.047
HH size	-0.004	0.017	-0.010	0.009	0.006	0.006
Total labour	-0.034	0.022	0.034**	0.016	-0.020*	0.011
Risk attitude	2.193***	0.612	0.097	0.076	0.009	0.051
Nature of work	-0.385**	0.153	-0.064	0.075	0.096*	0.050
Transfer	0.145	0.236	0.050	0.102	0.019	0.069
Subsidy	-0.331	0.258	0.200**	0.079	-0.134**	0.053
Credit access	-0.505	0.396	0.105	0.173	0.227*	0.117
Irrigation	-0.295	0.198	0.677***	0.104	-0.011	0.070
HWI	0.098**	0.046	0.001	0.023	-0.024	0.015
Agriculture income share	1.157**	0.488	0.384*	0.212	-0.081	0.143
Land holding	-0.009	0.017	0.015***	0.004	0.002	0.003
Crop portfolio	-0.265**	0.106	0.191***	0.040	-0.051*	0.027
Cash crop	-0.083	0.339	0.417***	0.141	-0.082	0.095
SQI	-0.904	0.985	0.864**	0.361	0.353	0.243
Std. Rainfall	0.002	0.002	0.000	0.001	0.000	0.001
Std. Temperature	-0.025	0.109	-0.088	0.055	0.035	0.037
Risk count	-0.293***	0.105	-0.051	0.034	-0.001	0.023
Loss count	-0.265**	0.115	0.049	0.040	0.021	0.027
Extension access	0.102	0.421	0.003	0.095	-0.025	0.064
Market information	0.141	0.137	-0.055	0.065	0.036	0.043
Road	0.070	0.094	0.049	0.043	0.021	0.029
Market	-0.191	0.161	0.223**	0.086	0.018	0.058
Membership	***0.701******	0.223	***0.158****	0.089	***0.049***	0.060
Insurance needs	***-0.638******	0.159	***0.102***	0.084	***-0.005***	0.057
Insurance knowledge	***-0.317****	0.180	***0.032***	0.085	***-0.021***	0.057
Resid risk attitude	-0.636**	0.323				
Resid extension access	-0.053	0.198				
Constant	-1.578	1.037	2.723***	0.465	0.135	0.313

***, **, * represent 1%, 5%, and 10% significance level, respectively.

Reported standard errors are the bootstrapped standard errors.

Appendix A3

Table A4: Means and standard deviation of variables by risk management strategy

	RMP0		RMP1		RMP2		RMP3		RMP4		RMP5		RMP7		Total	
Variables	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Log of agric income	5.47	0.64	5.34	0.57	6.12	0.64	5.56	0.52	5.76	0.55	5.57	0.43	5.87	0.57	5.44	0.57
Std. agric income	0.36	0.35	0.34	0.31	0.18	0.16	0.28	0.27	0.30	0.23	0.27	0.22	0.20	0.16	0.32	0.30
Age	52.78	13.55	53.44	13.43	51.93	12.34	51.99	12.77	54.17	13.12	52.50	13.25	52.86	11.57	52.99	13.27
Gender	0.91	0.29	0.91	0.29	0.98	0.15	0.95	0.22	0.94	0.24	0.95	0.22	0.92	0.28	0.92	0.27
Education	0.47	0.50	0.38	0.48	0.72	0.45	0.37	0.48	0.41	0.49	0.35	0.48	0.49	0.51	0.38	0.49
HH size	9.35	4.69	9.55	5.31	10.51	5.66	10.03	5.18	9.28	5.08	10.47	5.28	10.81	5.30	9.77	5.26
Total labour	3.92	2.45	3.96	3.15	4.91	3.35	4.17	3.42	3.77	3.13	4.19	2.86	4.14	4.10	4.03	3.14
Risk attitude	0.60	0.49	0.32	0.47	0.95	0.21	0.41	0.49	0.51	0.50	0.36	0.48	0.92	0.28	0.37	0.48
Nature of work	0.42	0.49	0.50	0.50	0.70	0.46	0.61	0.49	0.64	0.48	0.61	0.49	0.73	0.45	0.54	0.50
Transfer	0.11	0.31	0.10	0.29	0.14	0.35	0.09	0.29	0.06	0.24	0.13	0.33	0.11	0.31	0.10	0.30
Subsidy	0.59	0.49	0.48	0.50	0.91	0.29	0.44	0.50	0.72	0.45	0.65	0.48	0.84	0.37	0.51	0.50
Credit access	0.04	0.19	0.04	0.19	0.26	0.44	0.04	0.20	0.32	0.47	0.03	0.17	0.24	0.43	0.04	0.21
Irrigation	0.28	0.45	0.20	0.40	0.86	0.35	0.13	0.33	0.73	0.45	0.10	0.29	0.65	0.48	0.19	0.39
HWI	0.46	1.63	-0.03	1.76	0.82	2.14	-0.14	1.63	0.97	1.49	-0.29	1.51	0.22	1.76	-0.03	1.71
Agriculture income share	0.95	0.15	0.88	0.26	1.00	0.02	0.93	0.17	0.96	0.13	0.86	0.23	0.96	0.12	0.89	0.23
Nonfarm income	107076.2	381070.6	143865.6	504769.8	268488.4	940071.3	96016.4	296266.5	56419.8	194947.5	149520.2	375919.1	87702.7	272869.5	132643.1	449802.1
Land holding	4.80	8.94	5.12	8.46	5.18	4.80	6.22	8.88	3.53	4.08	6.25	5.94	5.38	10.03	5.44	8.23
Crop portfolio	1.90	1.04	2.09	1.00	1.86	1.17	2.39	1.06	1.46	0.90	2.45	1.02	1.84	1.19	2.17	1.03
Cash crop	0.23	0.28	0.27	0.28	0.02	0.10	0.29	0.24	0.05	0.15	0.35	0.27	0.12	0.23	0.28	0.27
SQI	0.35	0.12	0.39	0.10	0.37	0.06	0.40	0.09	0.34	0.11	0.38	0.09	0.34	0.10	0.39	0.10
Rainfall	643.28	305.30	652.25	294.94	587.94	271.11	667.64	287.87	573.61	287.54	694.46	287.90	690.66	359.08	658.90	293.90
Temperature	35.68	1.42	35.70	1.43	35.49	1.55	35.68	1.43	35.48	1.70	35.65	1.41	35.41	1.41	35.68	1.43
Std. Rainfall	98.67	37.55	99.21	35.30	91.86	24.96	100.55	34.72	94.04	32.14	103.34	36.38	104.06	43.85	99.89	35.43
Std. Temperature	2.44	0.60	2.44	0.60	2.41	0.68	2.46	0.60	2.33	0.60	2.47	0.60	2.36	0.64	2.45	0.60

Notes: RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping.

Table A4: Means and standard deviation of variables by risk management strategy (*continued*)

	RMP0		RMP1		RMP2		RMP3		RMP4		RMP5		RMP7		Total	
Variables	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Risk count	1.04	1.31	1.77	1.38	0.05	0.21	1.84	1.59	0.83	1.30	3.18	1.57	0.84	1.26	1.90	1.55
Loss count	1.22	1.04	1.62	0.98	2.14	0.99	1.59	0.97	1.51	1.04	2.45	1.25	1.92	1.19	1.71	1.07
Extension access	0.23	0.42	0.14	0.34	0.37	0.49	0.10	0.30	0.74	0.44	0.15	0.36	0.46	0.51	0.15	0.36
Market information	0.53	0.50	0.50	0.50	0.56	0.50	0.49	0.50	0.58	0.50	0.51	0.50	0.43	0.50	0.50	0.50
Road	3.76	0.91	3.58	0.88	4.18	0.45	3.67	0.81	3.87	0.78	3.40	0.92	3.78	0.92	3.59	0.88
Market	3.93	0.46	3.98	0.45	4.13	0.44	3.93	0.43	4.00	0.60	3.94	0.46	3.89	0.71	3.96	0.45
Membership	0.32	0.47	0.12	0.32	0.42	0.50	0.08	0.27	0.70	0.46	0.09	0.29	0.32	0.47	0.13	0.34
Insurance needs	0.29	0.45	0.36	0.48	0.26	0.44	0.45	0.50	0.84	0.37	0.40	0.49	1.00	0.00	0.39	0.49
Insurance knowledge	0.26	0.44	0.23	0.42	0.26	0.44	0.27	0.45	0.98	0.16	0.33	0.47	0.97	0.16	0.27	0.45
Storage technology	0.09	0.29	0.16	0.37	0.07	0.26	0.20	0.40	0.01	0.11	0.23	0.42	0.11	0.31	0.17	0.38
Support needs	0.70	0.46	0.75	0.43	0.95	0.21	0.72	0.45	0.95	0.22	0.80	0.40	0.92	0.28	0.75	0.43
Type of support needs	0.53	0.50	0.51	0.50	0.74	0.44	0.48	0.50	0.77	0.43	0.49	0.50	0.78	0.42	0.51	0.50
Mean land holding	0.08	0.10	0.11	0.13	0.02	0.08	0.14	0.16	0.04	0.10	0.14	0.13	0.05	0.09	0.11	0.13
Mean fertilizer quantity	0.56	0.63	0.36	0.54	1.57	0.51	0.37	0.56	1.12	0.65	0.33	0.52	1.11	0.60	0.40	0.57
Mean seed quantity	4.65	5.57	4.28	5.14	11.83	9.54	4.91	5.56	5.29	7.07	5.50	5.90	6.16	5.75	4.68	5.49
Mean production cost	6591.5	20582.5	3115.3	13394.8	30254.6	29200.6	3110.6	7804.2	14762.6	18693.0	2514.7	5786.5	18259.2	56269.5	3736.3	13744.0
Fertilizer use (kg/ha)	159.83	259.83	93.99	1816.04	393.92	289.27	49.63	115.8	306.31	247.53	26.03	68.68	218.45	260.79	86.55	1396.48
Seed use (kg/ha)	80.03	268.79	60.35	841.57	118.50	94.34	33.61	58.10	60.79	56.61	30.51	21.61	59.68	49.44	52.73	649.04
Hired labour per ha	0.07	0.30	0.11	0.84	0.12	0.21	0.05	0.50	0.10	0.30	0.01	0.11	0.08	0.21	0.08	0.69
Land productivity (kg/ha)	2257.5	4324.8	1197.7	15265.4	4609.0	3786.1	696.1	1150.0	3570.8	2886.5	627.8	1135.8	2358.6	2421.1	1155.1	11791.1

Notes: RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping.

Appendix A4

Table A5: Estimates of agriculture income equations

	RMP0		RMP1		RMP2		RMP3		RMP4		RMP5		RMP7	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Age	-0.005	0.007	0.000	0.002	-0.005	0.034	-0.001	0.003	-0.003	0.144	-0.001	0.025	-0.046	0.046
Gender	0.369	0.347	0.085	0.080	0.776	1.678	0.397*	0.220	0.352	2.501	0.104	0.593	-0.094	0.712
Education	-0.018	0.246	-0.045	0.036	0.679	1.009	-0.014	0.050	-0.100	5.602	-0.017	0.244	0.777	0.689
HH size	-0.011	0.033	-0.002	0.004	0.041	0.139	0.004	0.007	0.015	0.285	0.008	0.049	-0.074	0.087
Total labour	0.024	0.047	0.010*	0.006	-0.008	0.225	0.006	0.013	-0.003	0.237	0.001	0.110	0.217	0.149
Risk attitude	0.119	0.546	-0.031	0.119	0.952	2.338	0.143	0.146	0.127	6.576	0.036	0.549	1.610*	0.850
Nature of work	-0.036	0.495	-0.004	0.059	-0.031	0.997	0.040	0.090	-0.003	6.070	-0.040	0.827	-0.055	0.618
Transfer	0.029	0.277	-0.016	0.067	0.030	1.176	0.034	0.083	0.175	2.332	0.039	1.974	-1.963***	0.642
Subsidy	0.092	0.177	0.056	0.074	-0.158	1.847	0.032	0.098	-0.006	5.311	0.033	0.583	2.333***	0.834
Credit access	0.108	0.547	0.023	0.078	0.506	0.996	0.157	0.114	0.100	2.593	-0.058	0.096	-1.026	0.800
Irrigation	0.470	0.429	0.139*	0.079	0.229	1.574	-0.047	0.133	0.039	3.450	0.015	0.575	-0.454	0.814
HWI	-0.015	0.039	-0.007	0.014	0.162	0.435	-0.002	0.018	0.100	0.199	-0.024	0.189	0.057	0.275
Land holding	0.006	0.114	-0.001	0.003	-0.032	0.195	0.004	0.019	-0.021	0.104	-0.002	0.072	0.371	0.187
Crop portfolio	0.193	0.325	0.170***	0.032	0.453	0.709	0.135***	0.043	0.172	1.047	0.071	0.193	-1.295**	0.508
Cash crop	0.370	1.010	0.123	0.169	-9.624	16.436	0.176	0.351	0.425	82.881	0.056	1.757	0.864	0.950
SQI	1.082	1.082	-0.539	0.380	-0.288	4.842	-0.101	0.589	0.291	13.978	0.044	6.940	-8.439***	0.710
Rainfall	0.000	0.000	0.000	0.000	0.001	0.002	-0.000	0.000	0.000	0.001	0.000	0.001	-0.000	0.001
Temperature	-0.025	0.063	0.008	0.011	-0.057	0.246	0.001	0.018	-0.030	0.522	0.022	0.084	0.245	0.323
Risk count	0.031	0.141	-0.017	0.043	8.196	9.526	0.020	0.054	0.044	0.445	0.019	0.427	-0.526	0.431
Loss count	-0.041	0.240	0.015	0.037	-0.183	0.667	-0.027	0.055	-0.061	1.872	0.030	0.311	0.446	0.363

Notes: RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping. ***, **, * represent 1%, 5%, and 10% significance level, respectively. Reported standard errors are the bootstrapped standard errors.

Table A5: Estimates of agriculture income equations (*continued*)

	RMP0		RMP1		RMP2		RMP3		RMP4		RMP5		RMP7	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Extension access	-0.107	0.174	0.105*	0.053	0.244	1.059	0.151*	0.078	0.148	2.229	0.058	0.899	-2.965***	0.770
Market information	-0.046	0.207	-0.004	0.028	-0.138	0.619	0.019	0.043	0.024	1.281	0.014	0.172	-0.146	0.690
Road	0.091	0.116	-0.030	0.037	1.270	1.748	-0.010	0.050	0.230	0.676	-0.012	0.240	-0.668	0.551
Market	0.091	0.305	0.124**	0.059	-0.507	1.530	-0.089	0.082	-0.151	1.017	0.085	0.614	1.149	0.718
Mean land	0.771	5.438	0.932***	0.227	-7.575	7.800	0.622	0.380	-0.367	106.591	1.097	2.022	0.339	0.361
Mean fertilizer quantity	0.002	0.005	-0.001	0.003	0.003	0.014	0.005	0.004	-0.004	0.008	-0.000	0.107	0.002	0.027
Mean seed quantity	0.017	0.032	0.018***	0.005	0.016	0.056	0.014**	0.005	0.009	0.052	0.007	0.199	-0.070	0.099
Mean production cost	0.000	0.000	0.000	0.000	-0.000	0.000	-0.000	0.000	0.000	0.000	0.000	0.000	-0.000	0.000
Joint significance of crop varying covariates	0.47		48.55***		1.00		8.09**		0.40		0.75		4.43	
rmp0	-0.030	0.565	-0.595	0.593	3.563	3.428	0.170	0.620	0.834	18.073	-0.759	2.636	-3.460***	0.218
rmp1	-0.248	1.483	-0.167	0.115	-5.790	4.067	-0.593	0.788	-0.909	20.639	-0.253	10.082	7.487***	0.500
rmp2	-0.916	1.275	-0.712*	0.382	-0.224	0.619	-0.647	0.451	-0.643	21.413	2.757	168689.300	2.860***	0.601
rmp3	0.896	4.315	-0.734	0.757	6.392	4.098	0.142	0.202	0.409	36.676	-0.311	2.623	-8.803***	0.191
rmp4	-0.799	1.416	-0.965***	0.280	-1.886	2.031	0.000	0.416	0.089	0.601	-1.057	5.012	-9.857***	0.636
rmp5	0.017	1.860	-0.453	0.664	-5.573	8.084	0.116	0.697	0.530	38.106	-0.025	0.537	-0.630	0.487
rmp7	-0.063	1.229	0.002	0.314	-0.168	2.866	-0.410	0.400	0.976	21.794	-0.985	13.397	0.330	0.498
Constant	4.466**	1.985	3.715***	0.612	0.301	15.657	4.270***	1.168	4.863	9.970	3.363	8.111	-1.280	12.018

Notes: RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping. ***, **, * represent 1%, 5%, and 10% significance level, respectively. Reported standard errors are the bootstrapped standard errors.

Appendix A5

Table A6: Estimates of standard deviation of agriculture income equations

	RMP0		RMP1		RMP2		RMP3		RMP4		RMP5		RMP7	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Age	0.001	0.002	0.001	0.001	0.002	0.025	0.000	0.002	0.004	0.008	0.001	0.006	0.004	0.013
Gender	-0.042	0.094	0.016	0.031	2.425	1.843	-0.063	0.116	0.033	0.265	-0.045	0.773	-0.471*	0.258
Education	-0.016	0.066	0.019	0.019	-0.370	0.915	-0.032	0.025	0.042	0.250	0.000	0.504	0.369*	0.219
HH size	0.000	0.008	0.002	0.002	0.003	0.084	0.005*	0.003	-0.014	0.019	0.000	0.070	-0.023	0.027
Risk attitude	-0.016	0.136	-0.023	0.027	-1.267	1.638	0.017	0.054	0.138	0.358	-0.044	0.301	0.345	0.293
Nature of work	0.140*	0.072	0.005	0.025	0.018	0.648	-0.014	0.059	0.126	0.247	0.015	0.764	-0.109	0.238
Transfer	0.030	0.106	-0.018	0.031	0.397	0.931	-0.053	0.049	0.212	14.467	0.004	1.688	0.370	0.267
Subsidy	-0.140*	0.081	-0.024	0.028	0.064	1.487	-0.034	0.043	-0.208	0.265	0.008	0.717	0.313	0.313
Credit access	0.219	0.181	-0.041	0.031	-0.402	0.677	-0.026	0.058	0.005	0.277	-0.011	0.054	0.098	0.262
Irrigation	-0.089	0.136	0.006	0.031	-0.057	1.110	-0.028	0.077	-0.142	0.383	-0.016	0.589	0.160	0.285
HWI	-0.024	0.020	0.012*	0.006	-0.062	0.225	0.002	0.009	-0.024	0.077	0.008	0.084	0.017	0.101
Land holding	0.004	0.012	0.002	0.005	0.007	0.134	0.004	0.005	0.026	0.066	0.004	0.042	0.011	0.067
Crop portfolio	0.009	0.059	-0.042***	0.015	-0.156	0.449	-0.025	0.023	0.090	0.169	-0.042	0.142	-0.146	0.179
Cash crop	0.028	0.290	-0.100	0.082	3.648	12.152	-0.177	0.165	-0.498	1.927	-0.028	2.583	0.952***	0.329
SQI	0.412	0.389	0.195*	0.108	-2.040	3.856	0.157	0.299	1.363	1.227	-0.013	4.241	-1.562***	0.321
Rainfall	0.000	0.000	-0.000	0.000	-0.000	0.001	-0.000	0.000	-0.000	0.000	-0.000	0.001	0.000	0.000
Risk count	0.047	0.074	0.008	0.017	-1.233	8.227	0.019	0.036	-0.115	0.230	-0.001	0.601	0.068	0.149
Loss count	0.014	0.046	-0.008	0.014	0.077	0.534	0.011	0.024	-0.131	0.127	0.025	0.263	0.134	0.113
Land productivity	0.000	0.000	-0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Extension access	-0.046	0.071	-0.029	0.022	-0.106	0.611	-0.066*	0.040	-0.110	0.201	-0.060	0.383	0.079	0.279
Market information	0.021	0.050	0.000	0.013	0.019	0.444	0.008	0.026	-0.022	0.170	0.012	0.497	-0.208	0.235
Agriculture income share	-0.093	16.707	0.029	0.966	-30.104**	12.534	0.066	0.739	-0.673	637.153	-0.175	3.402	-0.360	0.239

Notes: RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping. ***, **, * represent 1%, 5%, and 10% significance level, respectively. Reported standard errors are the bootstrapped standard errors.

Table A6: Estimates of standard deviation of agriculture income equations (*continued*)

	RMP0		RMP1		RMP2		RMP3		RMP4		RMP5		RMP7	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Nonfarm income	-0.000	0.000	0.000	0.000	-0.000	0.000	0.000	0.000	-0.000	0.001	-0.000	0.000	-0.000	0.000
Mean land	-0.932	0.795	-0.044	0.152	1.568	10.008	-0.095	0.312	-0.277	12.050	-0.074	2.406	-1.241***	0.186
Mean fertilizer quantity	-0.001	0.002	-0.001	0.001	-0.000	0.006	-0.002	0.001	-0.002	0.005	-0.001	0.042	-0.001	0.009
Mean seed quantity	0.001	0.006	-0.001	0.003	0.004	0.036	-0.002	0.005	-0.001	0.012	-0.005	0.268	0.011	0.034
Mean production cost	0.000	0.000	0.000**	0.000	-0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Joint significance of crop varying covariates														
$\chi 2$ (3)	1.41		2.7		0.04		2.65		0.16		0.0		45.58***	
rmp0	-0.023	0.107	-0.041	0.166	-0.128	2.755	-0.097	0.305	-0.245	1.268	-0.382	6.889	-0.295**	0.143
rmp1	-0.350	0.480	-0.081	0.070	1.680	3.597	0.059	0.391	0.018	1.187	-0.104	9.826	-1.288***	0.282
rmp2	-0.199	0.423	-0.314	0.222	-0.131	0.502	0.169	0.268	0.250	1.737	1.637	33272.350	-1.158***	0.240
rmp3	0.274	0.679	-0.009	0.165	-3.040	5.347	0.041	0.082	1.474	2.172	-0.370	4.963	-3.844***	0.320
rmp4	-0.137	0.315	-0.109	0.148	-0.351	1.678	0.329	0.268	-0.038	0.168	-0.119	3.606	-1.751***	0.298
rmp5	0.310	0.895	-0.029	0.212	2.698	10.849	0.204	0.349	-1.802	5.279	-0.057	1.632	-0.405	0.251
rmp7	-0.085	0.496	-0.139	0.191	-0.752	2.682	-0.068	0.238	-0.338	1.053	0.246	33.698	0.036	0.147
Constant	0.173	16.720	0.282	0.968	30.447**	13.160	0.271	0.839	0.838	637.084	0.354	9.904	-2.457**	1.196

Notes: RMP1 – denotes risk mitigation, RMP2 – denotes risk transfer, RMP3 – denotes risk coping, RMP4 – denotes risk mitigation and transfer, RMP5 – denotes risk mitigation and coping and RMP7 – denotes risk transfer and coping. ***, ** represent 1%, and 5% significance level, respectively. Reported standard errors are the bootstrapped standard errors.

Appendix A6
Soil Quality Index (SQI) Calculations

In computing the soil quality index for the study, we used the "Soil nutrient maps of Sub-Saharan Africa[19]" raster file at 250 m resolution provided by the International Soil Reference and Information Centre (ISRIC). Nutrients covered in this data include; total nitrogen (N), total phosphorus (P), extractable phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), aluminium (Al), boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) in (ppm). For the estimation approaches for the nutrients data, curious readers are referred to Hengl *et al.*, (2017). Additionally, we used soil physical and biochemical properties data[20] provided by ISRIC for the computation of the index. We also used free spatial data from DIVA-GIS[21] in the form of shapefiles for administrative regions of our study country. Using the free and open source geographic information system, software called QGIS (previously known as Quantum GIS) and the geographic coordinate data of farm households, we calculate the soil parameters for each farm household. The Soil Quality Index (SQI) was calculated following the approaches described in Zheng *et al.*, (2005); Mukherjee and Lal (2014); and Zhang *et al.*, (2015). First, we used principal component analysis (PCA) to identify a minimum data set (MDS) to reduce the indicator load in the estimation of the index and avoid data redundancy. During the principal component analysis, only the 'highly weighted' variables were retained in the MDS. After selection of parameters for the MDS, all selected observations were transformed using linear scoring functions (less is better, more is better and optimum) based on the recommendations in the empirical literature (Amacher *et al.*, 2007; Mukherjee and Lal, 2014). Thereafter, the weighted additive SQI was computed using the formula below:

$$SQI = \Sigma \text{ Weight} * \text{Individual oil parameter score}$$

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