Climate change and agriculture in Sub-Saharan Africa: Four approaches to modeling rural households

Klimaendringer og landbruk i Afrika sør for Sahara:
Fire tilnærminger til å modellere landbrukshusholdninger

Philosophiae Doctor (PhD) Thesis

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Sofie Waage Skjeflo

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Measuring household vulnerability to climate change – Why markets matter

(Sofie Waage Skjeflo)

Paper 2

Learning the hard way? Adapting to climate risk in Tanzania

(Sofie Waage Skjeflo and Nina Bruvik Westberg)

Paper 3

Droughts and floods in an imperfect economy: Linking rural households in Malawi

(Sofie Waage Skjeflo)

Paper 4

Economy-wide effects of input subsidies in Malawi: Market imperfections and household heterogeneity

(Sofie Waage Skjeflo and Stein Holden)

Summary

The purpose of this thesis is to contribute to increased knowledge of potential impacts of climate change on the welfare of households in developing countries. It focuses on impacts of changing temperature and precipitation as well as weather extremes, with agriculture as the main channel of impact. The intended contribution of the thesis is twofold. The first contribution is methodological, in further developing approaches to modeling rural households in developing countries. The second contribution is empirical, in applying these approaches to relevant contexts. The thesis consists of four independent research papers and an introductory chapter.

Paper 1 comments on often-used approaches to measuring household level vulnerability to climate change. By simulating yield changes in maize by 2030 due to climate change in a computable general equilibrium model of Malawi, I show that some agricultural households may gain from climate change if food prices increase. The simulations show large food price increases in some scenarios, and this has negative impacts on the welfare of poor urban households that spend a disproportionate share of their incomes on food. On the other hand, increased food prices are beneficial for farm households that are net sellers of food. However, the majority of farm households in Malawi are net food buyers, and increased returns to land and agricultural labor are not sufficient to compensate for the increased cost of living. Approaches to measuring vulnerability that do not separate between net food buyers and net food sellers among farm households, or do not account for the potentially large impacts of climate change on food prices, are therefore likely to be misleading.

The second paper investigates the scope for adapting to climate risk among farm households in Tanzania. By combining panel data on rural households with historical weather data with detailed spatial resolution, we investigate the effect of past drought exposure on households' ability to cope with current droughts. Specifically, we look at impacts on crop yields and impacts on children's nutritional indicators . We find that droughts reduce yields, and that the impact is increasing in the severity of the shock. We also find that severe droughts worsen short-term nutritional outcomes for children. However, for less severe shocks, households with more previous shock exposure seem to be less affected by current droughts, in terms of agricultural outcomes and impacts on children's nutrition. When investigating potential mechanisms that may explain these results, we find that past droughts increase the probability that farmers invest in water harvesting and soil conservation facilities, and that off-farm employment may be an important coping strategy when experiencing a

severe drought. Our results also indicate that farmers react to climate risk by intensifying agricultural production, perhaps to ensure a minimum consumption level in case of drought.

Paper 3 also looks at impacts of climate variability, by simulating droughts and floods in a simple economy-wide model. The model is based on a new social accounting matrix of the Central and Southern Malawi, which takes into account that a large share of production by small-scale farmers is consumed on the farm, and that household labor is an important input in production. These features of the rural economy limit the links between production sectors and households, and reduce the economy-wide impacts of climate shocks. A large share of the variation in impacts across household groups in the model is due to the types of crops grown by the households. Households in the Southern region rely more on local maize varieties that are more drought sensitive, and in addition, the Southern region is more prone to flooding. However, the results also show that reduced demand for farm labor from households affected by climate shocks may have additional negative impacts on households that rely on the rural labor market for cash income.

The final paper looks at a large farm input subsidy program in Malawi that has been implemented to improve household level and national food security. In addition to helping targeted households to increase production by providing improved maize seeds and cheap inorganic fertilizer, the program has been claimed to benefit non-targeted poor households by lowering food prices and increasing rural wages. We investigate the impacts of the program on farm households by simulating varying access to subsidized fertilizer in a set of farm household programming models. These models represent typical households in Central and Southern Malawi, and take into account that the households may face liquidity constraints, seasonal labor shortages and limited off-farm employment opportunities, subsistence constraints for food consumption and transaction costs related to trade. Combined with heterogeneity in terms of labor and land endowments, we show that the ability of households to respond to access to subsidized inputs may be limited. We argue that market imperfections may explain why empirical studies of the economy-wide effects of the subsidy program have found small impacts on food prices and wages.

INTRODUCTION

1 Introduction

Despite remarkable achievements in improving standards of living and reducing the proportion of the world's population living in poverty over the past century (Easterlin, 2000; Chen and Ravallion, 2010), securing basic needs remains a challenge for a large share of the global population.[1] The majority of the world's poor live in rural areas, and rely on agriculture as their main livelihood (World Bank, 2014). In the face of a changing climate, the challenge of improving the livelihoods of the poor may be even greater (IPCC, 2014a). The physical characteristics of agriculture create a strong link between the climate, agriculture and poverty (Porter et al., 2014). Understanding the potential impacts of climate change[2] therefore requires knowledge of how the rural poor might be affected by climate change, through which channels and how policies to improve livelihoods interact with the rural economy. This thesis consists of four independent research papers, focusing on impacts of climate change, climate variability, adaptation to climate change and impacts of agricultural policy in Sub-Saharan Africa. The purpose of the thesis is to contribute to increased understanding of the potential impacts of climate change for the rural population, and more generally, to improve the understanding of rural economies in developing countries. The intended contribution is twofold: methodological, in further developing and applying four different approaches to modeling rural households, and empirical, in applying the methods to relevant contexts.

This introduction starts by an overview of the literature on climate change impacts in developing countries, with a particular emphasis on agriculture in Sub-Saharan Africa. The purpose of the section is not to provide a complete review of the literature, but rather to place the contribution of the thesis in a context. Next, the four papers of the thesis are briefly summarized, while in section 3, the data and methodologies are discussed. The final section offers a conclusion with some overarching implications for policy and further research.

[1] In 2010, the estimated share of the world's population living in extreme poverty, defined as less than $1.25 per day measured in purchasing power parity terms, was about 20 percent (World Bank, 2014). In Sub-Saharan Africa, the estimated share is almost 50 percent (World Bank, 2014).

[2] In this thesis, I follow the Intergovernmental Panel of Climate Change (IPCC) definition of climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer" (IPCC, 2014b, p.5). Climate change thus refers to both changes in mean climate and climate variability.

2 Climate change impacts through agriculture

The most recent report from the Intergovernmental Panel of Climate Change (IPCC) concludes that the climate system is warming, and that it is very likely that weather extremes have become more frequent and severe due to climate change (IPCC, 2013). Projections show that continued greenhouse gas emissions will cause average temperatures to increase further, and there is high confidence that the near-term increase will be larger in tropical and sub-tropical regions than mid-latitude regions. Projections for average precipitation are less clear. It is likely that precipitation variability will increase, but the projections are uncertain and vary considerably across regions in Sub-Saharan Africa (IPCC, 2013). Studies of impacts of climate change in developing countries have to a large extent focused on impacts through agriculture, both because of the importance of the agricultural sector in terms of production and employment, and because of the sensitivity of this sector to climate change (Arndt et al., 2012).

2.1 Impacts on crop yields

Early studies of quantitative impacts of climate change on agriculture relied on crop simulation models to simulate the impact of changing temperature, precipitation and concentration of CO_2 in the atmosphere on crop growth (Kurukulasuriya and Rosenthal, 2003). These models capture the effect of genetic factors, climate variables such as solar radiation, maximum and minimum temperatures and precipitation, as well as soil characteristics and farm management practices on yields (Parry et al., 1999). The models can also take into account the fertilization effect of increased CO_2 concentration in the atmosphere, as explained by Darwin and Kennedy (2000). A relevant example looking at impacts on crop growth in developing countries is the study by Jones and Thornton (2003). They estimate maize production losses due to climate change by 2055 in Africa and Latin America, based on projected weather data and a rainfall simulation model, which is used for simulations in a crop model. They estimate a total reduction in maize production of 10 percent due to climate change by 2055, but with considerable variation across and within countries.

2.2 Taking into account adaptation

As emphasized by several authors (Mendelsohn et al., 1994; Mendelsohn and Dinar, 1999; Skoufias et al., 2011), the direct impacts of climate change on crop yields may not be good predictors of the economic impacts of climate change. First, if the estimated impacts have not taken into account adaptation activities, they could overestimate the negative impacts, as farmers may adapt to climate change by switching crops and agricultural techniques, diversifying income sources, or migrating (Kurukulasuriya and Rosenthal, 2003).[3] The role of adaptation and the scope for adapting to climate change in agriculture has been a source of debate in the research community, see for instance Cline (1996), Darwin (1999) and Burke and Emerick (2013). The first and second papers of this thesis add to this literature in different ways. The first paper comments on often-used approaches to measuring household level vulnerability to climate change.[4] It shows that taking into account indirect effects of climate change on food prices gives very different answers to which households are most vulnerable than approaches that do not account for price changes.[5] The second paper provides an empirical investigation of adaptation to climate variability in Tanzania.

Secondly, Skoufias et al. (2011) argue that the distribution of impacts across the population will depend on heterogeneity in terms of productive assets and whether the households are net producers or net consumers of food. These factors are explored in detail in paper 1, where the role of farm households as both producers and consumers of food crops is taken into account in a Computable General Equilibrium (CGE) model of Malawi.[6] CGE models take into account autonomous adaptation to climate change, in the sense that changing market prices for goods and factors of production create incentives to reallocate resources (for instance to increase food production if food prices increase) and substituting between different food crops in consumption. As discussed by Arndt et al. (2012), this approach makes it possible to trace the causal links and mechanisms through which biophysical changes (e.g. decreased crop yields) impact the economy. Several studies have explored impacts of climate change by using CGE models of developing countries (some are mentioned in paper 1). For instance, Hertel et al. (2010) use a global CGE model and emphasize a similar result as in paper 1 in this thesis: taking into account the likely increase in food prices[7] due to climate change implies a positive "earnings effect" on farm households that sell some of their produce. The first paper of this thesis adds to existing CGE studies by using a highly disaggregated CGE model for Malawi, which makes it possible to separate between net buyers and net sellers of food among

[3]The IPCC defines adaptation as "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities" (IPCC, 2014b, p.1)

[4]A definition of vulnerability is provided in paper 1.

[5]Including the indicator approach, as used by O'Brien et al. (2004), and the "Ricardian approach", proposed by Mendelsohn et al. (1994).

[6]As in Morton (2007), farm households here refer to rural households in developing countries with farm income as the main income source, and who use mainly family labor in production.

[7]See for instance Rosenzweig and Parry (1994) and the review in Schmidhuber and Tubiello (2007).

farm households.

The literature discussed so far has mainly assessed impacts of projected changes in mean temperature and precipitation. Papers 2 and 3 of this thesis deal with the impacts of climate variability, specifically the impacts of droughts and floods on households through impacts on agriculture. To the extent that climate shocks are common shocks that simultaneously affect households in an area, the scope for informal risk sharing strategies is limited (Dercon, 2002). Formal credit and insurance markets are often missing or imperfect in developing countries (Besley, 1995), and the effect of increased climate variability on households will depend on their ability to smooth income and consumption through risk management strategies. These strategies may in themselves have important impacts on poverty, by locking poor households in low risk, low return agriculture (Dercon, 2002). Weather risk may thus contribute to increased inequality.

Paper 2 provides an empirical investigation of whether rural households in Tanzania are able to take advantage of learning from previous drought experiences in order to cope with current droughts, both in terms of mitigating negative impacts on crop yields and negative impacts on children's health. This paper adds to recent studies that exploit observed variation in temperature and precipitation to investigate impacts of climate change on economic outcomes, while controlling for time invariant unobservables by using fixed effects panel data analysis. An example from African agriculture is the study by Schlenker and Lobell (2010), who exploit panel data on crop yields for five staple crops in Sub-Saharan Africa, coupled with weather data, while controlling for country fixed effects. They use their estimated impacts to predict the effects of various scenarios for future temperature and precipitation, and find consistently negative impacts on yields.[8]

A review of papers using this approach is provided by Dell et al. (2013), who argue that the strength of the literature is to provide causal evidence on the impact of contemporary weather (rainfall, precipitation and extreme events) on economic outcomes such as agriculture, health and conflict. They also argue that there are challenges in extrapolating from the impacts of weather to impacts of long-run climate change, which may be larger (due to intensification) or smaller (due to adaptation). They suggest different approaches to maintaining the identification of causal impacts, while examining longer-run effects. One of these approaches, namely investigating if the impact of a current weather shock depends on previous shock experience within the same spatial unit, is followed in paper 2.

[8]This holds for all crops except cassava, which the authors argue does not have a well defined growing season, resulting in a poor model fit (Schlenker and Lobell, 2010).

The CGE studies discussed above are based on aggregate models that assume perfect factor and product markets, while econometric studies have shown numerous constraints to adaptation at the household level, many of them related to market imperfections. For instance, studies from South Africa and Ethiopia find that access to credit is a main constraint to adapting to climate change among farm households, as well as access to land (in Ethiopia) and information about adaptation options and climate projections (Deressa et al., 2009; Bryan et al., 2009; Di Falco et al., 2012).

The fundamental dependence of agriculture on weather and natural resources creates a strong link between the environment and the rural economy in developing countries. Binswanger and Rosenzweig (1986) show how the immobility of land causes spatial dispersion, high transport costs and synchronic timing of production activities in agriculture, while heterogeneity in input factors contribute to asymmetric information. Weather variability is linked to yield risk, market price risk and uncertain optimal timing of production activities. Binswanger and Rosenzweig (1986) show how a combination of these factors may explain credit market imperfections, labor and land market imperfections, as well as output market imperfections. As previously mentioned, paper 1 shows the importance of taking into account the dual role of farm households as producers and consumers of food when assessing household vulnerability to climate change. This is in line with the basic farm household model by Singh et al. (1986). They also showed that when markets for goods that the farm household both consumes and supplies (such as food or labor) fail, production decisions are no longer independent from consumption decisions. A number of studies have shown the implications of non-separability for farm household behavior, for instance in terms of low supply response to price incentives (de Janvry et al., 1991) and non-linear supply (Löfgren and Robinson, 1999).

Morton (2007) discusses potential impacts of climate change on smallholder agriculture, and mentions lack of market access for smallholders as a non-climatic stressor that increases smallholders' vulnerability to climate change. As previously discussed, market imperfections may also act as constraints to adaptation for farm households, and they are also likely to affect how households respond to planned adaptation policies. These issues are further explored in papers 3 and 4 of the thesis. Paper 3 provides a first step towards taking into account market imperfections combined with household heterogeneity in an economy-wide assessment of climate change impacts in Malawi. Paper 4 investigates the role of market imperfections and household heterogeneity in shaping households' response to input subsidies.

2.3 Adaptation policies in the rural economy

The adaptation discussed above may be categorized as "autonomous adaptation" since it refers to adaptive capacity already present in the economic system (Arndt et al., 2012). On the other hand, "exogenous adaptation", or planned adaptation, takes the form of policy response to climate change and climate risk (Arndt et al., 2012). Fankhauser et al. (1999) discuss how market failures warrant government intervention to ensure adaptation to climate change. They highlight situations where there are externalities related to the autonomous adaptation by farmers, information asymmetries that prevent credit market access, and where adaptation includes the provision of public goods, or providing safety nets for vulnerable persons. An important aspect of adaptation policies is to increase overall development in order to increase adaptive capacity (Fankhauser et al., 1999).

Devereux (2007) analyzes the impact of droughts and floods on food security and policy options, with the 2002 food crisis in Malawi as an example, based on Amartya Sen's entitlement approach (Sen, 1983). He shows that providing subsidized fertilizer and improved seeds can be seen as a policy to prevent the negative impacts on yields from droughts, since it increases agricultural productivity. Input subsidies can be seen as a "productivity enhancing safety net", both through its effect on crop production, but also through its indirect effect on lowering food prices (Devereux, 2007). The fourth paper of the thesis investigates the impacts of the large Farm Input Subsidy Program (FISP) in Malawi, with a particular focus on its potential to improve food security for households beyond those targeted by the program through lowering food prices. The FISP is seen as the pioneer of input subsidy programs in Sub-Saharan Africa (Denning et al., 2009). However, the impacts of the program have been disputed (Ricker-Gilbert et al., 2013a). The fourth paper of this thesis thus also adds to the literature on the impacts of the subsidy program in particular, and the interaction between the characteristics of rural households and markets with policy interventions that may create unexpected responses.

3 Summary of papers

This section provides a brief summary of the four papers of the thesis, focusing on the questions addressed and the contribution of the paper in terms of main findings. The data and methods are discussed in detail in the following section.

Paper 1:

Measuring household vulnerability to climate change - Why markets matter

In order to assess the potential impacts of climate change on households and to inform adaptation policy, several approaches to measuring the vulnerability of households to climate change have been developed across disciplines. This paper shows that these approaches largely ignore the indirect effects of climate change that are transmitted through prices, and, in particular, the potentially large impact of climate change on households in developing countries through food prices. To illustrate the importance of the indirect effects of climate change on households, a CGE model for Malawi is used to assess household vulnerability to climate change by 2030. The model contains a detailed disaggregation of households that captures their position in agricultural markets. The results show that some agricultural households can benefit from climate change due to higher food prices. However, the majority of rural poor in Malawi are net buyers of food and are vulnerable to the adverse impacts of climate change. These findings are contrary to results from studies using indicator approaches and the Ricardian approach. For instance, studies using aggregate indicators of vulnerability often categorize all agricultural households as vulnerable without taking into account their role as net sellers or net buyers of crops. Studies using the Ricardian approach have concluded that small-scale farmers may be less vulnerable to climate change than large-scale farmers, while this result could be reversed when price changes are accounted for. The most vulnerable households are those that experience increased food prices, spend a large share of their income on food, and do not benefit from increased returns to agricultural land and labour. The results of this study are also important in the context of existing CGE models that assess the impacts of climate change. These models have often been too aggregated to make the important distinction between net sellers and buyers among agricultural households. In line with previous studies using CGE models, I find that the urban poor are the most vulnerable to climate change due to the large share of their expenditures allocated to food. I also illustrate the importance of taking into account the impact of climate change on global food prices when measuring vulnerability by showing how adverse impacts on households are amplified when the price of imported as well as domestically produced food increases.

Paper 2:

Learning the hard way? Adapting to climate risk in Tanzania

The effect of repeated exposure to weather shocks, such as droughts, on the ability of farm households to cope with new shocks is not obvious. On the one hand, households may become more vulnerable to current shocks if they have coped with past shocks by depleting assets. On the other hand, they may be able to take advantage of learning from past shocks to mitigate the impact of new shocks. This question becomes especially relevant when considering the likely increase in extreme events due to climate change in the future. In this paper, my co-author and I use recent panel data on Tanzanian farm households to investigate how previous exposure to weather shocks affects the impact of a current shock. Specifically, we investigate the impact of current and past drought incidents on agricultural yield and children's health, measured by their nutritional status. Our results show that experiencing droughts negatively affects crop yields, with the impact increasing in the severity of the shock. The results also indicate that the more shocks a household has experienced previously, the less severe is the impact of a current shock on yields, but this only holds for mild droughts. We also find that farmers with more previous exposure to droughts have higher yields, perhaps indicating that farmers that continue in farming despite previous droughts increase their effort and investments in response to shocks as an adaptive measure. Exploring the technologies used by the households suggests that households invest in soil- and water conservation facilities in response to more frequent rainfall shocks, whereas they are less likely to apply fertilizer. Households seem to use off-farm income sources as a coping strategy when facing shocks, but this strategy appears less important for households that have more previous shock exposure. In terms of children's nutritional outcomes, severe droughts seem to have a negative impact on short-term nutritional indicators, but there are also indications that households with more previous shock experience are able to reduce impacts of less severe shocks on children. The findings suggest that households are able to learn from their past shock experience, and could imply that households, to a certain extent, are able to adapt to climate risk.

Paper 3:

Droughts and floods in an imperfect economy: Linking rural households in Malawi

This paper describes the development of a new Social Accounting Matrix (SAM) of six districts in the Central and Southern regions of Malawi, and uses the SAM to investigate the distributional impacts of droughts and floods. The detailed treatment of the agricultural production of six household categories in the SAM, and the partial integration of these households into incomplete rural markets, makes it possible to explore how impacts are distributed across household categories and disseminated through production and consumption linkages. Contrary to conventional SAMs, this SAM takes into account the large share of crops produced by households that never reach the market, but are consumed within the household. It also incorporates the use of family labor, and the transaction costs related to buying and selling crops and inputs in the market. I find that a large share of the variation in drought impacts across households is due to differences in the types of crops grown by households. Since households in the Southern region produce more drought-sensitive local maize, they are disproportionally affected by droughts. This is also the more flood-prone region of Malawi. The importance of on-farm consumption of own produce and the use of family-labor in production limits the links between the households in the SAM. However, I also find that floods in the Southern region of Malawi may affect households in the Central region through changes in labor and consumption demand from flood-affected households. The findings imply that providing information about improved drought resistant varieties, as well as encouraging their adoption, may be important policies to reduce vulnerability to climate variability. The results also demonstrate the importance of taking into account the potential diffusion of weather shocks through the rural labor market when assessing impacts of climate change on households.

Paper 4:

Economy-wide effects of input subsidies in Malawi: Market imperfections and household heterogeneity

The potential benefits of providing subsidized inputs to farm households in developing countries may reach well beyond the targeted households. More specifically, increased food production and demand for rural labor, and decreased off-farm labor supply by other farm households, may benefit poor households through lower food prices and higher rural wages. However, two recent empirical studies of a large input subsidy program in Malawi find that these effects are modest, despite the amount of fertilizer distributed and the number of households reached. The purpose of this paper is to provide potential explanations for what appears to be only a modest maize price decrease and a moderate increase in rural wage rates. Our hypothesis is that market imperfections limit households' ability to respond to the subsidy. To investigate this hypothesis, we run a series of simulations using six farm-household programming models representing typical household groups in Central and Southern Malawi. The models represent households in an environment with missing and imperfect markets, taking into account transaction costs related to input and output markets, seasonal liquidity constraints, missing land rental markets, limited access to off-farm employment and seasonality in labor demand. By removing transaction costs related to maize marketing, relaxing the assumption of no credit market, and allowing for land rental, we show that a combination of market imperfections and variation in household endowments constrain households' response to access to subsidized inputs and may explain why the observed economy-wide impacts of the subsidy program are small. Our findings suggest that input subsidy programs could be combined with improved market infrastructure and market access in order to increase non-beneficiary households' benefits from input subsidies.

4 Data and methods

All four papers of the thesis are empirical, but each takes on a different approach to modeling rural households. As mentioned in the introduction, one objective of this thesis is to contribute to improved modeling of rural households in developing countries. The data and methods are described in detail in the respective papers, including potential data weaknesses, whereas the purpose of this section is to compare and contrast the methods used, and offer some conclusions on their strengths and weaknesses.

Paper 1 uses a CGE model developed by the International Food Policy Research Institute (IFPRI), described in detail in Löfgren et al. (2001) and Löfgren (2001). The model is calibrated to a 1998 Social Accounting Matrix (SAM) of Malawi, described in Chulu and Wobst (2001). The model (and SAM) includes 14 household groups, categorized according to occupation, location, landholding and education. The model is static, and allows for comparative static analyses of shocks and policies.

Paper 2 estimates reduced form models of impacts of current and past droughts of various severity on crop yields and child health outcomes. The empirical analysis is based on two rounds of the Tanzania National Panel Survey, collected in 2008/09 (NBS, 2009) and 2010/11 (NBS, 2011). GPS coordinates from the survey data are used to couple the household data with gridded precipitation and temperature data from the University of Delaware, described in Willmott and Matsuura (2012a,b). The estimation is based on fixed-effects panel data analysis, with fixed effects at the plot level in some specifications, and at the grid cell level in other specifications.

The SAM of Central and Southern Malawi developed in paper 3 is based on survey data of 371 households from the 2008/09 agricultural season. The SAM accounts for consumption of own produce and the use of family-labor in production, by creating household-specific production activities, commodity accounts and factor accounts. The SAM is used to analyze impacts of droughts and floods of varying severity, based on a SAM multiplier model with supply constraints.

The Malawi survey data is part of a panel with data from four agricultural seasons, collected in 2006, 2007, 2009 and 2012. The first two rounds of the survey, the sampling strategy and the original sample of 450 households is described in Lunduka et al. (2009). The data from the first three rounds of the survey is used in paper 4, where linear programming farm household models representing households from Central and Southern Malawi are calibrated to the survey data. The models include detailed production activities for several crops and intercropping activities, allowing for use of subsidized inputs from the input subsidy program discussed above. Seasonality in production activities and the lack of access to credit is incorporated by introducing 11 sub-seasons, where the labor requirements vary over sub-seasons, and cash from crop sales at the end of the production year is not available for input purchases at the beginning of the year. A number of constraints reflect subsistence consumption requirements and seasonal constraints on access to off-farm employment, cash and subsidized inputs.

To summarize, the four papers of the thesis include CGE analysis, SAM multiplier analysis, farm-household linear programming models, and econometric analysis of reduced form models. The three former approaches are simulation models, where the CGE and SAM multiplier models are economy-wide models, while the farm household linear programming models are partial equilibrium models.

4.1 Methodological strengths and limitations

The standard SAM multiplier model is based on three main assumptions (Taylor and Adelman, 1996). First, there is excess capacity in production sectors, i.e. supply is perfectly elastic. Second, production technologies are linear, with fixed factor- and intermediate input shares, and average and marginal expenditure shares are equal (i.e. all expenditure elasticities are equal to unity). Third, prices are fixed. The limitations of the first and second assumptions are to a certain extent addressed in paper 3 by replacing average expenditure shares by estimated marginal expenditure shares in line with Pyatt and Round (1979), and by introducing supply constraints for crop production activities in line with Subramanian and Sadoulet (1990).

The assumption of fixed prices is, however, maintained. Taylor and Adelman (1996) discuss limitations of village SAM multiplier models, and argue that the critical question is whether prices are likely to change in response to the exogenous changes modeled. The results in paper 1 show that the price changes resulting from productivity changes in agriculture due to climate change have important implications for household level impacts. However, as discussed in paper 3, it is unrealistic to assume that farmers would be able to respond to price incentives in the short run. Whether prices would change also depends on the integration of the regional economy described by the SAM with the rest of Malawi and the rest of the world. If the region can be assumed to be a price taker, the assumption of fixed prices may not be too unrealistic. For instance, Ricker-Gilbert et al. (2013b) conclude, based on a survey of previous studies, that Malawi's maize markets are reasonably well integrated. Despite several limiting assumptions, the SAM multiplier model takes into account the links between households and production sectors created by consumption demand, intermediate input demand, factor demand and the pattern of factor ownership. It therefore goes beyond the direct impacts of production fluctuations due to extreme events, and, as argued by Round (2003), provides a useful first-cut assessment of the impact of droughts and floods on the households represented in the SAM, given the structure of the SAM.

On the other hand, in the case of long-run, gradual climate change, assuming fixed prices is likely to yield highly misleading results, especially given the projected increase in global food prices due to climate change. Shocks that lead to structural change with changes in relative prices are better analyzed in CGE models, where there are substitution possibilities and where prices and production are jointly determined (Sadoulet and de Janvry, 1995). Sadoulet and de Janvry (1995) emphasize that since CGE models are equilibrium models, the appropriate time-frame of the analysis is the time it takes for the economy to reach equilibrium after being subjected to a shock. For static CGE models, the period of analysis is constrained to the medium term, i.e. the time it takes to reach equilibrium, but before dynamic effects become important. This is a major limitation to the analysis in the first paper, where a static CGE model is used to assess the impact of climate change by 2030. As discussed by Skoufias et al. (2011), since the model does not take into account economic growth, and its effect on reducing poverty, the importance of agriculture in GDP and the share of food in household expenditures, it is likely to overestimate the adverse impacts of climate change on households in developing countries. As an attempt to remedy at least part of the problem, sensitivity analyses in the appendix of the first paper show the impact of simulating climate change scenarios for crops yields when the sectoral shares of services and agriculture are updated, based on projections for growth by 2030.

Several studies have shown that market imperfections may shape farm households' responses to external shocks, see for instance the summary in de Janvry and Sadoulet (2006). The CGE model in paper 1 does not take into account market imperfections that may cause production decisions to become dependent on household endowments and consumption preferences. Rather it models farm production as being undertaken by profit maximizing producers, independent of household preferences. A test of separation of production and consumption decisions in paper 3 shows that this may not be the case for rural households in Malawi. The SAM in this paper takes into account consumption of own produce and use of family labor in production, but since the multiplier model assumes fixed prices it does not account for the potentially important effects of shocks on household shadow prices. Although the assumption of perfectly elastic supply in the multiplier model can be relaxed, the implications of supply constraints are not treated in a satisfactory way in this modeling framework (Taylor and Adelman, 1996; Subramanian and Qaim, 2009). In real life, supply constraints would lead to high shadow prices if there are high transaction costs related to trade, for instance if a household is self-sufficient in food crops because of high transaction costs, in line with the framework by de Janvry et al. (1991). This is not taken into account in the simple SAM multiplier analysis in paper 3, as it is assumed that any change in demand for goods from supply-constrained sectors can be met by increased imports at fixed prices. A natural application of the SAM developed in paper 3, and a suggestion for further research, is to calibrate a CGE model to the SAM to allow prices to shape the allocation of resources in response to a shock, while accounting for important resource constraints and market imperfections. For instance, Taylor and Adelman (1996), Löfgren and Robinson (1999), Holden et al. (1999), Holden and Lofgren (2005) and Kuiper (2005) have made progress in this direction.

The linear programming models used in paper 4 are to a greater extent able to take market imperfections into account, and show that these market imperfections lead to non-linear and highly heterogeneous responses to access to subsidized inputs. The models are used to provide potential explanations of results from econometric studies of the effect of Malawi's input subsidy program on maize prices and wages (Ricker-Gilbert et al., 2013b; Ricker-Gilbert, 2014). The estimation methods used in these studies may provide good estimates of the average marginal impact of access to subsidized inputs, however the estimated reduced form models do not explain the causal mechanisms underlying these effects. Although the farm household models are highly simplified, being partial equilibrium models based on limited data, they can be used to experiment with policy variables (such as the amount of subsidized inputs) to investigate causal impacts on farm household production and consumption decisions, given the assumptions of the model.

This points to an important limitation of the reduced form models that are estimated in paper 2. The strengths of using exogenous variation in weather to estimate impacts of temperature, precipitation and extreme events on economic outcomes are discussed above and in Dell et al. (2013). However, as argued by Deaton (2010), the findings are not worth much in terms of informing policy makers unless we understand the causal mechanisms behind the results. We have tried to address this to a certain extent in paper 2 by investigating behavior of the households that could potentially explain the results. However, an important step towards uncovering causal mechanisms, and thus increasing the relevance of the reduced form results, would be to develop an underlying theoretical model with testable predictions.

To summarize, the methods of each paper have their strengths and limitations. The limitations arise both because of data- and time constraints. While I have attempted to apply models that are appropriate tools for the problem at hand in each paper, a number of potential extensions, improvements and suggestions for further work arise. Some of these are addressed in the papers, and some have been discussed here. As noted by Skoufias et al. (2011), the trade-off between the tractability of a model and the amount of heterogeneity that can be incorporated, is a major challenge in all modeling work. Accounting for household heterogeneity and specific market characteristics may increase the complexity of for instance general equilibrium models considerably. However, the results from paper 4 in this dissertation show that ignoring these aspects may lead to misleading conclusions.

5 Conclusion and policy implications

The contributions of each of the four papers in this thesis are policy relevant in the way of informing policy makers of what determines household level vulnerability to climate change. Understanding the potential impacts of climate change at the household level, and the potential for households to adapt, is necessary in order to correctly weigh costs and benefits of mitigation policies. It is also a necessary input for targeting adaptation policies to vulnerable household groups where possible, and safety nets where mitigation and adaptation efforts are not sufficient to avoid adverse impacts of climate change.

One key insight is that the indirect effects of climate change on food prices are important determinants of household level vulnerability to climate change. For instance, increasing food prices makes poor urban consumers vulnerable since food expenditures constitute a disproportionate share of their total expenditures. Although higher food prices reduce the negative impacts of decreased yields due to climate change for farm households, a large share of farm households, and the majority of the rural poor, are net food buyers. On the other hand, net food selling households may gain from climate change if crop prices increase.

The vulnerability of households to climate extremes, such as droughts, is highly dependent on the types of crops grown by the household. For instance, continued reliance on more drought sensitive crop varieties by poor households could accentuate the disproportionate strain of climate variability on these households. An important policy implication could thus be to provide information about the characteristics of improved, drought tolerant crop varieties, and make them available locally. If the characteristics of existing drought tolerant varieties are not suitable for local conditions and preferences, there should be continued investment in crop research to improve these varieties. Also of relevance to policy makers is the finding that despite the importance of family labor in production for many farm households, the adverse impacts of climate variability may be disseminated through the rural labor market, affecting households that depend on the labor market for cash income in addition to home production.

On a more positive note, the thesis also demonstrates the scope for adaptation. Households seem to be able to take advantage of their previous drought experiences to better cope with current shocks.

This adaptation likely takes place through investment in agricultural techniques, such as constructing water harvesting and soil conservation facilities, and through diversifying income sources. This suggests that there is a scope for reducing vulnerability to droughts, and perhaps to increased future climate variability, by providing information about and facilitating the adoption of adaptation technologies. On the other hand, the scope for adapting to severe droughts seems less promising. In this case, safety nets may be required to avoid long-lasting negative impacts, for instance through negative impacts on children's health.

Finally, the thesis also adds to the large amount of evidence demonstrating the importance of improving infrastructure and providing access to credit for rural households. Resource- and liquidity constraints facing these households limit their ability to respond to policies that aim to increase agricultural productivity and promote food security at the household and national level.

Perhaps less applicable in a policy context, but relevant for the research community, are the insights from the approaches to modeling rural households in developing countries. Although magnitudes based on any of the modeling approaches should not be interpreted as "predictions", the heterogeneity in responses and their directions from papers 1, 3 and 4 reveal the importance of paying more attention to household heterogeneity, market characteristics and the mechanisms underlying observed outcomes of policies or shocks.

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PAPER 1

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Measuring household vulnerability to climate change—Why markets matter

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ABSTRACT

Climate change and climate variability affect households in developing countries both directly through their impact on crop yields and indirectly through their impact on wages, food prices and the livelihoods of the poor. Therefore, vulnerable household groups cannot be identified without considering their position in and access to markets. I illustrate the effects – transmitted through markets – that are significant in household exposure, sensitivity and adaptive capacity to climate change by simulating productivity shocks to maize up to 2030 due to climate change in a computable general equilibrium model of Malawi. The results show that rural households with large land holdings may benefit from the adverse impact of climate change on maize yields as a result of increased maize prices. Urban poor and small-scale farmers are vulnerable to climate change due to the large portion of their incomes spent on food. Existing vulnerability measures that do not consider equilibrium effects and characterise all farmers as vulnerable may therefore be misleading.

1. Introduction

It is important to identify households that will likely be vulnerable to future climate change in order to effectively target adaptation policies. With this motivation, several approaches for measuring vulnerability have been developed across disciplines (Adger, 2006). This paper shows that these approaches largely ignore the second-order effects of climate change that are transmitted through prices of goods produced and consumed by households and, in particular, the potentially large impact of climate change on households in developing countries through food prices. To illustrate the importance of the indirect effects of climate change on households, a computable general equilibrium model of Malawi is used to assess household vulnerability to climate change by 2030. The model contains a detailed disaggregation of households that captures their position in agricultural markets. The results show that some agricultural households can benefit from climate change due to higher food prices. However, the majority of rural poor in Malawi are net buyers of food and are vulnerable to the adverse impacts of climate change. These findings are contrary to results from studies using indicator approaches and the Ricardian approach. The results of this study are also important in the context of existing computable general equilibrium models that assess the impacts of climate change. These models have often been too aggregated to make the important distinction between net sellers and buyers among agricultural households. In line with previous studies using computable general equilibrium models, I find that the urban poor are the most vulnerable to climate change due to the large share of their expenditures allocated to food. I also illustrate the importance of taking into account the impact of climate change on global food prices when measuring vulnerability by showing how adverse impacts on households are amplified when the price of imported as well as domestically produced food increases.

The next section discusses the existing literature on measuring vulnerability to climate change. Section 3 uses a computable general equilibrium model to measure vulnerability to climate change in Malawi. The results from this model are discussed in Section 4. Section 5 concludes the paper.

2. Literature on measuring vulnerability

The IPCC defines vulnerability to climate change as 'the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity' (Parry et al., 2007).

According to Hinkel (2011), measuring a theoretical concept such as vulnerability requires the use of a method for mapping vulnerability to something that is observable. One such method entails creating vulnerability indicators.

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The indicator approach measures vulnerability to climate change by combining indicators of biophysical impacts (exposure) with indicators of socioeconomic characteristics (sensitivity and adaptation) into an aggregate indicator of vulnerability (Gbetibouo et al., 2010). This approach has been used both at the global level (Brooks et al., 2005) and the national and regional levels (Gbetibouo et al., 2010; O'Brien et al., 2004). The latter two studies assume that access to markets increases adaptive capacity through access to agricultural input and output markets, as well as to outside employment opportunities. In addition, less dependency on agriculture is assumed to decrease vulnerability by decreasing sensitivity and increasing adaptive capacity. Neither of these assumptions takes into account the indirect effects of climate change through, for instance, food prices and agricultural wages or the exposure to indirect effects transmitted through markets in areas that are not directly affected by climate change. For instance, the vulnerability of the growing group of urban poor cannot be addressed without taking into account food price changes that may result from the effects of climate change on agriculture.

Another approach is to use poverty as a proxy for household welfare, and measure the degree to which households or individuals are susceptible to and unable to cope with the adverse impacts of climate change as a change in poverty status or a change in the depth of poverty. This is in line with the literature on vulnerability to poverty (Calvo and Dercon, 2005; Kamanou and Morduch, 2005; Ligon and Schechter, 2003). Household data are used to estimate either expected poverty measures or expected utility measures of vulnerability to a shock. A detailed description of these methods and the econometric issues related to them is provided in Hoddinott and Quisumbing (2003). In general, the approach is based on calculating the probability that the welfare of an individual or household will fall below a certain benchmark level in response to a shock or an exposure to risk. This approach is based on observed data. Therefore, the approach must rely on already observed climate variability to measure vulnerability to climate change. This method may therefore be more appropriate for looking at climate risk rather than at vulnerability to gradual change in temperature and precipitation.

A third approach that has been used to assess the potential impacts of climate change through agriculture and to assess the vulnerability of households based on these impacts is the Ricardian approach. The Ricardian approach uses cross-sectional data to estimate the impact of marginal temperature and precipitation change on land values. The analysis is based on returns to land under different climatic conditions, and assumes that farmers will adapt to climate change by switching to the available practices and crops that offer the highest return to their land. The impacts of climate change estimated using this method must therefore be seen as estimates of impacts in the long run, after all available adaptation has already occurred.

Mendelsohn (2008) summarises recent studies that have used the Ricardian approach. The impacts vary greatly depending on geographic location, access to irrigation and whether the focus is on mean climate change or climate variability.

Different authors have emphasised a number of weaknesses of the Ricardian approach. Hertel and Rosch (2010) provide a good discussion, pointing to the Ricardian approach's sensitivity to omitted variable bias and its lack of applicability to climates outside the observed range (i.e., impacts of non-marginal climate change). Additionally, they argue that the Ricardian approach does not address the costs of adaptation because it looks at impacts *after* adaptation has occurred.

Reilly (1999) adds that the Ricardian approach does not consider how changes in global food prices will affect farmers' adaptation and that the approach's results are therefore only valid if impacts on global food prices are small or if the research only examines the impacts on a closed economy.

Food expenditures constitute a disproportionate share of expenditures for the urban poor, and their livelihoods may be closely linked to those of agricultural households through food prices, labour markets and demand linkages between agricultural and non-agricultural sectors (Haggblade et al., 2007). This calls for the integration of methods for assessing impacts on crop yields with general equilibrium models in order to take into account the impact of crop yield changes on prices, supply and demand, and on the rest of the economy.

Many studies assessing the impact of climate change both globally and in specific developing countries have been conducted using computable general equilibrium models. For instance, Hertel et al. (2010) use the Global Trade Analysis Project (GTAP) model to assess the impacts of climate change by 2030 on poverty, and show that poverty impacts can be disaggregated into effects on the cost of living and on earnings. The positive impact on farm income from increased crop prices may outweigh the increased cost of living for some households. Thurlow et al. (2012b) use a similar approach at the national level to look at the poverty impacts of climate change and current climate variability in Zambia, while Arndt et al. (2012) look at impacts on food security in Tanzania using a recursive dynamic computable general equilibrium model. However, the previous studies have not focused on measuring household-level vulnerability, and the models are often too aggregated to distinguish between household groups according to the net seller or net buyer status of food crops. Pauw et al. (2011) look at disaggregated poverty impacts of droughts and floods in Malawi, and find that small-scale farmers in the country's southern region, as well as urban households, are vulnerable. A similar model is used in this paper, but the focus is on vulnerability to gradual climate change rather than extreme events, and also examines global food price changes resulting from climate change.

To measure vulnerability to climate change scenarios simulated in a computable general equilibrium model, some measure of household welfare is used as an indicator of vulnerability. The households' exposure to climate change is imposed through simulations, such as changes in crop productivity. Sensitivity is captured by the model, which describes the economic structure that determines how households are affected by exposure to climate change. Finally, the adaptive capacity of households is captured by the behavioural assumptions in the model, such as the assumptions that households maximise utility and producers maximise profits. However, as I will show, the computable general equilibrium model must distinguish between whether households are net food sellers or net food buyers to adequately assess household-level vulnerability to climate change because these characteristics determine the impact of food price changes on household welfare (Deaton, 1989).

3. An application – measuring vulnerability to climate change in Malawi

The severe impact of climate variability on households in Malawi became evident in 2001 and 2002 after local flooding slashed maize (the local staple crop) production by 32 per cent. The number of deaths from starvation and hunger-related diseases is estimated to be between 300 and 3000 (Devereux, 2002). Although the weather shock was relatively mild compared to previous shocks, the consequences for food security were severe (Dorward and Kydd, 2004).

The aggregate economic impacts of climate change and climate variability depend on the size of the agricultural sector in terms of GDP and employment, as well as on the links to the rest of the economy. Approximately 30 per cent of Malawi's GDP was generated by agriculture in 2004, and taking into account downstream agro-processing increases this share to nearly half of GDP (Benin et al., 2008). To investigate the more disaggregated impacts of climate change in Malawi, it is necessary to examine the characteristics of households and the systems of production that they are part of. The rainy season in Malawi occurs between November and April. The main planting is done at the beginning of the rainy season, and labour demand is therefore at its peak around November (Famine Early Warning Systems Network, 2013). Most small-scale farmers in Malawi sell some casual labour, known as *Ganyu* labour, during this time in addition to planting crops on their own land (Whiteside, 2000). The rainy season is also known as the hunger season because the stocks from last year's harvest are likely low by this time and maize prices are higher (Whiteside, 2000). Therefore, poor households depend on selling their labour to buy food. If labour demand is low due to unfavourable conditions, such as a drought or flood, it can severely impact poor households. In addition to reduced yields on their own plots, households must deal with high market prices for food and the absence of Ganyu-derived income. However, if the harvest is successful, prices will begin decreasing at the beginning of the dry season during the main harvest. This means that there are large seasonal variations in maize prices, as well as spatial variations due to poor market integration (Jayne et al., 2010).

3.1. A computable general equilibrium model of Malawi

The discussion of the literature in Section 2 shows that both the indirect impacts of climate change on agriculture and the characteristics of households are likely to be important determinants of the exposure, sensitivity and adaptive capacity of households in developing countries. To demonstrate this, a computable general equilibrium model of Malawi, described by Löfgren (2001) and in the Online Supplementary Material, is used to simulate the impact of three different productivity shocks to maize, as well as shocks to the global price of maize due to climate change. The simulations are thus illustrations of expected mean changes in temperature and precipitation due to climate change, and not climate variability.

The model has a detailed treatment of the agricultural sector and takes into account the fact that most agricultural households in Malawi are producer-consumer units, which is in line with the agricultural household literature (Singh et al., 1986). This aspect of the model makes it possible to incorporate more realistic household behaviour into the model, such as the possibility of upward sloping demand curves for food that is both produced and consumed by households that are net sellers of food. For these households, the higher profits from food sales when the price increases may outweigh the income- and substitution effects of the food price increase. The agricultural households in the model are disaggregated according to land holding size, and non-agricultural urban and rural households are disaggregated according to level of education. The impact of the productivity shock is conveyed through factor returns and commodity prices, thus affecting household real incomes, which makes this disaggregation useful for looking at impacts on separate household groups. Table 1 shows some summary statistics on the household groups in the model.

Maize is the most important crop in Malawi, both in terms of production and consumption. Thus, I focus on productivity and price shocks to maize to illustrate the potential importance of indirect impacts on household welfare. Maize is also a highly drought-sensitive crop, and shows little response to the fertilisation effect of increased CO_2 in the atmosphere (Ainsworth et al., 2008). As a sensitivity analysis, I also examine the impact of productivity changes in two other crop groups. As discussed in Online Supplementary Material, the results are largely robust to taking into account these productivity changes.

I look at three different productivity scenarios related to climate change: a high productivity scenario with a 2 per cent increase in maize productivity, a medium productivity scenario with a 10 per cent decrease in maize productivity, and a low productivity scenario with a 22 per cent decrease in maize productivity. All three scenarios consider the period from 2000 to 2030, i.e., near-term climate change impacts from the year 2000 (which fits well with the 1998 baseline data of the Malawi computable general equilibrium model). The yield shocks are based on the estimated productivity shocks for coarse grains in Malawi from Hertel et al. (2010). The low and high productivity scenarios represent the 5th and 95th percentiles in a yield impact distribution derived from recent literature on crop impacts for the regions in the Global Trade Analysis Project model. The medium productivity scenario is the "most likely" estimate. The yield shocks are based on studies in which the fertilisation effect of CO_2 is considered. Basing simulations on a range of studies may be a better approach than relying on output from specific climate models, as projections vary

Table 1
Household group descriptive statistics.

	Income share (%)	Population share (%)	Poverty head-count ratio (%)	Share of income from agricultural labour (%)	Share of income from land (%)	Share of income from non-agricultural labour (%)	Share of income from agricultural capital (%)	Share of income from non-agricultural capital
Rural agricultural households								
<1 ha land holding	15.2	39.3		52.7	3.9	42.1	1.4	
1–5 ha land holding	16.2	22.5		45.7	25.1	20.3	8.9	
>5 ha land holding	3.8	0.2		3.0	64.5	1.4	31.0	
Rural non-agricultural households								
No and low education	6.4	11.3		34.5		65.5		
Medium and high education	10.6	13.5		21.9		78.1		
Total rural households	52.2	86.7	60.6	31.6	18.7	41.5	8.3	
Urban households								
Agricultural	6.3	2.8		3.2	44.5	29.5	22.8	
No and low education	3.3	1.3		1.1		66.4		32.5
Medium and high education	38.2	9.2		0.6	5.6	32.3	5.5	56.1
Total urban household	47.8	13.3	50.8	1.6	16.7	42.7	9.4	29.5
Total	100	100	59.6	19.4	10.9	35.8	6.0	28.0

Source: Löfgren et al. (2002) and Chulu and Wobst (2001).

widely across models even within the same scenario. Choosing a specific model over another may thus hide the uncertainty in existing climate projections (Burke et al., 2011). Choosing the same yield impact scenarios as Hertel et al. (2010) makes it possible to use the international commodity price impacts derived from their simulations in the Global Trade Analysis Project model, in which price changes result from productivity shocks to six commodity groups across all regions in the model.

The productivity shock is implemented in the model by changing the productivity shifting parameter in the constant elasticity of substitution (CES) production function of maize:

$$Q = a \cdot ad\left(\sum\nolimits_f \delta_f \cdot F_f^{\;-\rho}\right)^{\frac{1}{\rho}} \tag{1}$$

where α is a shift parameter that is exogenously set to reflect the productivity change in the three scenarios, *ad* is the efficiency parameter, δ_f is the constant elasticity of substitution production share parameter for factor *f*, F_f is the use of factor *f* in production, and ρ is the elasticity of substitution production function exponent that reflects the possibility of substituting between the different inputs. International food prices are exogenous in the model, and the import and export prices of maize are changed to reflect the changes in global coarse grain prices that were found by Hertel et al. (2010) in the three scenarios.

A total of eight simulations are run. The high, medium and low productivity scenarios are first run, keeping international prices fixed. This illustrates a situation where we do not take into account how global food prices are affected by climate change. The same productivity scenarios are then simulated with the corresponding change in global maize prices. In these simulations, all factors except non-agricultural capital are flexible, and farmers can adjust by shifting labour, land and capital to maximise profits. To illustrate the importance of adapting to the productivity change by reallocating factors across sectors, the medium productivity scenario is run while keeping all factors except labour fixed in each sector. Singh et al. (1986) found that when agricultural households are sufficiently well integrated into markets, they act as profit maximising producer units, independently of consumption decisions. This type of adaptation is thus endogenous to the model. This is the same type of adaptation the Ricardian approach aims to capture, however, in this model we can follow the links in the economy to understand how the adaptation takes place.

The simulations are summarised in Table 2.

3.2. Economy-wide impacts

Results from the simulations with full adaptation (that is, when farmers can adapt to the yield shock by adjusting land and agricultural capital, in addition to labour), with and without world market price shocks, are shown in Tables 3 and 4, respectively. The larger the negative impact on maize productivity, the more GDP falls. In the high productivity scenario, GDP changes very little. In the most likely productivity scenario and the low productivity scenario, the domestic price increases are large: 10 and 26 per cent, respectively.

Table 2
Simulations in the Malawi computable general equilibrium model.

Simulation	Productivity shock	Price shock	Adaptation
1	+2 per cent	None	Full
2	+2 per cent	−5 per cent	
3	−10 per cent	None	Full
4	−10 per cent	+15 per cent	
5	−22 per cent	None	Full
6	−22 per cent	+60 per cent	
7	−10 per cent	None	Partial
8	−10 per cent	+15 per cent	

Table 3
Percentage change from base, full adaptation without price shocks.

	High productivity scenario	Medium productivity scenario	Low productivity scenario
Real GDP	0.18%	−0.97%	−2.29%
Maize price	−1.81%	10.35%	26.34%
Maize production	0.95%	−5.06%	−11.88%
Maize imports	−2.03%	11.79%	30.78%
Average return to small-scale agricultural land	−1.43%	8.12%	20.57%
Average return to agricultural labour	−0.35%	1.99%	4.99%

Table 4
Percentage change from base, full adaptation with price shocks.

	High productivity scenario	Medium productivity scenario	Low productivity scenario
Real GDP	0.18%	−1.00%	−2.58%
Maize price	−3.71%	16.73%	54.06%
Maize production	−0.26%	−2.09%	−3.15%
Maize imports	1.43%	2.08%	−2.23%
Average return to small-scale agricultural land	−3.15%	13.84%	44.97%
Average return to agricultural labour	−0.90%	3.85%	12.64%

When taking into account the international commodity price increase, the domestic price increase is even larger: nearly 17 per cent under medium productivity and 54 per cent under low productivity. Despite the price increase for domestic maize producers, maize production decreases because of the large negative productivity impacts in the medium and low productivity scenarios. Maize production also decreases slightly in the high productivity scenario when taking into account the change in the grain's global price because imported maize becomes cheaper than domestic maize. As shown in Table 3, imports increase when there is a negative yield shock and international commodity prices are kept unchanged, which partly dampens the effects of the shock on domestic prices and factor returns. However, considering the impacts of climate change outside of Malawi (which increase global maize prices), Table 4 shows that the domestic impacts are stronger, both on domestic prices and factor returns. In the medium productivity scenario, the domestic price increase is larger than the international price increase, and imports increase. In the low productivity scenario, the situation is reversed, and imports decrease.

As the price of maize increases, the return to all agricultural labour increases by 2 per cent in the medium productivity scenario and by nearly 4 per cent when the international price increase is considered, thus benefiting net sellers of agricultural labour. Returns to all non-agricultural labour decrease in the medium- and low-productivity scenarios, affecting both rural households that participate in the non-agricultural labour market and urban households that derive a large share of their income from non-agricultural labour, as shown in Table 1. The largest change in factor returns is observed in agricultural land, with returns to small-scale (non-estate) agricultural land increasing by nearly 14 per cent when considering the international price change in the medium productivity scenario.

In response to the increase in the price of maize, land area allocated to maize increases, although due to the productivity decrease, maize production still decreases slightly. Maize production already occupies the majority of arable land in Malawi, and increasing land scarcity and land degradation are significant problems for Malawian farmers (Ngwira et al., 2012). Land degradation problems are not taken into account in our model but are important to keep in mind. The partial adaptation simulations in which land and agricultural capital are kept fixed may thus be a better illustration. The direction and relative magnitudes of impacts in the partial adaptation simulations are similar to the case with flexible land and agricultural capital, but all impacts on factor returns and prices are magnified. For instance, maize prices increase by 27 per cent in the partial adaptation, medium productivity scenario when taking into account increased international maize prices.

The effects of the productivity shocks on the economy are transmitted through factor and commodity prices. More expensive factors of production and intermediate inputs pull in the direction of decreased activity, while cheaper inputs pull in the opposite direction. The total effect also depends on the substitutability between inputs in production. For instance, the production of other small-scale crops decreases as more land and labour is allocated to maize, increasing the price of small-scale land and agricultural labour. Food processing, such as grain milling and bakery activities, decreases in response to rises in maize prices. In addition, more expensive maize reduces activity in the livestock sector and, in turn, the meat processing industry. The next section looks at how these economy-wide impacts affect households.

3.3. Welfare impacts and vulnerability

To look at welfare impacts on the different household groups, the equivalent variation (EV) for each household group is calculated for the scenarios with and without international price change. The equivalent variation can be interpreted as the income change at the initial price level that would leave the household just as well off as after the price change. A negative equivalent variation thus corresponds to a welfare decrease and vice versa. This calculated welfare change is used as an indicator of vulnerability, with a larger decrease in equivalent variation as per cent of initial expenditure indicating higher vulnerability. The welfare change for small-, medium- and large-scale agricultural households, low- and high educated urban and rural households and urban agricultural households for the medium productivity scenario with constant international prices is shown in Fig. 1. Small-scale agricultural households are defined as those owning less than 1 ha of land, medium-scale agricultural households as owning 1–5 ha of land, and large-scale agricultural households as owning more than 5 ha of land.

Households are affected by the change in returns to the factors they own (Table 1 shows disaggregated sources of income for the household groups) and the prices of the goods they consume. The results show that the agricultural households with the largest land holdings benefit from the negative productivity shock. The positive effect on the earnings of these households through the increased returns to land outweighs the negative impact of increased food prices. As expected, the non-agricultural households experience the largest welfare decrease, particularly the urban low educated households. These households are likely to spend a large share of their incomes on maize and do not benefit from higher agricultural wages; in fact, they are hurt by higher food prices and by decreased returns to non-agricultural labour. Although these households constitute a relatively small share of the population, they are vulnerable to food price increases. Another vulnerable group is the small-scale agricultural household group, which constitutes the majority of Malawian smallholders, and has a high incidence of poverty (World Bank, 2007). These households are likely to be net buyers of maize and therefore do not benefit from the price increase resulting from the productivity shock. On the other hand, they are net sellers of agricultural labour and are therefore better off than households outside of the agricultural sector. Fig. 2 shows that the welfare changes are more extreme when households do not have the possibility of adapting through changing the allocation of land and capital. The autonomous adaptation made by the agricultural households in response to the price incentives thus mitigates some of the impact of climate change in this model.

As shown in Fig. 3, these results are maintained, but magnified, when taking into account the change in international maize prices, and they are further magnified in the low productivity scenario. In this scenario, the welfare change is equivalent to an approximate 17 per cent reduction in expenditures for the urban low education group, and the welfare benefit to the few large-scale agricultural households is more than 30 per cent of their baseline expenditure.

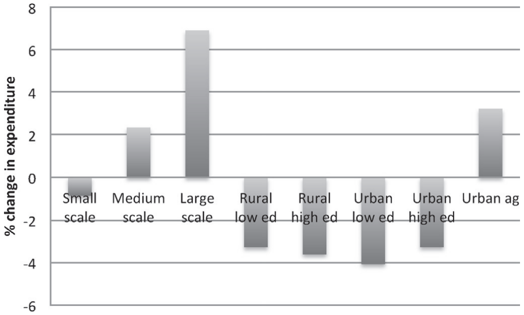

Fig. 2. Equivalent variation as per cent of baseline expenditures, medium productivity scenario without price shocks, limited adaptation.

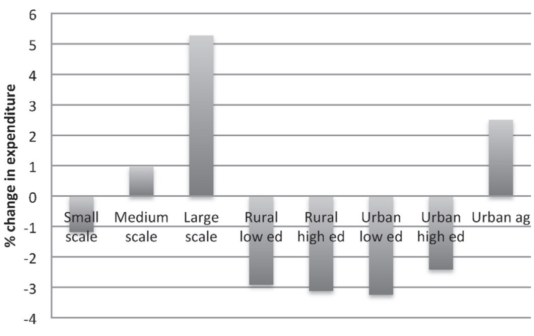

Fig. 1. Equivalent variation as per cent of baseline expenditures, medium productivity scenario without price shocks.

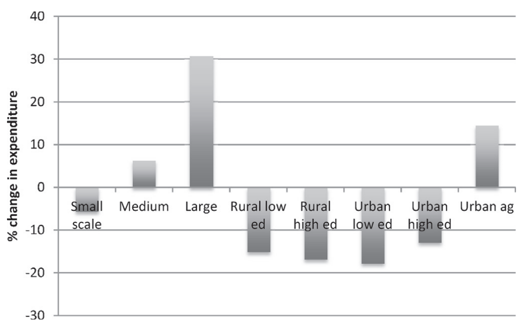

Fig. 3. Equivalent variation as per cent of baseline expenditures, low productivity scenario with price shocks.

These results support Hertel and Rosch (2010), who argue that in an economy with a large agricultural sector characterised by low elasticities of demand for crops produced, price increases resulting from yield declines may actually benefit some farm households. The model results show that the benefits largely accrue to the large-scale farmers that constitute a small share of the population and a small share of the poor. Agricultural households owning less than 1 ha of land are particularly vulnerable, as they are net buyers of food and the increased agricultural wage cannot compensate for the increased cost of living. In reality, some of these households are likely to be subsistence producers – transaction costs may be so large that they prefer not to sell their maize in the market. For these households, decreased yields may have large impacts on poverty and food security, particularly if the households are net buyers in the lean season, as is the case for many small-scale farmers in Malawi.

4. Discussion and conclusion

4.1. Comparing vulnerability impacts across measures

The computable general equilibrium model for Malawi allows for the disaggregation of the impacts of climate change through maize productivity across household groups. Although this paper looks at near-term scenarios of climate change, there are highly heterogeneous, large impacts on household welfare. The simulations illustrate the importance of the indirect impacts of climate change. However, one could expect similar results for developing countries with staple crops that are sensitive to climate change, where demand for the staple crop is inelastic, and where agriculture contributes to a large share of household income (directly or indirectly through agricultural wages). Studies using other methods for measuring vulnerability may not be directly comparable to the present results due to, for instance, different geographical or time scales, but it may still be possible to draw some comparative insights.

Studies using aggregate indicators of vulnerability often categorise all agricultural households as vulnerable without taking into account their role as net sellers or net buyers of crops. They also often assume that lower dependence on agriculture implies less vulnerability because of greater access to outside opportunities and decreased sensitivity. For instance, indicators such as the share of smallholders or the share of self-sufficient farmers may be included as indicators of additional vulnerability, but there is no explicit disaggregation of agricultural households that makes distinguishing between net sellers and net buyers possible. These studies do not take into account the additional impact on net food buyers of increased domestic and international food prices. The general equilibrium effects on agricultural wages and land returns, which this study has shown to be large, are not taken into account either. Assuming that households that are less reliant on agriculture are less vulnerable would yield results opposite to those rendered by the computable general equilibrium model for Malawi. The most vulnerable households are those that experience increased food prices, spend a large share of their income on food, and do not benefit from increased returns to agricultural land and labour.

Although an econometric analysis of poverty vulnerability to climate change may have yielded results similar to those of the computable general equilibrium model used here, in terms of the classification of net buyers as (more) vulnerable, it would not have been possible to trace the impact through direct and indirect channels.

The results from a Ricardian analysis of impacts of climate change through agriculture could be compared to our simulations with full adaptation, where farmers have adjusted land and capital in response to the productivity shock in order to maximise profits. Mendelsohn (2008) concludes that small household farms may be *less* vulnerable to climate change than large commercial farms because the smaller farms have a greater capacity to adapt by, for instance, switching between the cultivation of crops and livestock. Mendelsohn's conclusion is based on analyses that assume constant prices in response to climate change. This assumption seems unrealistic given the findings of for instance Hertel et al. (2010) and may lead to misleading policy implications. These contradictory findings demonstrate the importance of taking into account the impacts of climate change on prices when measuring vulnerability.

The usefulness of a computable general equilibrium model in terms of identifying vulnerable households depends on its ability to capture sensitivity and adaptive capacity. A model will always rely on simplifying assumptions, and these assumptions must be considered when interpreting results. The simple model of Malawi used here assumes that producers are profit maximising price takers and that households have access to well-functioning markets. High transportation costs, supervision costs related to hired labour and a lack of access to credit markets are factors that can affect the impact of climate change on household behaviour and thus the sensitivity and adaptive capacity of these households. When several markets for goods that are both produced and consumed by the farm household fail, farm production decisions will be tied to consumption decisions and household characteristics, as described in the theoretical framework of non-separable agricultural household models of De Janvry et al. (1991). Löfgren and Robinson (1999) and Holden et al. (1999) have made efforts to take this into account in computable general equilibrium models of developing countries.

In addition, the model used here is static and only shows the movement of the economy from the base year to a new equilibrium following a productivity shock. The supply of capital, labour and land is kept constant, and the simulations do not consider any other changes Malawi may face by 2030, ignoring the "multiple stressors" emphasised by O'Brien et al. (2004). The structure of the economy is also likely to change by 2030, which may affect the results. As a sensitivity analysis, the medium productivity scenario is also run in a setting where the share of services in the economy has increased at the expense of agriculture. As shown in the Online Supplementary Material, the results appear to be robust to this change in sector composition.

Thurlow et al. (2012b) show that current climate variability in Zambia has larger poverty impacts that expected climate change, and Thurlow et al. (2012a) propose a new approach to simulating climate uncertainty. The simple model used here does not take into account risk and how exposure to risk affects household decisions. A goal for future modelling efforts could therefore be to consider market imperfections and risk when assessing household vulnerability to climate change in a dynamic model.

Studies of adaptation to climate change in sub-Saharan Africa find that small-scale farmers are already using a wide range of risk coping strategies to deal with climate variability. For instance, these farmers are using new crop varieties, livestock choices, tree planting, soil conservation methods and diversification of on -and off-farm activities (Adger et al., 2003; Below et al., 2010; Mendelsohn and Dinar, 1999). However, studies also find that adaptation is constrained by certain factors, such as access to credit, tenure rights, off-farm activities and irrigation (Deressa et al., 2009; Gbetibouo, 2009). Adaptation by adjusting to changes in market prices is endogenous in the computable general equilibrium model, but additional adaptation strategies, such as adoption of new crop varieties, improved infrastructure and investment in irrigation, are ignored in the current model.

A number of institutional and social structures are not easily captured by the simple model used here. Examples include gender aspects, the specific inheritance system in different areas of Malawi (Benson et al., 2002), power and political structures, as well as informal insurance systems. As emphasised by Adger (2006) and Kamanou and Morduch (2005), quantitative assessments of vulnerability must be combined with qualitative studies that take into account a much more complex social and institutional context, and the approaches should be viewed as complements rather than substitutes.

5. Conclusion

The fact that climate change may lead to increased food prices and that the impact of food prices on rural households depends on the households' status as net sellers or buyers of food are not new insights (see for instance Parry et al. (2004) on global food supply, and Ivanic and Martin (2008) and Aksoy and Isik-Dikmelik (2010) on the poverty impacts of increased food prices). However, existing approaches to measuring vulnerability to climate change have failed to consider these insights.

The computable general equilibrium model of Malawi used here demonstrates the importance of taking into account the specific characteristics of households when assessing the impacts of climate change on a predominantly agricultural economy, the large potential indirect effects of climate change through prices, and the heterogeneity in the vulnerability of households to these changes.

Relying on existing vulnerability measures may lead to targeting adaptation efforts to parts of the population that are not vulnerable to climate change. Relying on these measures may also lead policymakers to underestimate the importance of food prices for vulnerability to climate change and, therefore, induce them to choose inappropriate adaptation measures. When targeting adaptation measures for farm households, net buyers or subsistence producers should be separated from net selling households.

The model results should be interpreted with caution, keeping in mind the underlying theoretical framework. Computable general equilibrium models are useful for keeping track of complicated links between sectors, households and factors of the economy, and give insights into the directions and magnitudes of impacts, given the model assumptions.

The results of the simple model used here illustrate that feedback effects through markets and the indirect effects of climate change for household groups, such as the urban poor, may be significant. Using aggregate impact assessment methods hides vulnerability by aggregating away social differences. Vulnerability indices may be better able to cope with this differentiation but do not take into account the important feedback effects of climate change through markets.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2013.08.011.

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Appendix A

The IFPRI Malawi computable general equilibrium model

The Malawi model is built on a social accounting matrix of Malawi described in Chulu and Wobst (2001), based on the 1998 Integrated Household Survey of Malawi and on macroeconomic data. This social accounting matrix is well suited for the purpose of this analysis since it distinguishes between agricultural and non-agricultural labor, as well as the skill-level of this labor. This is not the case for the two most recent social accounting matrices of Malawi from 2004 and 2007 (Douillet et al., 2012; Thurlow et al., 2008). The model is an extension of the basic computable general equilibrium model described in Löfgren et al. (2002). A detailed mathematical model statement is given in Lofgren (2001). The small country assumption is assumed to hold in the model – Malawi is assumed to be a price taker in world markets. Imports and domestically produced goods are imperfect substitutes in consumption and there is imperfect transformation between exports and domestic goods in production. This gives the domestic economy a degree of independence from world markets and prevents unrealistic responses to changes in global prices. Additionally, the Malawi model includes an explicit treatment of government and transaction costs, modeled as trade inputs. The model is static and allows comparative statics analysis of exogenous shocks in the medium run, or the time it takes for the economy to reach a new general equilibrium. The model contains a detailed treatment of the agricultural activities and factors used in agriculture, and households are disaggregated according to their level of education and landholding sizes. The model disaggregation is summarized in Table A1.

Producer, consumer and factor prices are endogenously determined in the model, but world market prices are exogenously given, in line with the small country assumption. Producers maximize profits subject to Constant Elasticity of Substitution (CES) production technologies. This specification allows substitution between primary factors to vary across activities but implies that production technologies stay constant in the face of exogenous shocks. Intermediate inputs in production are assumed to be used in fixed proportions. A composite supply function allows imperfect substitutability between imports and domestic goods in consumption. An output transformation (CET) function captures imperfect transformability between output exported and output sold domestically. Whenever producers sell their output, either domestically or as exports, and when consumers demand imported commodities, trade inputs are required. This feature incorporates transaction costs into

Table A1: Account disaggregation

Set	Elements
Labor (8)	Agricultural (no, low, medium and high education)
	Non-agricultural (no, low, medium and high education)
Other factors (5)	Land (small and large scale)
	Agricultural capital (small and large scale)
	Non-agricultural capital
Households (14)	Rural agricultural (land holding sizes <0.5 ha, 0.5-1 ha, 1-2 ha, 2-5 ha, >5 ha)
	Rural non-agricultural (no, low, medium and high education)
	Urban agricultural
	Urban non-agricultural (no, low, medium and high education)
Other institutions (5)	Enterprises (agricultural small and large scale, non-agricultural)
	Government
	Rest of the world
Agricultural activities (11)	Small-farmer crops (maize, tea, tobacco, other)
	Large-farmer crops (tea, sugar, tobacco, other)
	Non-crop (forestry, fisheries, livestock)
Non-agricultural activities (2)	Industry
	Services

Source: Lofgren (2001)

the model and takes into account the cost of transportation either across the border or to the local marketplace, as well as other marketing costs. It is assumed that fixed quantities of trade inputs are needed per unit of the traded commodity.

Households receive income from factors of production and transfers from other institutions, and pay taxes to the government. Households spend their disposable income on commodities according to a Linear Expenditure System (LES), which implies ensuring subsistence consumption of commodities and spending the rest of their income to maximize utility. Investments and government demand are determined by the base year (social accounting matrix) values, as well as by adjustment factors. The structure of the economy in the base year is described in Table A2.

Table A2: Structure of Malawi's economy in the base year (1998)

	Share in total value added	**Share in total employment**	**Share in total exports**	**Export share in sector output**	**Share in total imports**	**Import share in domestic use**
Agriculture	35.5	87.0	68.0	35.0	7.8	10.8
Maize	9.1	23.0	0.7	2.4	7.5	26.6
Tobacco	5.9	8.6	47.6	98.2		
Other crops	17.8	46.0	19.6	29.9	0.3	1.2
Other agriculture	2.8	9.4	0.1	0.8		0.5
Non-agriculture	64.5	13.0	32.0	9.1	92.2	30.2
Food processing	6.6	1.5	3.5	3.8	8.2	13.0
Other manufacturing	8.7	2.1	9.9	13.1	50.6	54.1
Other industry	5.1	1.4			6.8	21.9
Distribution services	16.1	3.1				
Public services	10.1	2.0				
Other services	17.9	2.9	18.6	27.2	26.6	42.7
Total	100	100	100	16.4	100	26.8

Source: Löfgren et al. (2001)

To ensure a simultaneous equilibrium in all markets, the system of equations describing behavior in the economy is subjected to a set of closure rules. These closure rules can be changed depending on what fits the analysis best. In this study's analysis, the following rules are applied:

1. Factor demand must equal factor supply, which is exogenously given (based on the social accounting matrix). Factor wages adjust to ensure that this holds. In the partial adaptation simulations, it is assumed that labor is mobile between sectors, while land and capital are fixed in each production activity. In the full adaptation simulations, all factors except non-agricultural capital are mobile between sectors and activities. All factors are assumed to be fully employed.

2. Supply of the composite consumption commodity must equal demand (from households, intermediate use, investment, government consumption, trade input use and stock changes). The quantities of goods imported and domestic demand prices vary to ensure that this holds.

3. Government savings are flexible and the direct tax rate is fixed. Because the model does not capture the welfare effects of government spending, government consumption is kept fixed (Löfgren et al., 2002). The chosen closure allows government savings to vary in order to keep tax rates fixed

and, all else being kept constant, should decrease the impact of a shock on household consumption, compared to an alternative scenario in which income tax rates are adjusted to keep government savings fixed. Appendix B shows results when total government savings are fixed as a share of GDP by uniformly varying the direct tax rate for the household groups that pay income taxes. These are high-income households representing approximately 12 percent of the population (Löfgren et al., 2001).

4. Current account balance implies that the amount of foreign currency spent on imports and transfers to the rest of the world must equal the amount of foreign currency received from exports, transfers and foreign capital inflows. The amount of foreign capital inflow is fixed, and the exchange rate varies to clear the current account balance and to keep the trade deficit fixed at the base level. This closure rule is chosen over the alternative with fixed exchange rate and flexible foreign savings because the latter would imply that Malawi could borrow as much foreign exchange as it wants when facing situations such as trade shocks.

5. Savings must equal investments. Savings are assumed to be investment driven. The marginal propensity to save for each household adjusts by uniform percentage points to keep a constant level of investments. Appendix B shows results from simulations in which investments are kept fixed as a share of GDP rather than in real terms.

6. A price normalization equation ensures that all price changes are denoted relative to the consumer price index (CPI). The CPI is the numeraire price.

According to Walras' Law, one equation from the equilibrium conditions above can be dropped. This ensures a unique solution to the system of equations.

The trade and production elasticities used in the model are based on available estimates from countries similar to Malawi (Löfgren et al., 2001). Imported and domestically produced food and agricultural goods are assumed to be more substitutable in consumption than imported and domestic services and industrial goods. This implies a larger product heterogeneity in manufactured goods and services than in food and agricultural goods, which seems reasonable. Table A3 shows the values of trade and production elasticities used in the model. The household consumption elasticities used in the model are estimated based on the 1997-1998 Integrated Household Survey of Malawi (Löfgren et al., 2001).

Table A3: Elasticities of production and trade

	Production	Armington	CET
Agriculture			
Maize	0.5	1.1	0.5
Tea	0.5	1.1	1.5
Sugar	0.5		
Tobacco	0.5		10
Other	0.5	1.1	1.5
Fishing	0.5	1.1	1.5
Livestock	0.5	1.1	1.5
Forestry	0.5		
Industry			
Mining	0.5		
Meat	0.5	1.1	
Dairy	0.5	1.1	
Grains	0.5	1.1	1.5
Bakery	0.5	1.1	
Processed sugar	0.5	1.1	1.5
Beverages	0.5	1.1	1.5
Textiles	0.5	1.1	1.5
Wood	0.5	0.4	0.5
Paper	0.5	0.4	0.5
Chemicals	0.5	0.4	0.5
Soap	0.5	1.1	1.5
Other	0.5	0.4	0.5
Electricity	0.5		
Construction	0.5		
Services			
Distribution	0.5		
Hotels	0.5	0.3	0.4
Telecommunication	0.5	0.3	0.4
Banking and insurance	0.5	0.3	0.4
Business	0.5	0.3	0.4
Public services	0.5		
Personal services	0.5		

Production: Elasticity of substitution between factors in value added production function.

Armington: Elasticity of substitution between imports and domestic goods.

CET: Elasticity of transformation between exports and domestic sales.

Source: Löfgren et al. (2001)

Appendix B

Sensitivity analyses

B1 Macroeconomic closure

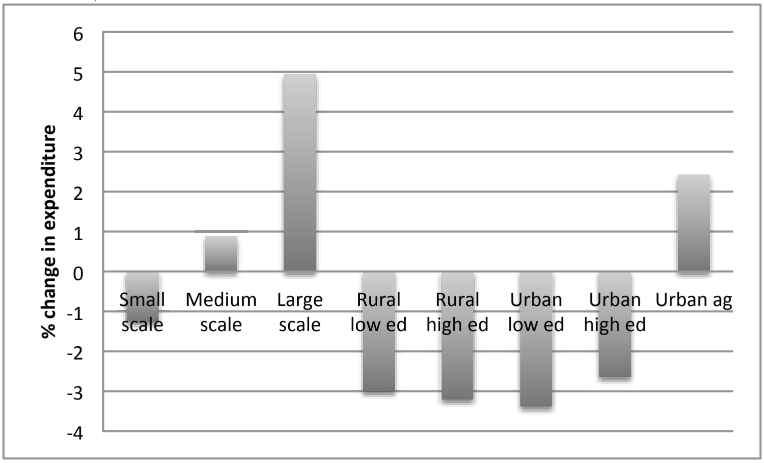
Figure B1 and Table B1 shows results from running the simulations under an alternative macroeconomic closure. Rather than assuming fixed investments and flexible government and household savings, a balanced closure where the impact of the shock is evenly distributed across investment, savings and consumption is chosen. Investments and government demand are fixed shares of nominal absorption, while the direct tax rate and the marginal propensity to save adjusts uniformly across households. Implicitly, household consumption is also a fixed share of nominal absorption. The exchange rate adjusts to keep foreign savings fixed. The alternative closure rule does not change the direction of the results, and the magnitude of the results is similar. The results for the full adaptation simulations without price changes are shown below, but the results are robust in all simulations.

Table B1: Percentage change from base, full adaptation without price shocks, balanced closure

	High productivity scenario	Medium productivity scenario	Low productivity scenario
Real GDP	0.18 %	-0.97 %	-2.31 %
Maize price	-1.81 %	10.30 %	26.20 %
Maize production	0.95 %	-5.01 %	-11.76 %
Maize imports	-2.03 %	11.76 %	30.70 %
Return to small-scale agricultural land	-1.43 %	8.1 %	20.51 %
Average return to agricultural labor	-0.34 %	1.90 %	4.73 %

Source: Malawi CGE model

Figure B1: Equivalent variation as percent of baseline expenditure, medium productivity scenario without price shocks, balanced closure



B2 Climate change impacts through other crops

The two largest crop groups in terms of production levels (except maize) are "other crops", which includes legumes, tubers and grains other than maize, and tobacco. Both crop groups are produced on small-scale and estate farms. The focus on maize in the main simulations is meant to show the direction of the agricultural impacts on disaggregated household groups. A comprehensive vulnerability assessment would have to include detailed impacts on other crops and sectors of the economy, and would require disaggregated crop model output specific to Malawi. To show the direction of the impacts of climate change through "other crops" and tobacco, I simulated productivity shocks identical in size to those in the maize simulations. These simulations show whether the directions of the impacts on households in the main simulations are sensitive to productivity shocks in two other large crop groups. Figures B2 and B3 show the welfare impact on household groups when adding productivity shocks to tobacco and other crops, respectively, of the same direction and magnitude as maize. The figures show that the direction of the impacts is unchanged for each household group, but that impacts are larger in each direction. However, being able to shift land and agricultural capital seems to mitigate much of the impact of the scenario for other crops. Because the other crops category is largely a small-scale activity, intensive in unskilled agricultural labor and small-scale land, productivity shocks in the same direction as those of maize reinforce the impact on factor prices, and thus the impact on household groups. This impact is stronger in the partial adaptation simulations when households cannot switch land and labor to other crops. Tobacco is, to a large extent, an estate crop, intensive in estate land and large-scale agricultural capital, which does not impact households in the same direction as the shocks to maize productivity.

Figure B2: Equivalent variation as percent of baseline expenditure, medium productivity scenario for maize and tobacco without price shocks

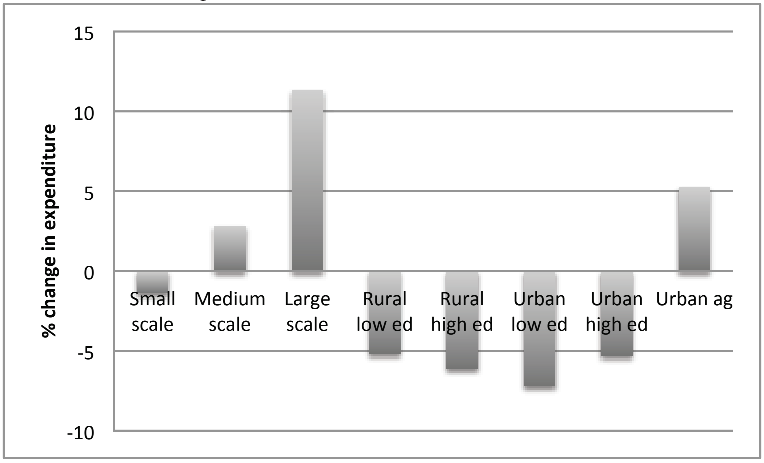
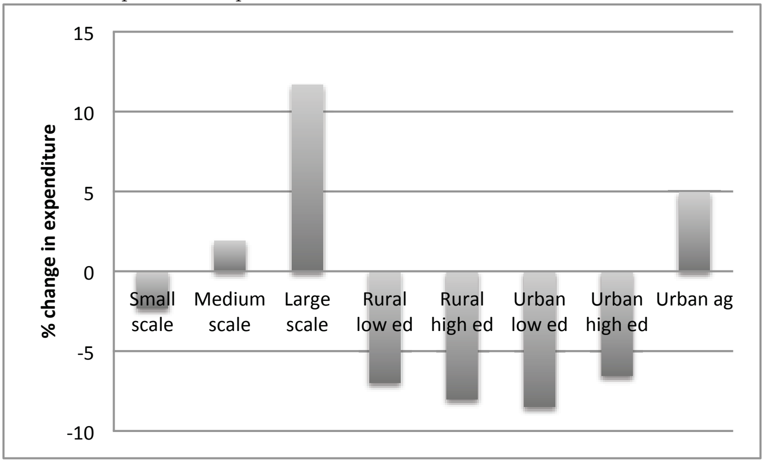


Figure B3: Equivalent variation as percent of baseline expenditure, medium productivity scenario for maize and other crops without price shocks



B3 Economic structure

The model used in this paper is a static model calibrated to a social accounting matrix from 1998. The simulations show the response to a shock in the medium run, or the time it takes the economy to reach a new equilibrium. However, we wish to examine scenarios for changes in crop productivity over a 30-year period. The purpose here is not to predict the evolution of the Malawian economy over these 30 years, but to illustrate the impact of crop productivity changes resulting from climate change on household level vulnerability. On the other hand, these impacts may be sensitive to structural changes in the economy, such as a shift away from agriculture towards industry or services. As a sensitivity analysis, I have simulated the medium productivity scenario in a setting where the share of agriculture has decreased from 35 percent of GDP to 30 percent, and the share of services has increased from 44 percent to 50 percent. At the same time, the price of Malawi's major export crop, tobacco, has decreased by 2.5 percent. These changes are in line with the trends reported by the World Development Indicators for Malawi between 2000 and 2011 (World Bank, 2013). In this setting, maize production is lower, and the economy relies more on food imports. As shown in Figure B4 and Table B2, the direction of the results is robust to the change in economic structure, and the magnitudes of the welfare impacts are similar.

Figure B4: Equivalent variation as per cent of baseline expenditure, medium productivity shock without price shocks in economy with lower dependence on agriculture

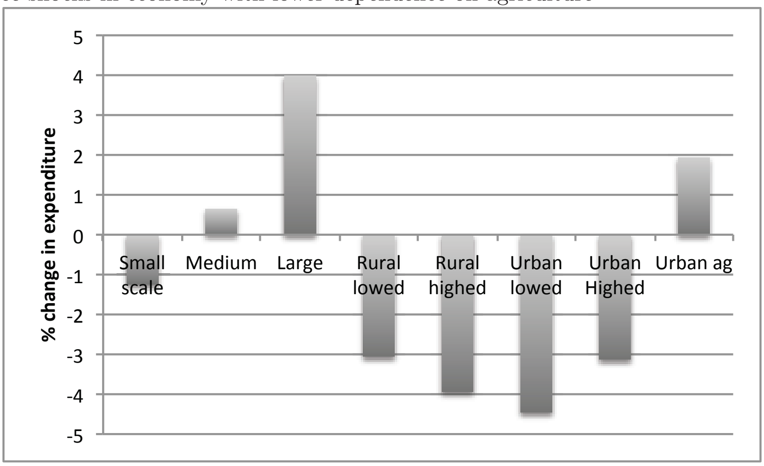


Table B2: Percentage change from base, full adaptation without price shocks, balanced closure

	Medium productivity scenario
Real GDP	-0.76 %
Maize price	8.62 %
Maize production	-5.01 %
Maize imports	10.86 %
Return to small-scale agricultural land	5.84%
Average return to agricultural labor	0.39 %

Source: Malawi CGE model

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PAPER 2

Learning the hard way? Adapting to climate risk in Tanzania

Sofie Waage Skjeflo* and Nina Bruvik Westberg†‡

Abstract

We use recent panel data on Tanzanian farm households to investigate how previous exposure to weather shocks affects the impact of a current shock. Specifically, we investigate the impact of droughts and past drought incidents on agricultural yield and children's health, measured by their nutritional status. As expected, we find that droughts negatively impact yields, with the impact increasing in the severity of the shock, and that severe droughts have a negative impact on short-term nutritional outcomes of children. We also find that households with more shock experience are less affected by current droughts in terms of crop yields and their children's nutritional outcomes. However, this only holds for less severe droughts. This suggests that households are able to learn from their past shock experience, and could imply that households, to a certain extent, are able to adapt to climate risk. We explore mechanisms that could explain our findings.

Keywords: Rainfall shocks, crop yields, adaptation, child health, Tanzania

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1 Introduction

The recent report from the Intergovernmental Panel on Climate Change concludes that climate change is likely to have severe impacts on agriculture in Sub-Saharan Africa with large consequences for food security, creating an urgent need for adaptation (Niang et al., 2014). The report finds that although adaptation strategies are already being used to cope with current climate variability, there are considerable institutional, financial, physical, political and informational barriers to adapting to climate change for small-scale farmers in Africa.

This paper uses nationally representative panel data from Tanzania, coupled with gridded weather data, to explore the impact of climate risk on agricultural yield and children's health among farming households. We aim to contribute to the literature on impacts of climate variables on economic outcomes. There is a large literature on the impact of climate shocks on economic and health outcomes using cross-sectional data, such as Miguel (2005), Feng et al. (2012) and Kudamatsu et al. (2012). The more recent literature uses panel data to control for time-invariant factors while exploiting exogenous variation in temperature, precipitation and extreme events (see Dell et al. (2013) for a recent review). A limitation of these studies is that using short-run weather variation to predict long-run impacts of climate change requires out-of-sample extrapolations that may not be valid (Dell et al., 2013). For instance, Burke and Emerick (2012) show that US farmers are unable to adapt to long-run variations in climate, as opposed to findings based on short-term weather variations. Similarly, when assessing the impacts of climate risk, defined as the probability of experiencing a negative climate shock, extrapolating from the impact of one climate shock to impacts of increased climate variability due to climate change may not be valid. Our contribution is to investigate whether the impact of a climate shock, more specifically droughts, depends on a household's previous experience with such shocks. As far as we know, this is the first paper that does this. Understanding how long-run exposure to negative climate shocks affects households can then be used to inform our understanding of the scope of adaption to increased climate variability due to climate change.

We focus on the impact of shocks and previous shock exposure on two outcomes: crop yields and children's health, measured by their short-run and long-run nutritional status. Farmers with previous exposure to shocks may be less severely affected by a new shock if they are able to apply their knowledge derived from previous shocks, for instance through altered crop and input choices, new farming techniques and income diversification. In this case, the impact of a current shock would be decreasing in the number of shocks previously experienced. On the other hand, exposure to repeated shocks could make households more vulnerable to new shocks, for instance if the households cope by depleting assets, including human capital. In this case, we would expect the negative impact of a shock to be increasing in the number of shocks the household has experienced previously.

Several studies have investigated the potential impacts of climate change on agriculture at an aggregated level. An early application of panel data to this task is the study of U.S. agriculture by Deschênes and Greenstone (2007), later discussed by Fisher et al. (2012). Assessing impacts on Sub-Saharan African agriculture, Schlenker and Lobell (2010) match historical country-level yield data on five crops to weather data from 1961 to 2002. They use their estimated parameters to predict crop production losses due to climate change by year 2065, and find that the production of maize, groundnut, sorghum, millet and cassava is expected to decrease by respectively 22, 18, 17, 17, and 8 percent. Relevant to our context, Rowhani et al. (2011) use regional panel data on maize-, rice- and sorghum yields in Tanzania from 1992 to 2005. The data is coupled with observations from weather stations and gridded, interpolated weather data. They find that precipitation variability during the growing season, measured in terms of the coefficient of variation, has a negative impact on all three crops. Ahmed et al. (2011) use the same data to investigate the impact of rainfall and temperature on yields, and the impact of projected future climate variability on poverty distributions. They argue that the uncertainty related to expected climate volatility makes it difficult to quantify expected shifts in poverty distributions in Tanzania.

Evidence of the impact of weather variability on agriculture at the household level using panel data seems less common, an important exception being Rosenzweig and Binswanger (1993). Using the ICRISAT village surveys from India, which include daily rainfall data, they find that a delay in monsoon onset significantly reduces crop- and total farm profits. Further, they find that farmers exposed to more weather variability choose less risky and less profitable investments, and that this effect is stronger for poorer households who are less likely to be able to cope with income variability following a shock.

The impacts of climate variability on households is perhaps better understood when broadening the focus beyond agriculture. A few papers look at the impacts of climate variability on consumption (Skoufias and Vinha, 2013; Lazzaroni and Bedi, 2014), whereas several studies have analyzed the effect of weather shocks on health,[1] either implicitly or explicitly assuming an income effect through agriculture. The impact on children's health is seen as particularly important – if parents are unable to maintain investments in their children's human capital (for instance through schooling or health) during shocks, the effect of negative shocks may persist over generations (Dercon, 2002). With this motivation, Hoddinott and Kinsey (2001) investigate the impact of drought[2] on growth in height, and find a slower growth rate among Zimbabwean children aged 12-24 months old. Maccini and Yang (2009) extend the perspective to adult outcomes and focus on positive rainfall shocks rather than negative ones. They find that Indonesian rural females who experienced 20 percent more rainfall than the district mean as infants become taller as adults (0.57 cm on average).

In terms of short-term nutritional status (weight-for-height and weight-for-age), the evidence on impacts of weather shocks is less clear. Jensen (2000) compares children's health and educational outcomes in Cote d'Ivoire based on their exposure to a recent weather shock.[3] In the exposed areas, malnutrition (defined as weight-for-height Z-score more than two standard deviations below the reference median) increased among children aged 0-10 years, school enrollment decreased by more than one third and the use of medical services for children that were ill decreased, without significant difference between the exposed and unexposed children prior to the shock. However, more rainfall can trigger increased risk of disease, through a change in the prevalence of vector- and water borne diseases, that in part counteracts the income effect (a disease channel). Tiwari et al. (2013) investigate the impact of excess monsoon rainfall on short- and long-run nutritional status in Nepal, matching clusters from the Demographic Health Surveys (DHS) with predicted weather patterns based on rainfall and elevation. A positive contemporaneous rainfall shock (disease channel) results in lower weight-for-age for infants, whereas a positive shock in the previous season increases weight-for-age for all age-groups below three years old. The latter finding suggests that the income effect dominates over the lagged disease effect from the past season. Height-for-age is only positively affected by more rainfall in the second year of life, and only for children aged 12-35 months.[4] Lechtenfeld and Lohmann (2014) widen the focus to self-reported illness among adults and health expenditures, in addition to self-reported anthropometric measures. They assess the effect of a

[1] Others again analyze the impact of weather shocks on mortality, which can be viewed as the cumulative result of negative impacts on children's health. For instance, Rose (1999) explores gender differences in child mortality following a positive rainfall shock, Kudamatsu et al. (2012) analyze the impact of droughts on infant mortality among African farming households.

[2] Defined as a season with rainfall below the average historical mean.

[3] Defined as rainfall more than one standard deviation below the historical mean.

[4] This contrasts to Maccini and Yang (2009), who find a positive effect on stature from more rainfall in the first year of life. However, they use a more long-term outcome, namely adult height.

drought severity index[5] on these measures using four rounds of household panel data from rural Vietnam. A higher drought severity index increases the probability of illness and reduces weight among adults and children, whereas they find no significant impact on weight-for-age Z-scores of children below five. They attribute the negative impact on weight to an income effect, through increased agricultural yields.

Although several papers have analyzed the reduced form impact of weather shocks on health, few assess this explicitly through its effect on agriculture - instead implicitly assuming that this is the main channel. A related, and equally important, question is how previous shock exposure may interact with a new shock in explaining differences in both agricultural and health outcomes. We exploit detailed plot level data on crop production and anthropometric measures of respondents in the Tanzania National Panel Survey to explore these questions. Our results show that experiencing droughts negatively affects crop yields, with the impact increasing in the severity of the shock. The results also indicate that the more shocks a household has experienced previously, the less severe is the impact of a current shock on yields, suggesting that households may learn from previous shocks how to mitigate impacts of current shocks. In terms of children's nutritional outcomes, severe droughts seem to have a negative impact on short-term nutritional indicators, but there are also indications that more previous shock experience mitigates impacts of less severe shocks.

In the following we present our conceptual framework in Section 2, Section 3 gives an overview of the setting, while the data and the empirical strategy to be employed are described in Sections 4 and 5. We present the results in Section 6, followed by a discussion of possible causal mechanisms and caveats in Section 7. Section 8 concludes the paper.

2 Conceptual framework

The impact on farming households of repeated shock exposure, for instance droughts or flooding, in the context of a rural developing country, is not obvious. Market imperfections in insurance and savings are often pervasive, leaving households' response to income shocks largely dependent on their own endowments, and linking poverty vulnerability to risk (Dercon, 2002).

The effect of a weather shock, such as a drought, and its interaction with previous shock exposure on households' consumption and welfare is expected to manifest itself through agriculture. The

[5] Based on the annually aggregated shortfalls of monthly district level rainfall from the local historical mean.

majority of the farming households in our sample rely on rain-fed agriculture,[6] and we would therefore expect rainfall variability to affect their agricultural output. Previous exposure may have led the household to develop techniques to better tackle new shocks, such as shifting the timing of planting or fertilizer application, switching crop varieties and types, or implementing soil- and water conservation technologies (Burke and Lobell, 2010; Di Falco and Veronesi, 2013), which we term adaptation. Alternatively, their ability to invest in (costly) adaptive strategies may be reduced. Previous shock exposure may have triggered asset depletion, such as selling of livestock or other productive assets (Dercon, 2002), reducing their investment capabilities and ability to deal with more recent shocks. Based on this, we expect past shock experiences to influence the impact of a current shock on agricultural yield. Exposure to climate risk is also likely to have an effect on production and yield in non-drought years. The seminal model by Sandmo (1971) predicts that risk-averse firms in an environment with missing insurance and credit markets will produce less than a risk-neutral firm. Dercon and Christiaensen (2011) show that consumption risk reduces the use of fertilizer in Ethiopia. Based on this, one could expect lower use of "risky inputs", such as inorganic fertilizer and high-yielding (but not drought-resistant) improved crop varieties, and lower yields on plots that have frequently been exposed to shocks. This may also be driven by the depletion story discussed above, whereby repeated shock exposure reduces households' ability to invest in farm production. On the other hand, in a setting with volatile food prices and lack of outside income opportunities, subsistence orientation could be a self-insurance mechanism. Taking into account the consumer-producer role of farm households in developing countries, Finkelshtain and Chalfant (1991) show that under certain conditions, price risk and risk aversion may lead to higher output.[7] Similarly, Fafchamps (1992) shows that with thin food markets causing price volatility, and high correlation between farm output and market prices, farm households use subsistence orientation as a self-insurance mechanism. A first step to understanding potential long-run impacts of climate risk is therefore to investigate the impact of shocks and repeated shock exposure on agriculture, more specifically crop yields.

Rural households may derive income and consumption from other sources than own farm production. Income diversification (Rose, 2001), asset depletion (Rosenzweig and Wolpin, 1993), self-insurance through savings (Paxson, 1992) and altered labor supply (Kochar, 1995; Rose, 2001) are possible smoothing strategies that farmers use to adapt to fluctuations in agricultural income

[6] In a given year less than 5 percent of the households in our sample have one or more irrigated plots.

[7] For instance, a more risk averse net food buyer is shown to increase production in response to more price risk.

(Morduch, 1995; Dercon, 2002). The extent to which rainfall variability affects total income and consumption is therefore not readily derived based on own production only. Moreover, the combined effect of multiple households' responses in a drought year may result in increased food prices and lower wages when markets are poorly integrated (Jayachandran, 2006), which again affects households' consumption depending upon their position in the market. Even if all income sources were identified, measuring households' total income would be problematic. The alternative measure, consumption, is believed to suffer less from measurement error in rural settings, but is also difficult to capture (Deaton, 2005). However, a desirable outcome from income- and consumption smoothing is better child health outcomes. We therefore investigate the effect of a shock and previous exposure to similar shocks on child health, measured by the children's short- and long-run nutritional status.

Rainfall shocks may affect children's nutritional status in two ways. First is the above-mentioned income effect, whereby households' income available for consumption may fall due to lower yields. For households that are net buyers of food, a related increase in food prices will add to this. The extent to which a drought affects child nutrition thus depends on the opportunities for income- and consumption smoothing. If households are able to perfectly smooth consumption when facing agricultural income shocks, then we do not expect any impact on investment in children's health. Secondly, rainfall shocks can have an additional direct effect on health through access to clean water and the prevalence of vector- and water-borne diseases (Tiwari et al., 2013; Rabassa et al., 2014).

Similar to the discussion of agricultural outcomes, the effect of past shock experiences on the impact of a current shock on child health is not clear a priori. On the one hand, if households learn income- and consumption smoothing methods from previous shocks, and are able to take advantage of these when facing new shocks, then we expect the impact of a current shock on child nutrition to be decreasing in households' previous shock experience. If adaptation mainly occurs through (better) income- and consumption smoothing, we would expect to find adaptation only for child health outcomes, and not through adapting agricultural techniques. If we observe adaptation both for yield and children's health, we cannot disentangle adaptation through agricultural measures from adaptation through income- and consumption smoothing. On the other hand, if we observe that previous shock exposure magnifies the negative impact of a current shock on child nutrition then this could indicate an asset depletion story. In this case we could also expect to see an independent negative effect of past shock experiences on children's outcome in non-drought years. We may also observe adaptation in yield, but depletion or no adaptation in terms of child health. This could indicate that households adapt by producing less risky, but less nutritious crops, or that agricultural adaptation is costly, and that this is taking place at the expense of children's health, for instance in terms of time use (Kim, 2010).

Finally, for both agricultural and health outcomes, we expect the timing of past shocks to affect the total impact of a new shock. Rebuilding the asset stock following a shock may take time. Households' ability to cope with a new shock could therefore be greater the more time has passed since the last shock, implying a negative relationship between the impact of a new shock and the time that has passed since the last shock. On the other hand, it may be easier to learn from a more recent shock than from shocks that happened a long time ago, whereby the negative impact of a new shock would increase with the time that has passed since the last shock experienced by the household. We investigate these scenarios in the empirical analysis below, and start by describing the study context.

3 Climate and agriculture in Tanzania

We focus on farmers' behavioral responses to weather variability in Tanzania. A substantial share of the population relies on agriculture as their main income source, with around 70 percent of the population residing in rural areas (NBS, 2014). Population density is relatively low throughout the country, but birth rates are high, with each woman on average giving birth to just over five children (NBS and ICF Macro, 2011).

The climate is characterized by both large regional, inter-seasonal and intra-annual variations. The country is dominated by highlands with a temperate climate, while the coastal areas are warm and humid. Northern and eastern regions experience two rainy seasons (bimodal rainfall pattern), while the rest of the country has one single rainy season (unimodal rainfall pattern). These rainfall patterns are largely the result of the Inter-Tropical Convergence Zone (ITCZ) and its movement across the country (McSweeney et al., 2010, 2014). Climate variability is in addition affected by the El Niño Southern Oscillation (ENSO)[8] and La Niña[9] (Camberlin et al., 2001; Wolff et al., 2011).

Cereals such as maize, rice and sorghum are farmed extensively, with maize as the most common crop. A large share of the maize production takes place in the southern highlands, whereas sorghum

[8]Warmer sea surface temperature in Pacific, that may result in more than average rainfall in the short rainy season but less in the long rainy season (Camberlin et al., 2001).

[9]Cooler sea surface temperature in Pacific, that may result in droughts in the northern parts of Tanzania, whereas more than average rainfall is likely to occur in southern parts (Wolff et al., 2011).

is mostly found in the drier central highlands and rice in southern regions (Rowhani et al., 2011). Given the limited use of irrigation, the timing of agricultural activities is closely linked to the seasonal rainfall patterns. The rainy season in the unimodal areas (*Msimu*) usually starts in October-November and lasts until April-May, with a dry-spell in-between, allowing for harvest from June to August. In the bimodal areas, the short rainy season (*Vuli*) typically lasts from October to December, whereas the long rainy season (*Masika*) occurs between March and June, with harvesting in July-August. Some crops, such as banana and cassava, may be harvested throughout the year (Kaliba et al., 1998a,b,c; Mafuru et al., 1999; Nkonya et al., 1999).

According to historical records, average annual rainfall in Tanzania has decreased over the past decades, whereas mean annual temperature has increased (McSweeney et al., 2010, 2014; Hulme et al., 2001). In terms of extreme rainfall weather events, the pattern is less clear (McSweeney et al., 2010, 2014). Climate model predictions suggest an increase in mean temperature, and particularly so during the dry season, whereas predictions on rainfall are less certain. For instance, Ahmed et al. (2011) note an increase, whereas Hulme et al. (2001) characterize the predictions from climate models for Africa as uncertain due to incomplete and lacking knowledge of the ENSO's effect and the failure to incorporate changing land cover and land use.

4 Data

4.1 Plot and household panel

We use the Tanzania National Panel Survey (NPS), a panel of nationally representative household surveys from 2008/09 (NPS1) and 2010/11 (NPS2). Households were sampled from 409 populated enumeration areas drawn from the Tanzania Population and Housing Census from 2002. The first round covers 3265 households (2063 in rural areas) and their 4321 farm plots, and was collected in the period October 2008-October 2009. The second round covers 3924 households, 3168 of them reinterviewed from round 1, and their 3882 farms plots, and was collected between October 2010 and November 2011. The observations are matched at the household- and plot level across the two survey rounds. Around 7 percent of the plots were measured with GPS in the first round and 80 percent in the second round (NBS, 2011).

The NPS has the advantage of providing detailed data on both agricultural production and child anthropometrics. Moreover, the panel nature of the data makes it possible to control for unobservable time-invariant factors that may be correlated with the climate variables as well as the outcomes we are interested in. Data on agricultural activities is gathered for the agricultural season preceding the interview. Thus, for NPS1 the agricultural season of interest when matching with weather data is 2007/08, whereas agricultural data from NPS2 is matched with rainfall for the 2009/10 season. Figure A1 in the appendix shows a map of the enumeration areas from 2008/09 to which we match the weather data.

In some specifications we use the unbalanced plot panel data, which gives us 5416 observations when we include households that reside in the same location across the two survey years and cultivate crops in both seasons. The balanced household panel gives us 2436 observations, covering both years. For children's nutritional outcomes, we pool the data and use nutritional outcome variables on 3189 children that are 60 months or younger residing in farming households.[10] Since we do not have weather data for 2011, we exclude children measured after the harvest from the 2010/11 rainy season, i.e. those measured after April in the unimodal areas and after June in bimodal areas.

4.2 Climate data

We use University of Delaware's (UDel) gridded precipitation and temperature data, described in Willmott and Matsuura (2012a,b). Each grid cell is 0.5 x 0.5 degrees, equivalent to around 55 x 55 km at the equator. The data is interpolated from weather station observations and provides monthly data on precipitation in millimeters and monthly mean air temperature in degrees Celsius.[11] Each set of GPS coordinates at the enumeration area level is matched to a grid cell. This results in the 391 enumeration areas being matched to 149 grid cells covering mainland Tanzania and Zanzibar, whereby several enumeration areas fall within the same grid cell.[12]

[10]There are unfortunately too few observations on children below 61 months in the same households over the two rounds of the survey to use the panel structure in this case. We are allowing children aged below 5 that are observed in both years to enter twice. We include children of farming households that were excluded in the yield analysis due to outliers or missing observations on agriculture.

[11]The climate data from UDel has been used extensively over the past years. We choose to use this data given its detailed historical and spatial coverage.

[12]We drop 18 enumeration areas due to lack of precipitation data. These are located along the coast or on islands. Given our focus on agricultural production, we do not believe that omitting these enumeration areas will bias our results, as many households in these areas are involved in other occupations than agriculture.

4.3 Measuring climate shocks

Previous studies on the impact of climate variability on agricultural output suggests that both precipitation and temperature are important. We define a negative precipitation shock in three ways: *(i)* a severe shock, with precipitation below the 10th percentile of the local historical distribution, *(ii)* a moderate shock, with rainfall below the 15th percentile, and *(iii)* a weak shock, with rainfall below the 20th percentile. Basing our definition of a drought period on deviations from the *local* precipitation pattern means that we control for the average local climate, which may be correlated with other characteristics that could influence our outcome variables (Kudamatsu et al., 2012). Moreover, a relative rather than an absolute measure of drought suggests that any deviations from the local historical mean, i.e. rainfall below the 10th, 15th or 20th percentile of the distribution, should be orthogonal to other factors that may affect households' adaptation. In any given year households in a grid cell have 10, 15 or 20 percent probability of experiencing a shock as defined above. Choosing a relative measure of rainfall shock is in line with previous work. For instance, Burke et al. (2014) define a shock as rainfall below the 15th percentile of a gamma distribution, and confirm the findings when using the 10th and 20th percentiles.

We proceed by identifying the historical distribution of rainfall in each grid cell based on the monthly precipitation data for the period 1960-2010. We restrict ourselves this period, as it provides a more representative distribution for recent weather patterns while at the same time giving us sufficient data to construct a distribution from which we draw our historical shocks.[13] All measures are constructed for the entire agricultural season, defined as July to June. A timeline describing the timing of the surveys and agricultural shocks is shown in Figure A2. As an alternative measure, we also define shocks based on precipitation in the relevant rainy season in the unimodal and bimodal areas of Tanzania. This is a more precise measure and is likely to reduce measurement error and thus attenuation bias in the shock variables, given that we are able to correctly identify the growing season. Unfortunately, the University of Delaware data only contains monthly mean air temperatures, which prevents us from developing a good indicator of temperature shocks,[14] but we include mean temperature during the growing season as a control in our analysis of agricultural outcomes.[15]

[13] The same approach is taken by Burke et al. (2014).

[14] Schlenker and Lobell (2010) and Lobell et al. (2011) use growing degree days (GDD) as a measure of accumulated temperature exposure for crops during the growing season, and degree days above 30 degrees Celsius as a measure of exposure to extreme heat.

[15] We choose to define the growing season based on the main rainy season, and in accordance with recorded planting

When investigating the impact of shocks on child health we identify the most recent agricultural season prior to the child's measurement, since this is the season relevant to the child's food consumption before being measured. The relevant season differs between the unimodal and bimodal areas, and we investigate the impact of shocks in the relevant season depending on when the child was measured. For children in households residing in unimodal areas, we use the rainfall shock in 2007/08 for all those measured prior to May 2008 in the first survey round, whereas those measured in May or later are assigned a shock value based on the 2008/09 rainfall season. We set the cut-off to July for the bimodal areas. The same procedure is used for the second survey round.

We identify previous exposure to the shocks by counting the number of similar shocks that have occurred over the last 10-year period, in other words 1997/98-2006/07 for the first survey round, and 1999/00-2008/09 for the second survey round.[16] This measure takes into account the most recent shocks relevant to each survey round. On the other hand, it only exploits variation in shock incidence in the first and last two years of the 10-year time period, as the window of "shock memory" is moved forward from the first to the second survey round, while we are controlling for plot fixed effects. When looking at the timing of past shocks, we count the number of years that have passed since the plot or child was last exposed to a similar shock. For each survey round, we count backwards from the relevant agricultural season or season in which the child was measured.

Importantly, since the previous shock exposure variable is based on the local historical distribution of rainfall over the past 50 years, all households across grid cells have an equal probability of experiencing a shock in a given year (withstanding temporal correlation). Consequently, areas that experience more weather shocks in the past decade should not differ systematically from areas that experience more shocks in any other decade of the 50 year period.

4.4 Measuring agricultural yield

We vary our measure of agricultural output, using maize, cereal and total yield (log of output per hectare) at the plot level. Total yield covers all crops from the long rainy season, including legumes, vegetables, roots, tubers and cash crops. Around 60 percent of the plots are planted with mono- or intercropped maize, followed by around 12 percent allocated to rice paddy. Beans, groundnuts and

times for maize which varies from October-February in the unimodal areas (Kaliba et al., 1998a,b,c) and from January-April (Mafuru et al., 1999; Nkonya et al., 1999; Kaliba et al., 1998b) in the bimodal areas. This differs from Ahmed et al. (2011) who use a general growing period for the entire country, i.e. from January to June, for maize, rice and sorghum.

[16] We also estimate the models with 15 and 20 years of shock history as a robustness check, results available upon request.

pigeon peas are typical crops used for intercropping, whereas few farmers have cash crops, such as tobacco, cotton and cashew nuts. For each output measure we exclude the lower and upper one percentile, but our results are robust to including these assumed outliers.

Each measure has both disadvantages and advantages. We suspect that using total yield is more likely to bias our results. Households with past shock experience that experience a current shock may be more likely to harvest cassava, which weighs more than cereals and is more drought-tolerant, than those that did not experience a shock, thus resulting in a higher total yield. The five cereals (maize, sorghum, millet (bulrush and finger), wheat and rice) that enter into the cereal yield variable are on the other hand more homogenous in weight, and using maize only provides an even more homogenous crop category.[17] On the other hand, restricting the agricultural yield data to only maize or cereal reduces the number of observations, primarily at the plot level, but also at household level. Further, the sample of households that grow maize in both years may be a select group, that is either unable to switch to alternative crops, or highly capable maize farmers. The choice of outcome variable also depends on the type of adaptation we expect. Crop switching is captured by using a more aggregate crop group, while focusing on cereals or maize may capture other types of adaptation such as timing of planting, irrigation and soil conservation practices.

4.5 Measuring children's health

We use three measures of children's nutritional status as outcome variables. First, *(i)* weight-for-age, which is referred to as the "classical index" in WHO (1986), capturing underweight, and can be supplemented or replaced by the following two; *(ii)* weight-for-height, which reflects short-run nutrition and recovers quickly after a period of insufficient nutrition (wasting, index of acute malnutrition) and *(iii)* height-for-age, which captures long-run nutrition (stunting, index of chronic malnutrition). Stunting and wasting react differently to the nutritional state, and are distinct biological concepts. Wasting is more prevalent between 12 and 24 months of age, while stunting is more prevalent above 24 months. Growth is a slow process, and cannot be reversed (you cannot lose height), while weight may react quickly to nutrition and disease (WHO, 1986). According to WHO (1986) it is most appropriate to look at these outcome variables for children aged 5 and younger. The weight-for-age, weight-for-height and height-for-age of the children in our sample are

[17] Improved maize varieties are typically more drought-tolerant than local varieties.

linked to the WHO reference population by creating Z-scores.[18] The standard allows us to create Z-scores for individuals aged 0-60 months. Individuals with a weight-for-age Z-score that is more than two standard deviations below the median are defined as underweight, whereas similar cut-offs apply for categorizing individuals as wasted (weight-for-height) and stunted (height-for-age). In line with Alderman et al. (2006) we drop individuals with Z-scores below -6 or above 6, resulting in the exclusion of 75 observations. In addition, we are forced to drop individuals that were not measured, due to illness or because they were not at home.

4.6 Descriptive statistics

In Table 1 we report descriptive statistics at the plot, household and child level. Maize yields average around 800 kg per hectare, whereas average cereal and total yields are closer to 880 kg per hectare. The household head is on average 49 years of age, and one fourth of the households are female-headed. Four percent of the households experience a severe shock (rainfall below the 10th percentile) in one of the surveyed agricultural seasons, e.g. 2007/08 and/or 2009/10, whereas 11 percent have experienced a weak shock (rainfall below the 20th percentile) in these same seasons. In terms of previous exposure, the households have experienced between zero and four severe shocks over the past decade. The number of years since a similar shock occurred varies between one and 41 years for the severe shocks, and one and 20 years for the weak shocks. In terms of child health, children are on average 1.8 and 0.9 standard deviations below the international reference population for height-for-age and weight-for-age, respectively, whereas they are on average close to the median of the reference population for weight-for-height. When using the cut-offs of two standard deviations below the median, we find that 36 percent of the children are stunted, whereas 14 and 6 percent are wasted and underweight, respectively.

[18] We subtract the median and divide by the standard deviation of the appropriate sex and age category of the reference population.

Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Plot level					
Total yield (kg/ha)	875.07	1050.29	18.42	11943.43	5416
Cereal yield (kg/ha)	889.74	930.95	29.16	5991.05	4313
Maize yield (kg/ha)	798.73	764.12	10.16	4447.90	3297
Household level					
Age hh head	48.695	15.345	19	105	2436
Female headed hh	0.25	0.433	0	1	2436
Year 2010/2011	0.5	0.5	0	1	2436
GPS measured plots	0.571	0.495	0	1	2436
Average temp. in growing season	23.758	3.163	7.34	28.76	2436
Rainfall below 10th percentile this season	0.042	0.201	0	1	2436
No. of seasons with rainfall below 10th perc., last 10 yrs	1.166	1.071	0	4	2436
Years since rainfall below 10th percentile	9.362	9.638	1	41	2436
Rainfall below 15th percentile this season	0.071	0.257	0	1	2436
No. of seasons with rainfall below 15th perc., last 10 yrs	1.829	1.406	0	6	2436
Years since rainfall below 15th percentile	5.697	6.153	1	35	2436
Rainfall below 20th percentile this season	0.112	0.316	0	1	2436
No. of seasons with rainfall below 20th perc., last 10 yrs	2.418	1.552	0	7	2436
Years since rainfall below 20th percentile	3.622	3.265	1	20	2436
Child level					
Length/height-for-age Z-score	-1.646	1.53	-5.91	5.93	2800
Weight-for-age Z-score	-0.895	1.169	-5	5.43	2801
Weight-for-length/height Z-score	0.053	1.274	-5.58	5.65	2795
Age in months	30.151	17.457	0	60	3137
Female	0.5	0.5	0	1	3137

5 Empirical specifications

5.1 Agricultural yield

To investigate the impact of shocks and previous exposure to shocks on agricultural yield, we estimate the following equation:

$$\text{Y}_{phct} = \alpha + \beta_1 \text{Shock}_{ct} + \beta_2 \text{PrevShock}_{ct} + \beta_3 \text{Shock}_{ct} \times \text{PrevShock}_{ct} + \mathbf{X}'_{hct}\delta + \zeta_p + \eta_t + u_{phct} \quad (1)$$

where Y_{phct} is the outcome of interest (log of yield) for plot p in household h in grid cell c at time t. Shock_{ct} is a dummy equal to one if precipitation is below the 10th, 15th or 20th percentile at time t, PrevShock_{ct} is the number of years a grid cell c was exposed to such a shock in the past, and $\text{Shock}_{ct} \times \text{PrevShock}_{ct}$ is an interaction between the two. We look at the number of shocks experienced over a 10-year period prior to each agricultural season, but vary this time period as a sensitivity analysis. We include plot fixed effects, ζ_p, to control for time-invariant plot characteristics, and survey year fixed effects, η_t. u_{phct} is a mean zero error term, and we cluster the standard errors throughout at the grid cell level.

The choice of which control variables to include is not obvious. Following the recommendation by Dell et al. (2013) we only include regressors that can credibly be viewed as exogenous. Controlling for input use or crop choice when looking at agricultural yield would be problematic, since these variables are likely to be influenced by whether or not the household experiences a shock; in fact they may be important channels through which a household may adapt to climate risk. Angrist and Pischke (2008) calls this a "bad control problem" and shows that including regressors that are not exogenous to the weather variables we are interested in would bias the estimates of β_1, β_2 and β_3. The vector $\mathbf{X}_{hct}$ therefore only consists of a set of control variables at the household level, more specifically the age and gender of the household head, whether the households' plots were measured with GPS or not, and the mean temperature in the growing season.

The coefficient β_1 can be interpreted as the effect of being exposed to a shock without having been exposed to similar shocks over the past 10-year period. β_2 is the effect of past shock exposure on yield in a non-drought year, while β_3 is the effect of past shock exposure on the impact of a current shock. The average effect of a current shock is thus $\beta_1 + \beta_3 \times \overline{\text{PrevShock}}$ where $\overline{\text{PrevShock}}$ is the average number of shocks experienced. $\beta_3 < 0$ indicates that previous exposure to shocks makes the household less able to deal with a current shock (depletion), while $\beta_3 > 0$ indicates that households are able to learn from previous shock exposure to mitigate the impact of a current shock (adaptation). Similarly, $\beta_2 < 0$ indicates that more frequent past shock exposure leads to lower yield, while $\beta_2 >$ indicates the opposite. Since we are controlling for plot-level fixed effects, we are only exploiting variation within each plot over time. Any variation in the PrevShock_{ct} variable is thus variation in the number of shocks a plot has been exposed to between the first and the second survey round, and in the first two years that enter into the 10-year period. This means that an increase in previous shock exposure must come from experiencing a shock in the 2007/08 season and/or the 2008/09 season, whereas a decrease in shock exposure would occur when moving the 10-year window forward results in a shock year dropping out.

We also capture the effect of previous shock exposure on the impact of a current shock through LastShock_{ct}, replacing PrevShock_{ct}. This variable is based on counting the number of years since a similar shock, i.e. rainfall below 10th, 15th or 20th percentile, occurred. As described above, we expect that the timing of previous shock exposure may matter for the impact of a current shock. For instance, having recently experienced a similar shock could magnify the negative effect of a contemporaneous shock if households have depleted their asset stock, and adaptation to a new shock is costly. Alternatively, as time passes since the household last experienced a shock, their asset stock may be rebuilt, but knowledge of how to adapt to a shock may dissipate over time. Our second specification is as follows:

$$\text{Y}_{phct} = \alpha + \gamma_1 \text{Shock}_{ct} + \gamma_2 \text{LastShock}_{ct} + \gamma_3 \text{Shock}_{ct} \times \text{LastShock}_{ct} + \mathbf{X}'_{hct}\delta + \zeta_p + \eta_t + u_{phct} \quad (2)$$

where the average effect of a shock is $\gamma_1 + \gamma_2 \times \overline{\text{LastShock}}$. We include the same control variables as in the first specification.

5.2 Child health outcomes

We employ a reduced form model to investigate the impact of shocks and their interaction with previous shocks on child health outcomes:

$$\text{Y}_{ihct} = \alpha + \lambda_1 \text{Shock}_{ct} + \lambda_2 \text{PrevShock}_{ct} + \lambda_3 \text{Shock}_{ct} \times \text{PrevShock}_{ct} + \mathbf{X}'_{ihct}\delta + \xi_c + \varphi_t + u_{ihct} \quad (3)$$

where Y_{ihct} is a measure of the nutritional status for child i in household h in grid cell c at time t. We employ three outcomes: height-for-age Z-score, weight-for-age Z-score and weight-for-height Z-score. $\mathbf{X}_{ihct}$ includes a set of child-specific characteristics on age and gender, in addition to controls for birth- and interview month. Shock_{ct} refers to the last agricultural season prior to child measurement in grid cell c at time t. PrevShock_{ct} and the interaction term are defined as in the empirical specification for agricultural outcomes. We focus on the shock history relevant to the household, and not only shocks that occur in the child's lifetime, as the care-takers in the household are the ones who potentially learn and are able to protect children from shortfalls in income. We include grid-level fixed effects, ξ_c, rather than household or enumeration area fixed effects, as we are not able to use the data on the last children measured in the second survey round and therefore do not have sufficient variation within the household or enumeration area. This means that we are exploiting within grid cell variation to estimate the effects of rainfall shocks on child nutrition. We are thus comparing children from different households and, in some cases, different enumeration areas when several enumeration areas fall within the same grid cell. This should be kept in mind when interpreting the results.

We expect a contemporaneous shock (rainfall below the 10th, 15th or 20th percentile) to have a negative impact ($\lambda_1 < 0$) through income on short-term nutritional outcomes, i.e. weight-for-age and weight-for-height, but less so for height-for-age as this measure does not react quickly to changes in consumption. However, the disease channel may in part counteract this effect, since less rainfall could be beneficial if it reduces the prevalence of vector- and water borne disease. Similarly, past exposure to rainfall shocks could have an impact on child health (captured by λ_2) if the shocks occur during the lifetime of the child, especially on the long-run nutritional status. Accumulated negative income shocks at the household level could also have a negative impact on children's health, which would imply $\lambda_2 < 0$.

Finding $\lambda_3 < 0$ would indicate that households' repeated previous exposure to droughts makes child health more vulnerable to recent shocks. For short-term nutritional outcomes, we expect the impact mechanism to be through the income of the household, where the impact on household consumption is increasing in previous shock exposure, perhaps due to asset depletion and lack of consumption smoothing mechanisms. A child's previous exposure to shocks is expected to affect height-for-age negatively, which could imply $\lambda_3 < 0$ depending on when the previous shocks occurred. $\lambda_3 > 0$ would, on the other hand, indicate that households are able to take advantage of learning from previous shocks, through improved income- and consumption smoothing and/or through agricultural adaptation, depending on the sign of β_3 from specification 1.

Similar to the specification in eq. (2), we also look at the importance of timing of past shocks for child nutritional outcomes.

6 Results

6.1 Agricultural yield

We start off by presenting our results for agricultural outcomes, in line with the first empirical specification in eq. (1), using the plot-level panel. We report here the results from using log of cereal yield as the outcome variable, and refer to the appendix for the results on log of total yield and maize yield. Plot-level fixed effects are included throughout, and we are therefore exploiting the within-plot level variation. Panel A, Table 2 shows that experiencing a negative rainfall shock decreases cereal yields. The impact of the shock is increasing in the severity of the shock, i.e. the more severe shocks have a larger negative impact on crop yields. More specifically, rainfall below the 10th percentile results in an average reduction in cereal yield of 26 percent, whereas rainfall below the 15th percentile on average reduces yield by 18 percent. The impact of a weak shock suggests an average decrease in yield by 10 percent, but is not statistically significant.

Next, we include an interaction term between the frequency of past shocks and a shock this agricultural season, while controlling for the number of shocks experienced, thus estimating the full specification in eq. (1). When controlling for past shock experience, the impact of a current shock is no longer statistically significant. This may be because we have insufficient plot observations without any previous shock experience to estimate this coefficient. The impact of a current shock is smaller for plots with more previous shock experience, corresponding to $\beta_3 > 0$ in our empirical specification, but only for the least severe shock. The magnitude indicates that an additional shock experience on average reduces the impact of a current shock by about 12 percent for cereal yields. Farmers with more shock experience seem better able to cope with a current shock, but only for mild shocks, perhaps because available adaptation strategies are not sufficient to mitigate the impact of severe droughts. It may also be that we are unable to estimate a significant coefficient on the interaction term because there are too few plot observations with past shock experience and a current shock for the more severe, and therefore rarely occurring, shocks. The coefficients on the number of past shocks and the interaction term are jointly significant for the moderate and mild shocks, but not for the severe shock.

The results also show that plots with more shock experience on average have higher yields, corresponding to $\beta_2 > 0$ in the empirical specification. A potential explanation for this finding is that farmers invest in higher-yielding technologies as a self-insurance mechanism to mitigate the impact of shocks and ensure a minimum production level when facing risk. The farmers that continue in farming despite previous droughts[19] appear to increase their effort and investments in response to shocks as an adaptive measure. Those with more frequent shock exposure seem to intensify production more, on average leading to between 15 and 30 percent higher yields depending on the severity of the shock. The difference in yield due to varying the number of shocks experienced is smaller for more severe shocks. This may be because severe shocks have such a large impact on households' income that adjustment is difficult, or because experiencing a severe shock triggers an adjustment in behavior regardless of how many shocks they have experienced. Furthermore, it may also indicate that intensification is costly, if farmers are more reluctant to increase investments and efforts when experiencing only a few moderate or mild shocks.

These results are similar when looking at the three different outcome measures, see Table A1 for results on total yield and maize yield. We find the largest negative effects of a severe shock for the more narrow yield definitions, i.e. 28 percent reduction for maize compared to 23 percent reduction in total yield.[20] This may be because the total crops category includes less drought-sensitive crops, and that there is more room for substitution between crops. Further, we do not find evidence that the impact of current shock is smaller for plots with more previous shock experience when looking at total yield, possibly because previous shock experience is less valuable than for a specific crop such as maize. We also vary the "shock memory" in the model, by counting the frequency of shocks over the past 15 and 20 years prior to the relevant agricultural season. The results largely hold (available upon request), but are weaker the longer the time period we take into account. The results are also largely robust to using a more narrow definition of the rainy season, described in Section 4.3, and as reported in Table A2.

[19] Either because they are especially skilled, or because they lack outside opportunities, as further discussed below.
[20] The impact is not statistically significant for the total yield variable.

Table 2: The effect of rainfall shocks on cereal yield

	Severe shock		Moderate shock		Mild shock	
Panel A:						
Shock this season	-0.260***	-0.103	-0.182*	-0.149	-0.106	-0.166
	(0.091)	(0.209)	(0.103)	(0.333)	(0.071)	(0.161)
Number of shocks last 10 yrs		0.149		0.234***		0.308***
		(0.095)		(0.074)		(0.067)
Shock this season * No. of similar shocks last 10 yrs		-0.035		0.082		0.117*
		(0.112)		(0.122)		(0.061)
Panel B:						
Shock this season		-0.451		-0.206		-0.190*
		(0.400)		(0.138)		(0.115)
Years since last shock		-0.021**		-0.030***		-0.043**
		(0.008)		(0.006)		(0.018)
Shock this season * Years since last similar shock		0.070		0.018		0.044*
		(0.118)		(0.027)		(0.026)
Number of Obs.	4313	4313	4313	4313	4313	4313
Mean of Dep. Var.	6.31	6.31	6.31	6.31	6.31	6.31

Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile.
Dep. var.: Total cereal yield (log), including maize, sorghum, millet, wheat and rice. Plot fixed effects. Survey year, age and sex of household head, GPS measurement of plot and average temperature in growing season included but not reported.
Shocks based on 12 month rainfall. Standard errors clustered at grid cell level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In Panel B, Table 2 we show the results from looking at the timing of past shocks. The results demonstrate that the timing of past shocks matters. Plots with more distant shock experience have lower yields, corresponding to $\gamma_2 < 0$, and this effect is declining in the severity of the shock. One way of interpreting this is that a shock has a stock effect on increased investments and effort, and that this stock depreciates more slowly for severe shocks, due to the lasting impression of such a shock. As discussed in the conceptual framework, we expect that more recent shock experience may provide households with the knowledge of how to cope with a new shock, but that this effect may dissipate over time. On the other hand, the household may need time to recover from a shock to be able to cope with a new shock. For the mild shock, the more time has passed since the last shock, the smaller the impact of a current shock, or $\gamma_3 > 0$ in eq. (2), which may indicate that the "recovery" effect dominates. For the moderate and severe shocks, the coefficient on the interaction term is not statistically significant. This could be explained by farmers' inability to mitigate the impact of more severe shocks, or because we do not have sufficient variation to estimate the coefficient. The results for total yield and maize yield are similar, as seen from Table A3.

6.2 Child health outcomes

Next, we investigate the impact of shocks and previous shock exposure on children's health among the same farming households. In Panel A in Table 3, we report the results on weight-for-age, referring to the appendix for results on height-for-age and weight-for-height. These are the results for the more narrow specification of the growing season for defining the weather shocks, as described in Section 4.3, while the results for the more general definition are shown in the appendix. The rainfall shocks are defined as rainfall below the 10th, 15th or 20th percentile of the local historical rainfall distribution in the months of the rainy season (the long rainy season in the bimodal areas). Grid cell, birth month- and interview month fixed effects are included throughout but not reported. We are therefore comparing children within the same grid cell, born in the same month (in part accounting for their exposure to rainfall shocks in utero) and interviewed in the same month. The results on children's health should thus be interpreted with caution, since we are not controlling for unobservable household characteristics that may be correlated with the climate variables and children's nutritional outcomes.

Table 3: The effect of rainfall shocks on children's weight-for-age Z-score

	Severe shock		Moderate shock		Mild shock	
Panel A:						
Unimodal/bimodal shock this season	-0.177*	-0.122	0.055	-0.160	-0.023	-0.270
	(0.092)	(0.194)	(0.101)	(0.159)	(0.094)	(0.167)
Number of unimodal/bimodal shocks, last 10 yrs		0.110		0.009		0.050
		(0.086)		(0.059)		(0.064)
Unimodal/bimodal shock this season * No. of unimodal/bimodal shocks, last 10 yrs		0.010		0.101**		0.122**
		(0.096)		(0.050)		(0.049)
Panel B:						
Unimodal/bimodal shock this season		-0.400***		0.325		0.093
		(0.140)		(0.215)		(0.144)
Years since unimodal/bimodal shock		-0.020		-0.000		-0.017
		(0.015)		(0.016)		(0.015)
Unimodal/bimodal shock this season * Years since unimodal/bimodal shock		0.056***		-0.060		-0.019
		(0.015)		(0.043)		(0.029)
Number of Obs.	2801	2801	2801	2801	2801	2801
Mean of Dep. Var.	-0.89	-0.89	-0.89	-0.89	-0.89	-0.89

Dep. var.: Z-score is deviation of child's weight-for-age from the median, divided by the standard deviation of the appropriate sex and age category of the reference population. Sample: individuals aged 0-60 months from farming households. Shocks based on unimodal/bimodal rainfall.
Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile, and mild below the 20th percentile.
Controls for age, sex, survey year, grid cell, birth- and interview month included but not reported.
Standard errors clustered at grid cell in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Looking first at the impact of a shock without controlling for past shock experience, we find that the most severe shock is associated with a lower weight-for-age Z-score, while we do not find statistically significant results for the less severe shocks. Experiencing rainfall below the 10th percentile of the local historical rainfall distribution in the rainy season prior to being measured is associated with a 0.18 standard deviation lower weight-for-age Z-score of children 5 years and younger. When we control for past shock experiences of the household to which the child belongs, the coefficients on the shock variables are all negative, but not statistically significant. The results also indicate that in households with more shock experience, a current shock is associated with a smaller decrease in short-run nutritional indicators.[21] The coefficient on the interaction term, λ_3 in the empirical specification, is positive and significant for both moderate and mild shocks for weight-for-age, which could indicate that households are able to use previous shock experiences to better shield their children from current shocks. The coefficient on the number of past shocks, λ_2, is positive but not statistically significant, but it is significant when using weight-for-height as the outcome variable. This could be an indication of a selection mechanism and is further discussed in Section 7.1. Again, the coefficients on past shock experience and the interaction term are only jointly significant for the moderate and mild shocks for weight-for-age Z-scores.

As shown in Table A4 in the appendix, there does not seem to be any impact of shocks on the height-for-age Z-score, which is as expected since height-for-age is a measure of long-run nutritional status. Past shocks are negatively associated with height-for-age, as expected, but the association is not statistically significant. Using rainfall over the 12 month period, rather than unimodal/bimodal rainfall, as reported in Table A5, gives similar results, although the shock variable alone is no longer statistically significant for weight-for-age.

Lastly, we investigate the importance of the timing of past shock experience for the impacts on child nutrition. As seen from Panel B in Table 3, when we control for the timing of past shock experiences, a severe shock is associated with a 0.4 standard deviation decrease in the weight-for-age of children 5 years and younger. The impact of less severe shocks is not statistically significant. We also see that the impact of a severe drought is smaller the more time has passed since the last severe drought the household was exposed to, which could be because the household has had time to recover and rebuild their asset stock. The results are similar when looking at the weight-for-height Z-score, as shown in Panel B in Table A6, but they also indicate that children with more distant

[21] This also holds for the weight-for-height Z-score, as shown in Panel B, Table A4.

shock experience (both for severe and mild shocks) on average have worse weight-for-height Z-scores, which is surprising. One would expect recent shocks to have a negative impact on short-term child nutrition, since these are more likely to have occurred during the lifetime of the child. We discuss this result further below. As before, there are no results for the long-run nutritional indicator, height-for-age, as seen in Panel A, Table A6.

7 Discussion and caveats

Our results suggest that households with more previous exposure to negative rainfall shocks use higher-yielding and, in some cases, less drought-sensitive technologies. They also indicate that households with more past shock experience to some extent are able to mitigate the impacts of current shocks on children's nutrition. They do not, however, say anything about the type of technology or adaptation that takes place, i.e. the mechanisms behind the results. There are also caveats with regards to interpreting the difference in yield, drought-sensitivity and children's nutritional outcomes as being caused by previous shock experience.

7.1 Mechanisms

Previous studies suggest that farm households undertake a range of actions to reduce their vulnerability to weather shocks. Shifting the timing of planting or fertilizer application, switching crop varieties and types, and implementing soil- or water conservation technologies are potential adaptation strategies in agriculture (Burke and Lobell, 2010; Di Falco and Veronesi, 2013). The NPS-data does not contain detailed information on the timing of cropping activities, but we have information on the type of crop grown, as well as what inputs have been used and whether soil- and water conservation technologies have been implemented. Switching crop varieties and implementing soil-and water conservation are actions that may also increase yield (see for instance Banda et al. (1994); Vancampenhout et al. (2006).) Further, if households intensify production as a risk-coping mechanism, i.e. subsistence orientation, then this may take place through increasing labor effort or the use of other inputs.

We investigate potential causal mechanisms by estimating the association between technology choice, past and current shock experiences, and the interaction between the two, similar to the empirical specification for investigating impacts on crop yields (eq. (1)). We first compare the probability of investing in erosion control and water harvesting facilities on plots. As seen from Panel A in Table 4, households with plots that have experienced on average more moderate and weak shocks, are more likely to have these measures in place.[22] Given that these investments increase yields and protect households from shortfall in yield in drought years, this may be one of the behavioral responses that contribute to our previous finding that plots with more frequent previous exposure to shocks on average have higher yield. We find no change in these investments in years of drought, which is as expected since these are likely to be time-consuming measures that do not immediately yield benefits and are therefore unlikely to be implemented in response to a current drought.

Next, we look at the use of inorganic fertilizer, as reported in Panel B in Table 4. Plots with no previous drought experience receive less inorganic fertilizer in years with severe and moderate droughts, whereas the total reduction in inorganic fertilizer on plots with previous exposure to rainfall shocks is smaller. More frequent previous exposure over the past decade reduces the use of inorganic fertilizer, which is in line with the findings of Dercon and Christiaensen (2011). The latter result may also be driven by an income effect triggering a binding liquidity constraint.

We also compare the use of other technologies and inputs, including improved maize varieties, intercropping, and total labor days, but do not find any clear differences based on previous shock exposure and its interaction with current shocks (available upon request). We do however find negative impacts of droughts alone on use of more variable inputs such as labor, measured in terms of total labor days.

The above mechanisms relate to agricultural production, however, we are also interested in possible mechanisms that may explain our findings on child health outcomes. As discussed in the conceptual framework, indications of previous shock experience mitigating current shock impacts on child health may both be due to adaptation in agriculture, that reduces the yield impact of shocks, and adaptation taking place outside agriculture. Potential coping strategies in this context are income diversification, asset depletion and self-insurance through savings, where we hypothesize that households may use their experience with these strategies from previous shock exposure to mitigate impacts of current shocks.

[22] The most common erosion control and water harvesting facilities reported in both years of the survey are terraces and bunds.

Table 4: The effect of rainfall shocks on use of agricultural technologies

	Severe shock	Moderate shock	Mild shock
Panel A: Erosion control/water harvesting, dummy			
Shock this season	0.133	0.086	-0.048
	(0.106)	(0.076)	(0.106)
Number of shocks last 10 years	0.031	0.066^{***}	0.065^{***}
	(0.034)	(0.025)	(0.023)
Shock this season * No. of similar shocks last 10 yrs	-0.064	-0.013	0.019
	(0.042)	(0.020)	(0.027)
Number of Obs.	5403	5403	5403
Mean of Dep. Var.	0.14	0.14	0.14
Panel B: Inorganic fertilizer, dummy			
Shock this season	-0.517^{**}	-0.361^{**}	-0.059
	(0.106)	(0.140)	(0.106)
Number of shocks last 10 years	-0.051^{*}	-0.053^{**}	-0.027
	(0.027)	(0.021)	(0.017)
Shock this season * No. of similar shocks last 10 yrs	0.167^{**}	0.073^{**}	-0.004
	(0.080)	(0.031)	(0.032)
Number of Obs.	5416	5416	5416
Mean of Dep. Var.	0.10	0.10	0.10

Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile.
Survey year, age and sex of household head, and average temperature in growing season included but not reported.
Standard errors clustered at grid cell in parentheses. Plot fixed effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In order to investigate potential mechanisms, we use the same approach as above to estimate the relationship between an indicator of income diversification and shocks, previous shock exposure and their interaction, while controlling for household fixed effects.[23] As an indicator of income diversification we use a dummy variable equal to one if the head of the household's main occupation was outside agriculture in the 12 months preceding the survey, and zero otherwise. Results in Table 5 show that experiencing a severe shock increases the probability of the household head's main occupation being outside agriculture, which may indicate that this is an important strategy to cope with severe shocks that lead to large shortfalls in agricultural income. For all three shocks, more frequent past shock exposure decreases the probability of non-agricultural employment, and non-agricultural occupation seems to be less important as a coping strategy for households with more previous shock experience. This may suggest that households opt for subsistence orientation in response to risk exposure. On the other hand, it may also be the result of selection, whereby households with outside income opportunities that have experienced more shocks have left agriculture. We discuss this latter possibility further below.

Table 5: The effect of rainfall shocks on household head's main occupation

	Severe shock	Moderate shock	Mild shock
Head's main occupation is non-agricultural, dummy			
Shock this season	0.252*	-0.047	0.064
	(0.131)	(0.116)	(0.100)
No. of shocks., last 10 yrs	-0.072**	-0.060**	-0.065***
	(0.032)	(0.027)	(0.024)
Shock this season * No. of shocks, last 10 yrs	-0.165***	-0.026	-0.052*
	(0.054)	(0.030)	(0.029)
Number of Obs.	2436	2436	2436
Mean of Dep. Var.	0.53	0.53	0.53

Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile, and mild below the 20th percentile. Household fixed effects. Standard errors clustered at grid cell in parentheses.
Survey year, age and sex of household head, and average temperature in growing season included but not reported.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

[23]Unfortunately, we do not have access to data on household savings and an adequate measure of asset holdings and can therefore not investigate these potential coping mechanisms.

7.2 Endogenous placement and selection issues

In the above analysis we have treated previous shock exposure as orthogonal to household characteristics. There are several reasons why this assumption may be problematic. Households may adapt to shocks by migrating, as documented by Munshi (2003) in the Mexican setting. The households we observe who are still in agriculture after several shocks may be different from the ones that have left agriculture or migrated. For instance, they may be better at agriculture, so that the coefficient on our interaction term is overestimated, or they may be less skilled, and thus unable to find other income sources, in which case we could be underestimating the interaction term.

To shed some light on the potential selection effects, we compare the characteristics of the households that moved between the first and the second survey round, or were not possible to track, with the households that stayed. Results are reported in Table 6. Heads in households that moved or were not tracked down in the second survey round, are on average younger, and the household size is on average smaller. There is no significant difference in terms of education, sex of head of household, or quality of housing, measured by the share that have metal roof. If these characteristics are representative of households' ability to farm and adapt to climate variability, then we find no clear indication of neither positive or negative selection into agriculture.

As a second approach, we compare the characteristics of households based on their previous shock exposure over the past 10 years, dividing them into two groups: those that have experienced no shocks and those that have experienced at least one. If our results are driven by positive selection into agriculture, resulting in an overestimated interaction coefficient on adaptation, then we expect the households who are still farming despite repeated exposure to have among other higher levels of education and better housing. We investigate this by comparing households based on their previous shock exposure, as shown in Table 7. The results show that the households with no shock experience are on average larger, and a larger share is female-headed. There is no significant difference in age or years of education of household head at the 5 percent level of significance. However, these are characteristics of households *after* experiencing shocks, and all household characteristics are essentially endogenous to the shocks. Especially in terms of household wealth, we could expect households that have experienced more negative shocks to be less wealthy. Indeed, our results show that households with no shock experience on average have better quality housing, measured by the share that has metal roofing or better versus grass, bamboo and mud.

We would ideally like to observe households before they experience shocks to see whether house-

Table 6: Difference in characteristics between those who stayed and those who left

Variable	Observed	N	Mean	St. Dev	p
Age hh head	Stayed	1218	47.66	15.29	0.000
	Moved/Not tracked	143	42.58	15.30	
Household size	Stayed	1218	5.42	2.95	0.000
	Moved/Not tracked	143	4.46	2.29	
Years of education hh head	Stayed	1218	4.49	3.37	0.198
	Moved/Not tracked	143	4.87	3.35	
Female hh head	Stayed	1218	0.25	0.43	0.128
	Moved/Not tracked	143	0.19	0.39	
Metal roof	Stayed	1218	0.48	0.50	0.224
	Moved/Not tracked	143	0.43	0.50	

Comparison of households in first survey round based on whether they moved/were not tracked or not in second round. Households in the unbalanced panel with cultivated plots, characteristics in 2008/09 survey. The majority of those that did not stay fall into the category "Moved" rather than "Not tracked".

Table 7: Comparison of households in first survey round by exposure to rainfall shocks

Variable	Risk exposure	N	Mean	St. Dev	p
Age hh head	No shock last 10 years	412	50.19	15.19	0.000
	At least one shock last 10 years	806	46.34	15.18	
Household size	No shock last 10 years	412	5.45	2.72	0.772
	At least one shock last 10 years	806	5.40	3.06	
Years of education hh head	No shock last 10 years	412	4.29	3.66	0.141
	At least one shock last 10 years	806	4.59	3.21	
Female hh head	No shock last 10 years	758	0.24	0.43	0.723
	At least one shock last 10 years	806	0.24	0.43	
Metal roof	No shock last 10 years	412	0.62	0.49	0.000
	At least one shock last 10 years	806	0.41	0.49	

Households from balanced panel, characteristics in 2008/09 survey. A shock is defined as rainfall below the 10th percentile of the local historical rainfall distribution, "last 10 years" refers to 1997/98-2006/07.

holds that experience shocks are different than those that do not experience shocks. Since each cluster has the same probability of experiencing a shock, there should be no difference between households prior to the shock. We therefore investigate whether households that experience shocks in 2010/11 were different in 2008/09. The results are shown in Table 8. We find that households that experience a shock "next season" on average have older and less educated household heads, and a larger share are female-headed. We find no significant difference in terms of housing quality before the shock occurs.

So far we have assumed that the household that experienced a contemporaneous shock, is the same household that experienced similar shocks over the past 10 years. The estimated effect from previous shock exposure will be biased if the household we observe in the panel is not the same

Table 8: Comparison of households in first survey round by rainfall shock in second survey round

Variable	Risk exposure	N	Mean	St. Dev	p
Age hh head	Rainfall below 10th perc. 2009/10	28	48.04	18.79	0.891
	No shock	1190	47.64	15.21	
Household size	Rainfall below 10th perc. 2009/10	28	3.90	2.04	0.006
	No shock	1190	5.46	2.96	
Years of education hh head	Rainfall below 10th perc. 2009/10	28	4.07	3.41	0.506
	No shock	1190	4.5	3.37	
Female hh head	Rainfall below 10th perc. 2009/10	28	0.39	.50	0.068
	No shock	1190	0.24	0.43	
Metal roof	Rainfall below 10th perc. 2009/10	28	0.75	0.44	0.004
	No shock	1190	0.47	0.50	

Households in balanced panel, characteristics in 2008/09 survey. Shocks based on percentiles in local historical rainfall distribution. Results are similar for shocks defined as rainfall below the 15th or 20th percentile.

household that operated the observed plots 10 years ago. The survey asks how long each individual has lived in the community, enabling us to assess to what extent this might be affecting our results. Around 73 percent of the households that enter into the plot analysis report to have a household head that has always lived in the given location, and this percentage is similar across both male- and female-headed households. This suggests that the shock history is likely to be relevant to the large majority of the households' decision-making.

There are also potential selection problems in terms of impacts of shocks on children's health. Since droughts may increase child mortality (Kudamatsu et al., 2012), the children we observe may be more resilient (positive selection). This is the so-called *culling effect* (Almond and Currie, 2011), and could positively bias the estimate of the shock impact. On the other hand, children who have been exposed to droughts may have suffered previous health shocks that make them more vulnerable to a current shock, since the distribution of infant health stock is shifted leftwards (the *scarring effect*) (Almond and Currie, 2011), which would negatively bias the estimate of the shock impact.

Our findings with regards to past shock experience may also be driven by a select sample of children, whereby the positive coefficient on the interaction between a contemporaneous shock and past shock experience, λ_3, is explained by the culling effect, rather than households' adaptation. Past shocks may have shifted the cut-off of the distribution of surviving children rightwards, whereby only the strongest children are observed in our sample. In other words, the households may not themselves have learnt from previous shock, rather the children are more "tolerant" to new shocks. The positive and significant coefficient on past shock experience, λ_2, for weight-for-height falls in line with this selection story, as seen from Panel B, Table A4. Unfortunately, based on the data available we are not able to determine whether selection is driving our results.

7.3 Functional form

In the above regressions, exposure to previous climate shocks is included as a continuous variable interacted with the shock variable. This means that we implicitly assume that the number of shocks a household has previously been exposed to has a linear impact on how much a shock last season affects yields. This may not be a valid assumption. Lack of sufficient variation prevents us from investigating our hypothesis by including a quadratic term. Of those that have experienced a shock in one of the relevant years, the previous exposure to a similar shock is limited to up to three for severe shocks, four for moderate shocks and up to five for weak shocks.

7.4 Using gridded weather data

Auffhammer et al. (2013) discuss common pitfalls when using gridded weather data in econometric analyses. First, the choice of weather data set matters, as data from different sources may agree on average temperatures, but not on the deviations from average values, which is the variation we are using in our analysis. This is issue is particularly important when using weather data from developing countries where the spatial coverage of weather stations may be limited, and it is therefore recommended to use at least one other weather data set to check the robustness of the results. The measurement error may cause attenuation bias that is amplified when using fixed effects, causing potentially large biases to our estimated coefficients (Angrist and Pischke, 2008). Another issue is spatial correlation. Although we have included average temperature as a control variable in addition to the rainfall shocks, there may be other climate variables (Auffhammer et al. (2013) mention wind and relative humidity) that are correlated with the included weather variables. This is an important problem if the goal of the analysis is to extrapolate potential climate change impacts based on the econometric study, as the estimated coefficients will pick up the effect of the omitted variables on the outcome of interest as well. We do not consider this to be a great concern in our study, since our goal is not extrapolation, but we recognize that our measures of "drought" may be picking up the effect of other weather variables. A greater concern is that these omitted weather variables are likely to be spatially correlated,[24] and omitting them causes a spatially correlated error term. Auffhammer

[24]Both due to physical factors governing the climate, and because of how the data is interpolated. The latter cause of correlation could be even more important if there are few weather stations, and several grid cells are based on data

et al. (2013) recommend adjusting the standard errors to account for the spatial correlation, and note that this adjustment is likely to increase the standard errors significantly. Although we have clustered the standard errors in our analysis at the grid cell level, we have not made further steps to account for additional spatial correlation. Robustness checks using a different climate data set as well as further adjustment of the standard errors to account for spatial correlation remain tasks for further robustness checks.

8 Conclusion

In this paper we have investigated to what extent previous shock exposure affects the impact of contemporaneous shocks on households. We focus on two outcome variables, crop yield and child health outcomes. Our results show that experiencing droughts negatively impacts crop yields, with a larger negative impact of more severe droughts. The results indicate that households with more previous drought experience are better able to handle rainfall shocks, but only less severe shocks, and that the timing of past droughts matters. More previous drought experience is associated with higher yields, which could be due to subsistence orientation and intensification in response to increased risk. These results hold when controlling for plot-level time-invariant unobservables. Exploring the technologies used by the households suggests that households invest in soil- and water conservation facilities in response to more frequent rainfall shocks, whereas they are less likely to apply fertilizer. In terms of children's nutritional outcomes, severe droughts seem to have a negative impact on short-term nutritional indicators, while we find suggestive evidence that more previous shock experience mitigates impacts of less severe shocks. Children are less affected by a severe drought the more time has passed since the household was last exposed to a similar shock. Households seem to use off-farm income sources as a coping strategy when facing shocks, but this strategy appears less important for households that have more previous shock exposure.

Our results have important policy implications. We find large reductions in yield in years of drought, and similar negative effects on short-run nutritional outcomes under severe droughts, suggesting that households are unable to compensate for the shortfall in consumption from own-production with alternative income- and consumption smoothing strategies. Although previous experience with similar shocks seems to mitigate the impact of less severe current shocks, this does not seem to hold for the most severe shocks, suggesting the need for external safety-nets in years of

from the same stations.

severe droughts.

However, the relatively higher yields that we observe for households with more past shock experience, and the related investment in erosion control and water harvesting, highlights the importance of combining targeted safety nets with general improvements in knowledge of and access to technologies and techniques that may reduce shortfall in yield in a drought year. Similarly, the reduced use of inorganic fertilizer following years of drought, underline the importance of improving credit- and insurance markets so as to allow farmers to fully partake in agricultural input (and output) markets.

We do not attempt to extrapolate these findings and apply them to long-term changes due to climate change. However, our results indicate that farmers are able to adapt to climate variability, and that they are able to take advantage of previous experiences to reduce the impact of current shocks, but only less severe shocks. This could imply that farmers to a certain extent may be able to adapt to increased climate variability due to climate change. On the other hand, the farmers appear to be vulnerable to severe droughts, and the possibility of adapting to increased frequency of severe rainfall shocks seems limited based on our results.

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Appendix

Figure A1: Enumeration Areas from NPS1 2008/09

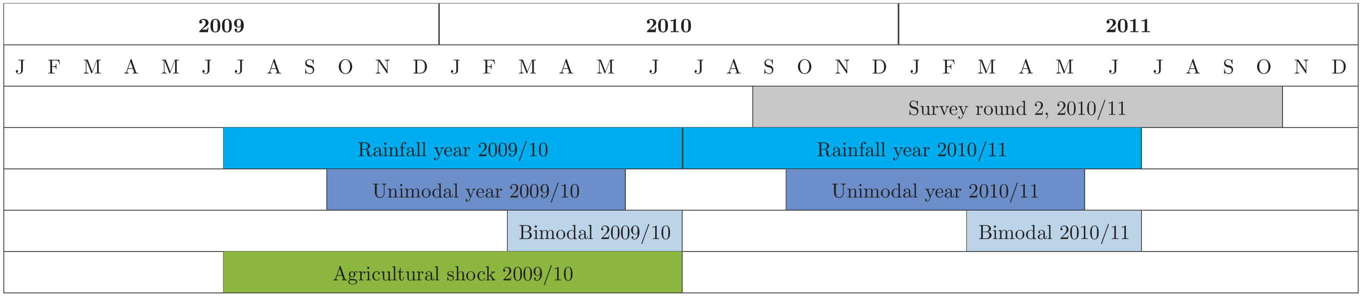

Figure A2: Timeline: agricultural shock, survey round 2 (NPS2)

Table A1: The effect of rainfall shocks on total yield and maize yield, number of shocks

	Severe shock		Moderate shock		Mild shock	
Panel A: Total yield (log)						
Shock this season	-0.231	0.019	-0.208*	0.032	-0.106	-0.042
	(0.150)	(0.242)	(0.108)	(0.250)	(0.080)	(0.159)
Number of shocks last 10 yrs		0.095		0.152**		0.249***
		(0.094)		(0.068)		(0.065)
Shock this season * Number of shocks last 10 yrs		-0.094		-0.026		0.047
		(0.173)		(0.108)		0.047
Number of Obs.	5416	5416	5416	5416	5416	5416
Mean of Dep. Var.	6.21	6.21	6.21	6.21	6.21	6.21
Panel B: Maize yield (log)						
Shock this season	-0.287**	-0.217	-0.207	-0.528	-0.092	-0.253
	(0.130)	(0.343)	(0.138)	(0.384)	(0.082)	(0.180)
Number of shocks last 10 yrs		0.239**		0.215**		0.320***
		(0.121)		(0.091)		(0.078)
Shock this season * Number of shocks last 10 yrs		0.037		0.201		0.163**
		(0.147)		(0.135)		(0.066)
Number of Obs.	3297	3297	3297	3297	3297	3297
Mean of Dep. Var.	6.22	6.22	6.22	6.22	6.22	6.22

Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile.
Dep. var.: Total yield (log), includes all crops. Maize yield (log), includes local and improved maize varieties.
Survey year, age and sex of household head, GPS measurement of plot and average temperature in growing season included but not reported. Shocks based on 12 month rainfall. Plot fixed effects. Standard errors clustered at grid cell level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A2: The effect of unimodal/bimodal rainfall shocks on total yield, cereal yield and maize yield, number of shocks

	Severe shock		Moderate shock		Mild shock	
Panel A: Total yield (log)						
Unimodal/bimodal shock this season	-0.289**	0.166	-0.182*	0.149	-0.109	0.123
	(0.129)	(0.206)	(0.093)	(0.352)	(0.080)	(0.170)
Number of unimodal/bimodal shocks last 10 yrs		0.145		0.272***		0.302***
		(0.107)		(0.071)		(0.065)
Unimodal/bimodal shock this season * Number of unimodal/bimodal shocks last 10 yrs		-0.156		0.000		0.031
		(0.114)		(0.118)		(0.073)
Number of Obs.	5416	5416	5416	5416	5416	5416
Mean of Dep. Var.	6.21	6.21	6.21	6.21	6.21	6.21
Panel B: Cereal yield (log)						
Unimodal/bimodal shock this season	-0.217**	0.153	-0.107	-0.383	-0.124*	-0.207
	(0.103)	(0.191)	(0.091)	(0.380)	(0.070)	(0.176)
Number of unimodal/bimodal shocks last 10 yrs		0.346***		0.387***		0.371***
		(0.096)		(0.072)		(0.064)
Unimodal/bimodal shock this season * Number of unimodal/bimodal shocks last 10 yrs		-0.052		0.238**		0.174**
		(0.090)		(0.117)		(0.068)
Number of Obs.	4313	4313	4313	4313	4313	4313
Mean of Dep. Var.	6.31	6.31	6.31	6.31	6.31	6.31
Panel C: Maize yield (log)						
Unimodal/bimodal shock this season	-0.200*	0.329*	-0.086	-0.578	-0.102	-0.280
	(0.113)	(0.193)	(0.111)	(0.492)	(0.083)	(0.217)
Number of unimodal/bimodal shocks last 10 yrs		0.385***		0.367***		0.404***
		(0.122)		(0.091)		(0.080)
Unimodal/bimodal shock this season * Number of unimodal/bimodal shocks last 10 yrs		-0.131		0.302**		0.228***
		(0.088)		(0.152)		(0.087)
Number of Obs.	4313	4313	4313	4313	4313	4313
Mean of Dep. Var.	6.31	6.31	6.31	6.31	6.31	6.31

Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile. Shocks based on unimodal/bimodal rainfall.
Dep. var.: Total yield (log), includes all crops. Cereal yield (log), includes maize, sorghum, millet, wheat and rice. Maize yield (log), includes local and improved varieties.
Survey year, age and sex of household head, GPS measurement of plot and average temperature in growing season included but not reported. Plot fixed effects.
Standard errors clustered at grid cell level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A3: The effect of rainfall shocks on total yield and maize yield, years since last shock

	Severe shock	Moderate shock	Mild shock
Panel A: Total yield (log)			
Shock this season	-0.633	-0.243*	-0.247**
	(0.681)	(0.135)	(0.015)
Years since last shock	-0.009	-0.021***	-0.038**
	(0.011)	(0.006)	(0.015)
Shock this season * Years since last similar shock	0.136	0.015	0.059**
	(0.183)	(0.012)	(0.025)
Number of Obs.	5416	5416	5416
Mean of Dep. Var.	6.21	6.21	6.21
Panel B: Maize yield (log)			
Shock this season	-0.387	-0.051	-0.116
	(0.430)	(0.150)	(0.119)
Years since last shock	-0.032***	-0.030**	-0.036**
	(0.009)	(0.014)	(0.016)
Shock this season * Years since last similar shock	0.045	-0.023	0.024
	(0.151)	(0.025)	(0.023)
Number of Obs.	3297	3297	3297
Mean of Dep. Var.	6.22	6.22	6.22

Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile.
Dep. var.: Total yield (log), includes all crops. Maize yield (log), includes local and improved maize varieties.
Survey year, age and sex of household head, GPS measurement of plot and average temperature in growing season included but not reported. Plot fixed effects. Shocks based on 12 month rainfall.
Standard errors clustered at grid cell level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A4: The effect of unimodal/bimodal rainfall shocks on children's height-for-age and weight-for-height Z-score, number of shocks

	Severe shock		Moderate shock		Mild shock	
Panel A: Height-for-age Z-score						
Unimodal/bimodal shock in season before child measured	-0.136	-0.368	0.105	-0.205	0.014	-0.258
	(0.094)	(0.247)	(0.122)	(0.171)	(0.116)	(0.200)
Number of unimodal/bimodal shocks, last 10 yrs		-0.127		-0.139		-0.122
		(0.134)		(0.100)		(0.103)
Unimodal/bimodal shock in season * Number of unimodal/bimodal shocks, last 10 yrs		0.088		0.096		0.074
		(0.136)		(0.073)		(0.064)
Number of Obs.	2800	2800	2800	2800	2800	2800
Mean of Dep. Var.	-1.65	-1.65	-1.65	-1.65	-1.65	-1.65
Panel B: Weight-for-height Z-score						
Unimodal/bimodal shock in season before child measured	-0.139	0.159	0.003	-0.019	-0.024	-0.124
	(0.098)	(0.193)	(0.088)	(0.151)	(0.076)	(0.131)
Number of unimodal/bimodal shocks, last 10 yrs		0.256**		0.132		0.183**
		(0.109)		(0.080)		(0.079)
Unimodal/bimodal shock in season * Number of unimodal/bimodal shocks, last 10 yrs		-0.078		0.053		0.105**
		(0.092)		(0.052)		(0.045)
Number of Obs.	2795	2795	2795	2795	2795	2795
Mean of Dep. Var.	0.05	0.05	0.05	0.05	0.05	0.05

Dep. var.: Z-score is deviation of child's weight-for-age from the median, divided by the standard deviation of the appropriate sex and age category of the reference population. Sample: individuals aged 0-60 months from farming households. Shocks based on unimodal/bimodal rainfall.
Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile.
Controls for age, sex, survey year, grid cell, birth- and interview month included but not reported.
Standard errors clustered at grid cell level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A5: The effect of rainfall shocks on children's height-for-age and weight-for-height Z-score, number of shocks

	Severe shock		Moderate shock		Mild shock	
Panel A: Height-for-age Z-score						
Shock in season before child measured	-0.021	0.127	0.144	0.012	-0.012	-0.260
	(0.144)	(0.255)	(0.142)	(0.189)	(0.118)	(0.166)
Number of shocks, last 10 yrs		-0.062		-0.037		-0.089
		(0.110)		(0.096)		(0.086)
Shock in season before child measured * Number of shocks, last 10 yrs		-0.161		0.063		0.102*
		(0.107)		(0.085)		(0.060)
Number of Obs.	2800	2800	2800	2800	2800	2800
Mean of Dep. Var.	-1.65	-1.65	-1.65	-1.65	-1.65	-1.65
Panel B: Weight-for-age Z-score						
Shock in season before child measured	-0.082	0.043	0.090	-0.046	-0.031	-0.304**
	(0.128)	(0.270)	(0.117)	(0.170)	(0.091)	(0.138)
Number of shocks, last 10 yrs		0.085		0.046		0.004
		(0.077)		(0.066)		(0.060)
Shock in season before child measured * Number of shocks, last 10 yrs		-0.055		0.100		0.127***
		(0.134)		(0.063)		(0.042)
Number of Obs.	2801	2801	2801	2801	2801	2801
Mean of Dep. Var.	-0.89	-0.89	-0.89	-0.89	-0.89	-0.89
Panel C: Weight-for-height Z-score						
Shock in season before child measured	-0.101	0.063	0.024	-0.016	-0.025	-0.178
	(0.121)	(0.242)	(0.087)	(0.141)	(0.069)	(0.112)
Number of shocks, last 10 yrs		0.203**		0.128*		0.102
		(0.085)		(0.065)		(0.063)
Shock in season before child measured * Number of shocks, last 10 yrs		-0.018		0.078		0.085*
		(0.129)		(0.058)		(0.044)
Number of Obs.	2795	2795	2795	2795	2795	2795
Mean of Dep. Var.	0.05	0.05	0.05	0.05	0.05	0.05

Dep. var.: Z-score is deviation of child's weight-for-age from the median, divided by the standard deviation of the appropriate sex and age category of the reference population. Sample: individuals aged 0-60 months from farming households. Shocks based on 12 month rainfall.
Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile.
Controls for age, sex, survey year, grid cell, birth- and interview month included but not reported.
Standard errors clustered at grid cell level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A6: The effect of unimodal/bimodal rainfall shocks on children's height-for-age and weight-for-height Z-score, years since last shock

	Severe shock	Moderate shock	Mild shock
Panel A: Height-for-age Z-score			
Unimodal/bimodal shock in season before child measured	-0.144	0.304	0.025
	(0.191)	(0.367)	(0.189)
Years since unimodal/bimodal shock	-0.001	0.025	0.003
	(0.015)	(0.022)	(0.022)
Unimodal/bimodal shock in season * Years since unimodal/bimodal shock	0.002	-0.056	-0.004
	(0.032)	(0.071)	(0.036)
Number of Obs.	2800	2800	2800
Mean of Dep. Var.	-1.65	-1.65	-1.65
Panel B: Weight-for-height Z-score			
Unimodal/bimodal shock in season before child measured	-0.441***	0.166	0.105
	(0.127)	(0.217)	(0.127)
Years since unimodal/bimodal shock	-0.030***	-0.023	-0.030**
	(0.010)	(0.018)	(0.015)
Unimodal/bimodal shock in season * Years since unimodal/bimodal shock	0.076***	-0.026	-0.016
	(0.014)	(0.045)	(0.022)
Number of Obs.	2795	2795	2795
Mean of Dep. Var.	0.05	0.05	0.05

Dep. var.: Z-score is deviation of child's weight-for-age from the median, divided by the standard deviation of the appropriate sex and age category of the reference population. Sample: individuals aged 0-60 months from farming households. Shocks based on unimodal/bimodal rainfall.
Severe shock refers to rainfall below the 10th percentile, moderate below the 15th percentile and mild below the 20th percentile.
Controls for age, sex, survey year, grid cell, birth- and interview month included but not reported.
Standard errors clustered at grid cell level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

PAPER 3

Droughts and floods in an imperfect economy: Linking rural households in Malawi

Sofie Waage Skjeflo*†

Abstract

This paper describes the development of a new Social Accounting Matrix (SAM) of six districts in the Central and Southern regions of Malawi, and uses the SAM to investigate the distributional impacts of droughts and floods. The detailed treatment of the agricultural production of six household categories in the SAM, and the partial integration of these households into incomplete rural markets, makes it possible to explore how impacts are distributed across household categories and disseminated through production and consumption linkages. The importance of on-farm consumption of own produce and the use of family-labor in production limits the links between the households in the SAM. I find that a large share of the variation in drought impacts across households is due to differences in the types and varieties of crops grown by households. I also find that floods in the flood-prone Southern region of Malawi may affect households in the Central region through changes in labor and consumption demand from flood-affected households.

Keywords: Social Accounting Matrix, Climate volatility, Agriculture, Malawi

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1 Introduction

The purpose of this paper is twofold. First, to describe the development of a regional social accounting matrix (SAM) of Central and Southern Malawi. Secondly, the SAM is used to investigate distributional impacts of climate shocks on households in the rural economy. There is a large literature on the direct impacts of weather shocks on households in developing countries,[1] but climate variability may also have economy-wide effects, due to the links between sectors and households created by interactions through markets (Subramanian and Sadoulet, 1990; Benson and Clay, 1998; Arndt and Bacou, 2000; Pauw et al., 2011). The extent of, and types of links depend on the particular market characteristics of the economy. This paper builds on previous work on economy-wide models that incorporates market imperfections in developing economies by constructing a SAM of the Central and Southern regions of Malawi, where the economy is characterized by subsistence production, transaction costs related to market participation and a large input subsidy program. Contrary to conventional SAMs, the SAM takes into account the large share of crops produced by households that never reach the market, but are consumed within the household. It also incorporates the use of family labor, and the transaction costs related to buying and selling crops and inputs in the market. Access to fertilizer through the large Farm Input Subsidy Program in Malawi, as well as the informal market for cheap inputs created by leakages from the program, are also integrated into the SAM.

A SAM is a square matrix that represents the transactions in a socio-economic system (Round, 2003). The use of social accounting matrices for development planning was pioneered by Pyatt and Round (1977) and Pyatt and Thorbecke (1976), while Adelman et al. (1988) were the first to use the SAM framework to describe a village economy. SAMs of developing economies have since been developed at various levels of aggregation and for various purposes.[2] Lewis and Thorbecke (1992) develop a regional social accounting matrix of a town and surrounding villages in Kenya to investigate farm – non-farm linkages in the economy. With this motivation, their SAM includes farm activities, rural non-farm activities and urban activities. Their SAM takes into account the value of unsold produce, as well as the value of unpaid family labor. They evaluate the multipliers in the economy under the assumption of excess supply capacity in all sectors, as well as with inelastic agricultural supply. They find that if agricultural supply is constrained, the consumption

[1] See for instance the discussion in Skjeflo and Westberg (2014).

[2] A full review will not be attempted here. Round (2003) summarizes methodological advances of SAMs for developing countries and discusses future challenges.

multiplier effects of farm households are greatly reduced. Providing an example of a national level SAM, Arndt et al. (2000) describe a 1995 SAM of Mozambique which takes into account marketing margins and on-farm consumption of agricultural output, based on national accounts data. A CGE model of Mozambique is calibrated to the same SAM in Arndt and Bacou (2000), and used to assess the economy-wide costs of drought, and the distribution of potential benefits of seasonal weather forecasts. Among the findings is that rural households are severely affected by droughts due to the large share of consumption of home produce. Benson and Clay (1998) investigate economy-wide impacts of droughts in Sub-Saharan Africa by mixing qualitative and quantitative methods. They find that the impacts of droughts were mostly confined to the agricultural sector for largely rural, rain-fed economies, while indirect impacts on non-agricultural sectors contributed to negative impacts on GDP for more advanced economies. As an explanation for these findings, they argue that a high level of self-sufficiency, incomplete and poorly integrated factor and product markets and few forward linkages from the agricultural sector to other sectors limit the economy-wide impacts of droughts for the least developed economies. Their findings thus emphasize the importance of incorporating market characteristics into economy-wide models when assessing impacts of climate variability.

A SAM multiplier model makes it possible to trace direct and indirect impacts of exogenous changes through an economy. The direct effect of a shock (such as a change in government policy, increased export demand or a productivity shock) creates indirect effects through factor and product markets, linking sectors and institutions in the economy. A multiplier model with supply constraints, in line with Subramanian and Sadoulet (1990), is used here to investigate the distributional impacts of fluctuations in agricultural productivity due to climate shocks with a particular focus on how households and markets are linked in a rural economy setting.

I find that transaction costs related to market participation, on-farm consumption of farm output and the use of family labor in production limit the links between households created by factor markets, intermediate demand from production activities and consumption demand. Despite this, labor market and consumption linkages create economy-wide effects of droughts and floods in the rural economy described by the SAM. The variation in the types of crops grown by each household category in the model explains a large share of the variation in drought impact. The household groups in the poorer, more densely populated Southern region of Malawi rely more on local maize varieties that are relatively more vulnerable to drought than improved varieties. Parts of the Southern region are exposed to flooding, and the results show that the households in the Southern region are hardest hit by both droughts and floods. On the other hand, net sellers of crops and suppliers of farm labor in the Central region are affected by floods in the south through decreased demand for crops and labor.

The contribution of the paper is thus first to contribute to improved methods for understanding rural economies where households interact through imperfect markets. Secondly, to increase the understanding of the distributional impacts of current climate variability in order to assess potential effects of increased climate variability in the future. I start by describing and discussing the development of a SAM of the rural economy consisting of farm households in six districts of the Central and Southern regions of Malawi. The study context is described, followed by a detailed description of the data and compilation of each element of the SAM. I then explore the impact of productivity shocks resulting from droughts and floods, with a particular emphasis on the indirect effects created thought links between the household groups.

2 A SAM of Central and Southern Malawi

A social accounting matrix is a square matrix that describes the payment flows in an economy in a given time period, where each cell in the matrix describes a payment from a column account to a row account (Pyatt and Round, 1977). The accounts in a SAM represent production activities, commodities, factors and institutions, and the disaggregation of the accounts depends on the purpose of constructing the SAM. SAMs exist at the global, national, regional and village level, and are used in SAM multiplier analyses and as the basis for Computable General Equilibrium (CGE) models (Round, 2003). According to Round (2003), a SAM should reflect the interdependencies between the agents in the economy by recording actual and imputed flows between them, with a particular focus on factors, households and institutions. This SAM represents rural households from the districts of Thyolo, Chiradzulu, Zomba and Machinga in the Southern region of Malawi and the districts of Lilongwe and Kasungu in the Central region of Malawi,[3] with a total rural population of just over 800 000 households in 2008 (National Statistical Office, 2010).

The SAM has a detailed treatment of agricultural production, with households producing food crops, cash crops, non-crop output (from forestry and livestock activities) as well as engaging in informal business activities and off-farm employment. They use land, labor and capital that they

[3]A map of Malawi showing the districts covered by the SAM is shown in Figure A2.

own, and in addition they buy inputs such as fertilizer and seeds for crop production, and may hire labor and rent in land. Since a large share of the food crops produced by the households is consumed on-farm, and a large share of the inputs used are household inputs, each activity in the SAM is linked to a household group, following the approach in Holden et al. (2005). This makes it possible to distinguish between net sellers and net buyers of each input and crop that is both produced and consumed by each household group. The households are thus treated as producer-consumer units in line with the literature on agricultural households (Singh et al., 1986).

Several attributes of the markets these households engage in are incorporated in the SAM. There are transaction costs related to buying and selling goods, which are shown in the SAM as separate transaction cost accounts. The informal land rental market in Malawi is taken into account by allowing for constrained access to rental land at a low price, which leaves households that rent in land with a profit equal to the difference between the low rental price and the high marginal value of land in production. Households have access to subsidized inputs through the The Farm Input Subsidy Program (FISP) that has been in place in Malawi since 2005. The use of subsidized fertilizer yields a profit equal to the difference between the commercial value of fertilizer and the cost of fertilizer at the subsidized price. Leakages from the FISP has created an informal market for cheap fertilizer (Holden and Lunduka, 2013), and this source of fertilizer is also included in this SAM.

Focusing on an economy consisting of farm households creates both opportunities and challenges. Narrowing down the focus from the national to the regional level allows a much more detailed disaggregation of the economy, with particular focus on the activities that constitute the livelihoods of the rural population of interest. It also makes it feasible to incorporate the particular market characteristics of the economy, as well as more household heterogeneity than in a national SAM. On the other hand, there is a clear trade-off between detail and scope, and the non-farm economy and urban households are not included in the SAM.[4]

2.1 The study context

More than 85 percent of the population in Malawi lives in rural areas and engages in crop production (National Statistical Office, 2012). The population is growing rapidly, and the population density

[4]This is despite the fact that it would be very interesting to investigate the farm non-farm linkages in Malawi, with an urban population growth of about 4 percent per year compared to 3 percent per year for the rural populaiton (World Bank, 2014). SAMs have been used extensively to investigate farm non-farm linkages, one example being Lewis and Thorbecke (1992).

is among the highest in Sub-Saharan Africa (World Bank, 2014). Almost all households cultivate maize for their own consumption, while the most important cash crop is tobacco (World Bank, 2007).

The highest share of poor lives in the Southern region, which on average has smaller plot sizes, higher population density, less engagement in cash crop production and a higher proportion of households reporting problems of food security (National Statistical Office, 2012). One in four rural households are female-headed, and in 2011 the largest share of female-headed households was located in the Southern region (National Statistical Office, 2012). Although female-headed households on average do not have smaller plots than male-headed households, they produce less cash crops, less improved maize varieties and have a higher incidence of poverty (National Statistical Office, 2012). The Southern region primarily follows a matrilineal inheritance system, where land is inherited through the woman's family such that the husband relocates to the wife's village upon marriage, contrary to the patrilineal system that dominates in the Northern region (World Bank, 2007). The Central region contains both patrilineal and matrilineal systems, but the patrilineal system dominates in the two districts covered by the survey used in this SAM (Lunduka, 2009).

Crop production is rain-fed,[5] with a single rainy season between November and April (McSweeney et al., 2010a,b). This leads to a distinct seasonal pattern in time use, labor demand, food stocks and food prices, with peak labor demand and labor shortages in December-January (Wodon and Beegle, 2006).[6] A report by World Bank (2007) shows a seasonal pattern in calories consumed per person per day, with average consumption dropping below 2000 Kcal per person per day in the months preceding harvest. It also demonstrates that poor households tend to buy maize when prices are highest, right before harvest (World Bank, 2007).

Supplying casual labor, or *Ganyu* is a common strategy to earn cash or food when food stocks run out before the next harvest (Whiteside, 2000). The *Ganyu* labor market is characterized by seasonality. Peak labor demand and supply coincide, as the lean season after stocks from the last harvest have been depleted, is also the time for main-season planting (Whiteside, 2000). There is limited access to off-farm labor in the high season, and limited access to off-farm employment in the low season (Wodon and Beegle, 2006). Whiteside (2000) finds that informal labor takes place both on the plots of other smallholders and on estates. He finds that the labor-constraints facing female-headed households limits their ability to participate in the informal rural labor market,

[5]Less than one percent of plots are irrigated (National Statistical Office, 2012).
[6]A seasonal calendar of a typical agricultural year is shown in Figure A1.

particularly far from their own farm, while male farmers may travel across the border to do *Ganyu* work. Traditionally, neighbors and relatives are given preferential treatment in terms of wages or hiring when food or cash is scarce, as it is seen as a moral obligation for better-off farmers to hire worse-off farmers (Whiteside, 2000). *Ganyu* labor is seen as something that is done out of necessity, and increased wages may decrease supply since workers may meet their needs by supplying fewer hours (Whiteside, 2000). The hypothesis of a backward bending labor supply curve is supported by Ricker-Gilbert (2014), who finds that a 1 percent increase in the wage rate decreases the labor supply of households that participate in the labor market, by 0.25 days on average.

The land market in Malawi is very limited, and in some cases traditional authorities may prohibit land sales and land rental (Holden et al., 2006). On average, less than 3 percent of plots are acquired through purchase, while more than 80 percent are inherited (National Statistical Office, 2012). Lunduka et al. (2012) find that there is an emerging land rental market in Malawi, and that this market is more active in patrilineal areas. They also find that poorer households are able to access land through the land rental market, and that the market seems to redistribute land from land-rich to land-poor. Holden et al. (2006) find some evidence of distress land rental by poor households to meet immediate needs for cash, and also that land rental is a way to balance labor/land ratios in the context of imperfect labor markets. However, the market is often influenced by traditional norms for land borrowing that contribute to high transaction costs (Holden et al., 2006).

There are also significant transaction costs related to buying and selling maize, and maize markets are subject to large price volatility (Jayne et al., 2010). The transaction costs arise both due to transportation costs and high risk and costs of storage. They compare sales prices at the farm gate reported by farmers from 42 villages in 7 districts, to the price at the nearest retail market center. There was significant spatial and temporal variation in farm-gate price, with an average ratio of farm-gate to retail price of 0.76. The ratio was higher in more accessible areas than remote areas.

The Farm Input Subsidy Program (FISP) also requires special treatment in the SAM. The FISP is a large scale input subsidy program that has been in place since 2005, distributing vouchers for highly subsidized fertilizer, free improved maize seeds and, in some years, other inputs (Dorward and Chirwa, 2011). The scale and level of the subsidy program have varied over the years, but in 2008/09, vouchers could be exchanged for fertilizer at less than 10 percent of the commercial price of fertilizer, and a full package of inputs consisted of two 50 kg bags of fertilizer and 2 kg of improved maize seeds.[7] Holden and Lunduka (2013) show that households in fact face three different sources of fertilizers. In addition to vouchers distributed through the FISP, a secondary market for cheap fertilizer has developed, where fertilizer could be bought at 45 per cent of the commercial price in 2008/09 (Holden and Lunduka, 2010a). Commercial fertilizer was also available at about 10 000 MWK[8] per 50 kg bag in the 2008/09 season. This is captured in the SAM by differentiating between fertilizer accessed from the three sources.

2.2 Data and representative household categories

The main data source for the SAM is a survey of rural households with detailed plot-level data on farm production during the 2008/09 agricultural season, carried out in June and July 2009. This is the third round in a panel from six districts in Central and Southern regions of Malawi: Lilongwe and Kasungu in the Central region, and Machinga, Chiradzulu, Thyolo and Zomba in the Southern region. The sampling and survey design are described in detail in Lunduka (2009) and Holden and Lunduka (2012), while a map of the sampled districts and sites is provided in Figure A2. The data was supplemented by more detailed data on the subsidy program, collected through a survey of 150 households in Kasungu and Zomba in 2009 and described in Holden and Lunduka (2010b).

Pyatt and Thorbecke (1976) recommend that household categories should be constructed to have as much within-group homogeneity relative to between-group heterogeneity as is feasible and supported by the data (cited in Round (2003)). Taylor and Adelman (1996) emphasize that the categorization of households depends on the purpose of creating the SAM. Holden et al. (1998) categorize the households in their Zambian village based on the level of market orientation, which is defined based on whether the household had access to a bicycle. Holden and Lofgren (2005) argue that oxen ownership is a good wealth indicator in Ethiopia, which also affects participation in land rental markets, and classify households based on the number of oxen they own. Kuiper (2005) focuses on migration in a Chinese village, and categorizes households according to their potential for off-farm income (potential for remittances or migration) and on-farm income (through the ownership of draught power; animal or machine). Kuiper (2005) mentions two important criteria for categorization of households. Households should be classified based on characteristics that are expected to influence their response to policy changes, and the categories should be stable, in the

[7] Initially, improved open-pollinated varieties (OPVs) were the focus of the program, but farmers have preferred hybrid/high yielding varieties (HYVs) when given the choice (Denning et al., 2009), and in 2008/09, 84 percent of the maize seeds distributed through the program were hybrid seeds (Dorward and Chirwa, 2011).

[8] In 2009, 1 USD was about 140 MWK.

sense that households are not expected to move in and out of categories when affected by a policy change.

Households in the Malawi SAM are disaggregated into six household categories, where female-headed households in each region are separate groups, and male-headed households are disaggregated according to land owned per household member. Male-headed households in each region with less than median land per household member are categorized as land-poor, while male-headed households with more than median land per household member are categorized as land-rich.[9] This gives the following six household groups: female-headed, male-headed land-poor, and male-headed land-rich households in the Southern districts; and female-headed, male-headed land-poor and male-headed land-rich households in the Central districts. The largest category is the group of male-headed land-poor households in the Southern districts, and the female-headed categories are the smallest.

Plot- and household level data from 371 households are used in the construction of the SAM, with the following allocation of respondents across the six household categories:

1. Female-headed south (17 per cent of sample)
2. Male land-poor south (24 per cent of sample)
3. Male land-rich south (17 per cent of sample)
4. Female-headed central (7 per cent of sample)
5. Male land-poor central (16 per cent of sample)
6. Male land-rich central (19 per cent of sample)

This categorization of households captures land scarcity when consumption needs and labor scarcity is taken into account (Holden, 2014). The median amount of owned land for the whole sample is at 0.155 hectares per household member. For land available for cultivation (after subtracting/adding rented out/in land) per household member, the median for the whole sample is 0.163 hectares. For either variable, there will be more households in the land-poor category in the Southern region than the Central region. Since land markets are limited, and the labor endowment of the household is fixed in the short run, grouping households based on land owned per household member seems like a relatively stable categorization. It is also important to distinguish between female-headed and male-headed households, since female-headed households may not face the same

[9] The median is calculated across all districts.

opportunities and constraints as male-headed households. For instance, female-headed households are less likely to grow cash crops (National Statistical Office, 2012), they are more labor constrained (Whiteside, 2000), and despite being targeted by the input subsidy program, they are less likely to receive subsidized inputs (Holden and Lunduka, 2013). Finally, the regional disaggregation of households allows us to take into account differential market and institutional characteristics of the Central and Southern regions, for instance differences in land scarcity and access to off-farm employment.

Table 1 shows summary statistics for each household group. The female household heads are on average significantly older and have less schooling than male household heads.[10] Female-headed households are smaller, but there is no significant difference between male-headed and female-headed households in terms of the amount of land owned. Households in the Southern region are on average significantly smaller, and thus have less labor available. On average, they own significantly less land, and have less land per household member. Comparing the male-headed land-rich and land-poor in each region, the land-poor households are larger, have a higher consumer-to-worker ratio and younger household heads in the Southern region. In the Central region, the only significant difference between the land-poor and land-rich categories are in terms of household size, where the land-poor are larger (in addition to the obvious difference in the amount of land owned).

2.3 Separability and estimation of shadow prices

Rural households in developing countries are likely to both supply and demand some of the same goods, for instance food crops and labor/leisure. Under the assumption of perfect markets, production decisions are made separately from consumption decisions, and the agricultural household can be modeled as a profit maximizing producer unit (Singh et al., 1986). Profits from farm production then enter the household's decision making in the budget constraint of the utility maximization problem. Singh et al. (1986) also showed that when one or more markets for goods or factors that the household both demands and supplies fails, household production decisions are no longer independent from consumption decisions. In this case, the relevant price for decision-making in the household is not the exogenous market price, but the endogenous household-specific shadow price that equates household supply and demand of non-traded goods. The price at which a good

[10] Results from t-tests and one-way ANOVA tests comparing means of household groups are available upon request. Any differences reported are at least significant at the 10 percent level.

Table 1: Summary statistics of household categories

	1	2	3	4	5	6	Total
Age of head of household	52.9	40.2	51.9	53.7	42.1	43.2	46.1
	(17.0)	(13.6)	(16.1)	(16.0)	(12.0)	(15.7)	(15.9)
Years of schooling head of household	3.02	6.11	5.40	2.31	5.35	6.25	5.11
	(3.24)	(4.06)	(4.11)	(3.36)	(3.50)	(4.12)	(4.03)
Size of household	4.03	6.06	4.83	5.08	6.21	5.25	5.30
	(1.68)	(1.85)	(2.00)	(2.06)	(2.12)	(1.80)	(2.03)
Male labor units	1.02	1.91	1.76	1.39	1.96	1.75	1.67
	(1.05)	(0.94)	(0.89)	(1.05)	(0.97)	(0.96)	(1.02)
Female labor units	1.39	1.43	1.28	1.51	1.66	1.33	1.42
	(0.55)	(0.78)	(0.65)	(0.90)	(0.83)	(0.69)	(0.73)
Total labor units	2.41	3.33	3.04	2.89	3.62	3.09	3.09
	(1.24)	(1.34)	(1.19)	(1.35)	(1.43)	(1.31)	(1.35)
Consumer to worker ratio	1.31	1.32	1.20	1.30	1.27	1.29	1.28
	(0.35)	(0.23)	(0.17)	(0.26)	(0.15)	(0.20)	(0.24)
Owned land (ha)	0.66	0.51	1.25	1.30	0.60	1.72	0.96
	(0.37)	(0.29)	(0.57)	(1.96)	(0.28)	(1.18)	(0.92)
Owned land per household member (ha)	0.20	0.09	0.27	0.55	0.10	0.34	0.22
	(0.17)	(0.04)	(0.09)	(1.94)	(0.04)	(0.23)	(0.54)
Observations	62	90	65	26	58	70	371

Mean of variable with standard deviation in parentheses. Source: 2008/09 survey data.
1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region
Male labor equivalence definition: Male=1, female=0.8 and child younger than 16=0.5.
Children younger than 8 are not included.

is valued in the SAM thus depends on whether the household is a net buyer, self-sufficient[11] or a net seller (Holden and Lofgren, 2005). Non-traded factors and commodities need to be valued at their shadow price in the SAM (Holden et al., 1998; Holden and Lofgren, 2005; Kuiper, 2005). Another important effect of non-separable production and consumption decisions is that producers and households in the SAM are linked, which creates the need for household group specific activity accounts (Löfgren and Robinson, 1999; Holden and Lofgren, 2005; Kuiper, 2005). In line with Kuiper (2005), I proceed by testing whether production decisions are separable from consumption decisions for the households in the 2009 survey data, following the approach by Benjamin (1992). The approach and results are presented in Appendix B, and show that the hypothesis of separability

[11]Being self-sufficient is here defined as being autarkic, i.e. the household neither buys nor sells the good in question.

is rejected. The production decisions of the households are influenced by their endowments, and potentially non-traded goods must be valued at their household specific shadow price.

2.3.1 Estimation of shadow prices

To estimate the shadow prices of land and household labor, in line with Kuiper (2005) I estimate the an aggregate agricultural Cobb-Douglas revenue function, following Jacoby (1993) and Skoufias (1994).

$$\begin{aligned} logY_h = \alpha_0 + \alpha_1 log\text{Land}_h + \alpha_2 log\text{Hhlab}_h + \alpha_3 log\text{Man}_h \\ + \alpha_5 logT_h + \sum_i \beta_i X_{i,h} + \epsilon_h \end{aligned} \tag{1}$$

where Y_h is the value of agricultural output for household h, valued at farm gate price, Land_h is the amount of land cultivated, measured in hectares, Hhlab_h are hours of household labor used in crop production, Ganyu_h are hours of hired labor used in crop production, Man_h is kg of manure used in crop production and T_h is the monetary value of traded inputs used, namely hired labor, fertilizer, seeds and pesticides. X_{ih} are controls for managerial ability (age and years of schooling completed by head of household), and district dummies to control for district fixed effects. Summary statistics are shown in Table A2. The regression results are presented in Table 2. All input variables have the expected positive sign and are significant in the production function, except for the manure variable, and the control variables have the expected signs. On average, a one percent increase in the amount of land cultivated is associated with a 0.43 percent increase in gross value of output. A one percent increase in household labor input is associated with a 0.19 percent increase in gross output value. The estimated coefficients, $\hat{\alpha}_i$, are used to calculate shadow prices for land and labor, using that the shadow price equals the value of the marginal product of the input.

The shadow price is then calculated as

$$\hat{P}_{ih} = \hat{\alpha}_i \frac{\hat{Y}_h}{N_{ih}} \tag{2}$$

where $\hat{P}_{ih}$ is the estimated shadow price of household h for non-tradable i, N_{ih} is the amount of non-tradable input i used in household h, and $\hat{Y}_h$ is the fitted value of output of household h from the estimated revenue function. The estimated shadow prices by household category are shown in Table 3.

Table 2: Dep. var.: Gross value of output, MWK (log)

	(1)
Log hectares of land used as input in crop production	0.427***
	(0.087)
Log hours of household labor used as input in crop production	0.189***
	(0.056)
Log Kgs of manure used as input in crop production	0.015
	(0.013)
Log value of tradable inputs (MWK)	0.282***
	(0.042)
Age of head of household	0.039***
	(0.014)
Age of head of household squared	-0.0004***
	(0.000)
Years of schooling of head of household	0.050***
	(0.011)
Number of Obs.	367
Mean of Dep. Var.	10.23

Robust standard errors in parentheses. District dummies included but not reported.
*p <0.1, ** p <0.05, *** p <0.01

Table 3: Shadow prices by household category

	1	2	3	4	5	6	Total
Shadow wage	5.0	7.1	6.3	9.4	7.3	13.8	8.7
	(6.1)	(8.8)	(8.2)	(16.3)	(5.5)	(17.8)	(11.3)
Shadow value of land	14 463	23 028	13 445	14 578	20 044	19 541	18 229
	(12348)	(21011)	(8287)	(8607)	(9993)	(10113)	(14049)

1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region
Mean values, with standard deviation in parentheses. Wage per hour and value of land per hectare.
Valued in 2009 MWK.

The shadow value of family labor is expected to be to be higher than the market wage if there are significant supervision costs related to using hired labor, or if there are labor shortages. In Central and Southern Malawi, however, the effects of limited access to off–farm employment and large transaction costs related to off–farm employment seem to dominate. In this case, we expect a lower shadow wage of family labor than the market wage. Another important aspect of the Malawian labor market is the seasonality in labor demand, which is not captured by the data. We do find lower shadow wages for family labor than *Ganyu* labor, with an average shadow wage of about 9 MWK per hour, versus about 35 MWK/hour for *Ganyu* labor.[12] This may also reflect that *Ganyu* labor is employed at highly labor intensive periods of crop production, while family labor is employed the entire year. The shadow wage is significantly higher in the Southern region.[13]

Agricultural land is scarce in Malawi and there are limited land rental and sales activities. As discussed above, the land rental market is largely informal, with some lending out plots to relatives for free, or at low prices. Land is especially scarce in the Southern region. The shadow value of land is therefore expected to be higher than the observed rental prices of land, and relatively higher shadow values in the Southern region. The first hypothesis is supported: the mean shadow value of land almost 20 000 MWK/ha while the mean rental price is about 1000 MWK/ha.[14] There is no statistically significant difference between shadow values of land between the Southern region and the Central region.

2.4 Elements of the SAM

The structure of the SAM is shown in Table 4. Each cell represents a payment from a column account to a row account, such that column sums represent total expenditures, and row totals represent total incomes. As previously discussed, production activities are tied to household groups to capture non-separability between production and consumption decisions, and market imperfections are captured though transaction cost accounts and profit accounts. Consumption of own production is captured by introducing household group specific commodity accounts, in addition to aggregate commodity accounts. In total, the SAM includes 167 accounts which are listed and described in Appendix B. The following sections describe the elements of the SAM and the data behind each element in detail.

[12]Assuming an 8 hour working day. The average daily *Ganyu* wage in the sample is shown in Appendix B.
[13]Results from t-tests comparing means are available upon request.
[14]Farmers were also asked about the price they expected to get if they sold their plot, and the average value is about 47 000 MWK/ha.

Table 4: Structure of SAM

	Household group activities	Household group commodities	Aggregate commodities	Factors	Profits	Savings and investment	Households	Government	Transaction costs	Rest of the world	Total
Household group activities		Output for home consumption	Marketed output								Activity income
Household group commodities	Household specific intermediate inputs						Consumption spending on own output				Total non-marketed demand
Aggregate commodities	Aggregate intermediate inputs					Investment demand	Consumption spending on market commodities		Trade inputs	Export payments	Total market demand
Factors	Household specific factors										Total factor income
Profits	Producer profits										Total profit income
Savings and investments							Savings	Government surplus/deficit		Loans	Total savings
Households				Factor payments to households	Profit payments to households					Remittances	Total household income
Government			Producer taxes and subsidies				Taxes				Government income
Transaction costs			Transaction costs for domestic sales, exports and imports								Transaction cost income
Rest of the world			Imports						Transfer of transaction costs to ROW		Foreign exchange outflow
Total	Total Gross output	Total non-marketed supply	Total marketed supply	Total factor spending	Total profit payments	Total investment spending	Total household spending	Government expenditure	Transaction cost payments	Foreign exchange inflow	

2.4.1 Crop production activities and input markets

Since the SAM represents rural households, it is natural to have a relatively detailed disaggregation of crop production activities. Separate accounts for two types of maize, local maize and improved maize, where the latter category covers improved open-pollinated and hybrid varieties, are included. The rest of the crops grown by households in the survey data are grouped into legumes, tubers, other crops (including other cereals) and tobacco. Harvest from the crop activities is summarized in Table 5. On average, the Central region households grow more improved maize, and in general the maize harvest is larger than for households from the Southern region. Households in the Central region also cultivate significantly more tobacco and legumes than households in the Southern region. Female-headed households on average produce less than male-headed households of all crop categories except local maize. Households in the male-headed land-rich groups produce more of all crop categories, except other crops, and except local maize in the Southern region.[15]

Table 5: Summary statistics of crop harvest (kg)

	1	2	3	4	5	6	Total
Improved maize varieties	105.9	369.9	275.0	456.5	406.0	908.0	422.8
	(167.1)	(456.2)	(441.7)	(538.5)	(482.3)	(1283.5)	(720.9)
Local maize varieties	290.3	278.8	321.0	167.7	182.4	336.5	276.4
	(389.8)	(431.6)	(629.3)	(297.5)	(319.8)	(558.7)	(470.8)
Legumes	71.60	128.0	130.5	253.1	142.1	474.4	195.8
	(94.90)	(260.7)	(251.3)	(505.2)	(196.8)	(557.4)	(360.7)
Tubers	27.37	93.83	129.8	35.77	68.28	176.5	96.60
	(69.19)	(237.6)	(309.2)	(98.31)	(234.5)	(475.7)	(291.6)
Other crops	139.0	279.1	417.5	0	35.86	40.77	176.9
	(562.1)	(774.1)	(880.2)	(0)	(138.8)	(157.2)	(598.9)
Tobacco	25.40	59.44	65.38	67.69	151.7	316.7	118.6
	(96.25)	(138.0)	(183.9)	(168.5)	(378.8)	(470.2)	(296.8)
Observations	62	90	65	26	58	70	371

Mean of variable with standard deviation in parentheses. Source: 2008/09 survey data.
1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region

The survey data also contains data on input use at the plot level, which makes it possible to disaggregate input use to the crop category level by each household group, creating an input-output

[15] Again, any differences reported are statistically significant at least at the 10 per cent level of significance, and test results are available upon request.

table.[16] In the SAM, the crop production activities involve use of fertilizer, seeds, rented in land and hired labor, in addition to on-farm inputs, namely land, labor and capital. Fertilizer used in maize production is disaggregated according to whether the inputs are subsidized, purchased through the informal market, or purchased elsewhere. Since the Farm Input Subsidy Program in 2008/09 included tobacco fertilizer, subsidized fertilizer is also an input in tobacco production in the SAM. Table 6 shows that a larger share of households in the Southern region obtained input coupons through the program, but the amounts of subsidized fertilizer and seeds used do not differ significantly between the regions. This could because input packages were more frequently split between households in the Southern region. Significantly more subsidized tobacco fertilizer is used in the Central region. Female-headed households on average use less subsidized inputs than male-headed households.

Table 6: Summary statistics of subsidized inputs

	1	2	3	4	5	6	Total
Voucher for subsidized fertilizer, dummy variable	0.71	0.79	0.78	0.68	0.65	0.65	0.72
	(0.46)	(0.41)	(0.42)	(0.48)	(0.48)	(0.48)	(0.45)
Quantity of subsidized fertilizer (kg)	35.32	57.06	52.31	39.42	46.81	53.17	48.99
	(30.00)	(47.46)	(56.89)	(34.77)	(82.92)	(101.2)	(66.10)
Quantity of subsidized maize seed (kg)	0.75	1.28	1.29	1.35	0.83	1.27	1.12
	(1.11)	(1.72)	(2.45)	(1.77)	(1.63)	(4.04)	(2.38)
Quantity of subsidized tobacco fertilizer (kg)	3.05	8.19	2.85	1.92	13.25	19.01	8.80
	(10.05)	(19.76)	(11.82)	(9.81)	(39.53)	(49.41)	(29.63)
Bought voucher, dummy variable	0.10	0.19	0.15	0.12	0.04	0.18	0.14
	(0.31)	(0.39)	(0.36)	(0.33)	(0.18)	(0.39)	(0.34)
Amount of fertilizer from informal market (kg)	9.13	16.67	11.54	6.73	2.59	22.54	12.73
	(36.01)	(52.47)	(33.97)	(21.86)	(14.58)	(60.23)	(43.17)
Observations	62	90	65	26	58	70	371

Mean of variable with standard deviation in parentheses. Source: 2008/09 survey data.
1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region

Households may also hire labor and rent in land as inputs in crop production. Table 7 shows the extent to which households in each group participate in the labor market and the land rental market.[17] About 45 per cent of households supplied informal labor over the 12 months preceding the survey, while about 37 percent used one or more days of *Ganyu* labor on their farm. A significantly

[16]Tables of summary statistics by crop category for each household group are omitted here for brevity, but are available upon request.

[17]Only about 6 per cent of households surveyed in 2008/09 report having bought at least one of their plots, and only 4 households report having sold a plot. The land sales market is not included in the SAM.

larger share of households in the Central region supply informal labor, with more than 70 per cent of the households in the male-headed land-poor category supplying *Ganyu*. This could perhaps be explained by the importance of tobacco production in the Central region, both by smallholders and on larger estates (FAO, 2003). According to Whiteside (2000), tobacco estates are the largest estate employers of *Ganyu*. The share supplying labor is lower among female-headed households. This is in line with the finding by Whiteside (2000) that the labor scarcity of female-headed households makes it difficult for them to supply labor off-farm, particularly far from home.

Table 7: Labor market and land rental activities

	1	2	3	4	5	6	Total
Dummy for household supplying ganyu	0.29	0.43	0.31	0.54	0.71	0.52	0.45
	(0.46)	(0.5)	(0.5)	(0.51)	(0.46)	(0.5)	(0.5)
Days engaged in ganyu over past 12 months	9.8	27.5	16.7	54.19	47.48	33.11	28.68
	(40.29)	(71.89)	(36.46)	(118.4)	(67.77)	(73.18)	(67.68)
Dummy variable for using ganyu labor	0.32	0.33	0.49	0.19	0.24	0.51	0.37
	(0.47)	(0.47)	(0.5)	(0.4)	(0.43)	(0.5)	(0.48)
Total days of ganyu labor hired	20.60	12.62	29.15	3.5	4.69	27.51	17.82
	(70.45)	(49.43)	(86.20)	(11.30)	(11.97)	(70.77)	(61.26)
Dummy variable for renting in land	0.13	0.22	0.14	0.19	0.28	0.23	0.2
	(0.34)	(0.42)	(0.35)	(0.4)	(0.45)	(0.42)	(0.4)
Area of rented in plot, hectares	0.32	0.72	0.77	0.41	1.26	1.19	0.81
	(1.25)	(1.85)	(2.62)	(0.91)	(2.59)	(2.76)	(2.21)
Dummy variable for renting out land	0.06	0.06	0.12	0.15	0.07	0.23	0.11
	(0.25)	(0.23)	(0.33)	(0.37)	(0.26)	(0.42)	(0.31)
Area of rented out plot, hectares	0.22	0.12	0.6	0.74	0.17	1.55	0.55
	(0.91)	(0.6)	(2.05)	(3.14)	(0.78)	(3.69)	(2.13)
Observations	62	90	65	26	58	70	371

Mean of variable with standard deviation in parentheses. Source: 2008/09 survey data.
1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region

In the 2008/09 survey, on average about 20 percent report renting in land, while about 11 percent rent out land. The majority of land rental transactions are fixed rent agreements. The rental market seems to be more active in the Central region than in the Southern region, perhaps because of less surplus land in the population dense Southern region. As expected, a smaller share of households in the land-poor household categories rent out land, and a larger share rent in land than the land-rich categories. The lack of balance between the amount of land rented in and the amount rented out in our sample could perhaps be due to households renting in land from outside the smallholder sector. For instance, Holden et al. (2006) report results from informal village surveys in Central and Southern Malawi, and in one group interviewed in Machinga, that the majority report renting in land from neighboring estates.

Since there is little reported use of pesticides, herbicides and manure in the data, these inputs are omitted from the SAM. For simplicity it is assumed that seeds for local varieties are obtained on-farm, while improved seeds are purchased. When balancing the input-output table, the recorded harvest is lower than gross output (value of output at input prices) for the female-headed and the male-headed land-rich households groups in the Southern region, perhaps due to underreporting of green harvest (harvesting of unripe maize) and legume harvest from intercropping. The survey data reveals that intercropping and mixed cropping with both local and improved maize is more common in the Southern region, where almost 50 per cent of households have at least one plot that is mixed or intercropped with local or improved maize. To account for intercropping, it is assumed that local maize activities in the Southern region give the reported maize harvest, plus a legume harvest equal to 10 per cent of the maize harvest. To account for harvesting of green maize (which is not recorded in the data), maize harvest is adjusted upward by 10 per cent for local maize production in both regions.

Use of on-farm inputs in crop production are recorded at the plot level, with man-days of household labor employed and the size of each plot measured by GPS. Since there is no information on the use of capital in production activities in the survey data, I use the shares of value-added to capital in similar production activities from the 2004 SAM of Malawi, described in Thurlow et al. (2008).

The observed prices on subsidized fertilizer and rented in land imply that there is a discrepancy between the shadow value of these commodities and their market price. This discrepancy means that households that receive subsidized fertilizer and rent in land derive profits. In line with Kuiper (2005), this is dealt with by using special profit accounts to take into account the difference between the value of the input in production and the market price. Similarly, for households that rent in land, the difference between the low rental price and the high shadow value of this land is returned as profits. In the SAM, household specific land rental activities and subsidy activities are introduced, where the activity pays returns to an aggregate commodity (the aggregate land commodity and subsidized input commodities), but also to a profit account. The output of the land rental and subsidy activities are then used at inputs in crop production.

2.4.2 Non-crop activities

The main income source for all household categories is crop production activities, but the survey data reveals that households also engage in livestock-, forestry- and informal business activities, in addition to formal and informal off-farm employment, and renting out land. The supply of informal labor and land rental activities are described above and shown in Table 7. The remaining activities are grouped into household group specific non-crop activities (forest and livestock activities) and business activities (including formal off-farm employment).

The forest and livestock activities are assumed to take place on communal land and forest areas not owned by the household. The inputs into these activities are therefore mainly household labor and capital (for the livestock activity). The survey contains information on the value of livestock[18] and forest activities undertaken by the household, and I assume that all value-added from the forest activity is to labor, while 25 per cent of return from the livestock activity is to labor and the rest to capital. About 75 per cent of households derive some income from livestock. In the survey, households are specifically asked about home consumption of livestock products and forest harvest, and the value of this consumption. Almost all households have some home consumption of forest products, while few sell forest products. I assume that the marketed surplus from livestock and forestry activities is exported, so the households are either net sellers or self-sufficient in these products.[19]

The business activities include household enterprises and formal labor activities. The survey includes data on investments, average monthly profits and duration of operation for household enterprises.[20] Table 8 shows that a smaller share of female-headed than male-headed households engage in business activities and derive income from formal labor. The share of households with formal labor income is significantly higher in the Central region, and higher among households in the land-poor categories.

In the SAM, I have assumed that household labor is used as input in the business activity. Labor input is calculated by assuming that all time spent on "other non-agricultural activities" by

[18] The survey only contains information on livestock sales and consumption on-farm, and no other livestock products such as milk or eggs.

[19] I thus implicitly assume that any forest and livestock products purchased by the households have been processed outside the SAM and are imported.

[20] Unfortunately, this data is only collected for enterprises that were active over the past month at the time of the survey, but it is assumed that the data is representative for activities throughout the year

households that engaged in business activities, is used as input into this activity for the duration of the business enterprise. The operating costs are assumed to be expenditure on the imported goods,[21] and investments are paid from the household specific capital accounts.

Table 8: Non-crop activities

	1	2	3	4	5	6	Total
Value of livestock sold (MWK)	12105.6	11835.8	8147.1	2780.8	5096.6	14547.2	10075.5
	(49762.7)	(39114.6)	(20812.8)	(7223.4)	(13035.1)	(47700.9)	(36393.5)
Value of livestock consumed (MWK)	4058.7	3086.7	6208.5	2826.9	4971.6	9402.8	5272.1
	(8871.5)	(5623.2)	(11987.3)	(3481.2)	(16501.8)	(22116.8)	(13610.1)
Value of forest products sold (MWK)	15.87	166.7	291.5	11.54	262.1	48.59	144.5
	(126.0)	(1060.0)	(966.4)	(43.15)	(1368.9)	(259.0)	(862.5)
Value of forest products consumed (MWK)	930.6	1437.8	907.4	450.8	731.6	1648.3	1121.2
	(2822.7)	(3702.0)	(2322.7)	(1184.5)	(1433.2)	(4259.4)	(3082.9)
Engaged in business activity, dummy var.	0.190	0.411	0.385	0.231	0.345	0.338	0.332
	(0.396)	(0.559)	(0.550)	(0.430)	(0.479)	(0.476)	(0.499)
Engaged in formal labor, dummy var.	0.07	0.17	0.08	0.12	0.28	0.14	0.14
	(0.25)	(0.38)	(0.27)	(0.33)	(0.45)	(0.35)	(0.35)
Observations	62	90	65	26	58	70	371

Mean of variable with standard deviation in parentheses. Source: 2008/09 survey data.
1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region

2.4.3 Household Income and Expenditures

The household categories in the SAM earn income from the returns to the factors that they own, namely labor, land and capital, through their use in the production activities described above. In addition, they receive remittances or transfers from households outside the SAM and may earn profits from some of the production activities, as previously discussed. The survey data contains information on the value of gifts, either cash, food or other in-kind gifts, received from people outside the household. Unfortunately, there is no information on where the transfers were received from. As a simplification, I assume that all transfers are received from outside the SAM (e.g. remittances from migrated household members).

Consumption of own farm output is an important component of household consumption. As an indicator of the amount of consumption of own produce, the amount sold is subtracted from the amount harvested of each crop for each household group. This is likely to be an overestimate of consumption, since it does not account for storage loss, but it provides a basis for the amount

[21] Some inputs could in fact be locally available, for instance for food processing businesses, but due to lack of data I cannot differentiate between imported and locally available inputs.

of consumption of own produce in the SAM. Expenditure data for food and non–food items with one month recall is recorded in June or July, which is during or just after the main harvest. It is therefore likely that the data underestimates food purchases, and overestimates purchases of other goods and "luxury goods". Table 9 shows summary statistics of household expenditures,[22] excluding consumption of own produce.

Table 9: Household annual expenditures on purchased goods

	1	2	3	4	5	6	Total
Maize	6723.8	6504	2593.8	46.15	3869.0	3380.3	4405.3
	(41677.8)	(22499.4)	(15641.5)	(235.3)	(23759.9)	(23143.3)	(25379.6)
Legumes	910.5	748	1162.2	87.69	1063.4	211.3	748.5
	(2409.4)	(1510.0)	(3076.6)	(310.3)	(4315.4)	(934.3)	(2510.2)
Tubers	133.3	460	101.5	221.5	221.4	375.2	272.5
	(340.2)	(1260.1)	(361.4)	(506.5)	(515.4)	(1161.7)	(867.8)
Other crops	722.9	1030	2822.8	1615.4	887.6	1935.9	1481.6
	(1202.6)	(2643.3)	(11905.8)	(4946.4)	(1369.5)	(6503.9)	(6062.0)
Imported foods	3752	6971.3	6604.6	8670	5489.0	10615.8	6945.3
	(4244.6)	(9425.0)	(6268.4)	(16041.3)	(5393.4)	(12963.0)	(9446.9)
Non-food expenditures	9630.3	14997.3	18493.8	9438.5	14748.4	17469.3	14744.5
	(18453.7)	(19015.6)	(31973.3)	(10294.3)	(15150.1)	(22915.8)	(21691.9)
Total expenditures	21872.8	30710.7	31778.8	20079.2	26278.8	33987.7	28597.6
	(47415.2)	(34821.0)	(42162.3)	(21912.8)	(29932.4)	(47185.3)	(39762.9)
Observations	62	90	65	26	58	70	371

Mean of variable with standard deviation in parentheses. Source: 2008/09 survey data.
1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region

To remedy some of the weaknesses in the consumption data, I use expenditure shares based on the consumption data from the Second Integrated Household survey, described in National Statistical Office (2005), and expenditure shares for food categories described in Ecker and Qaim (2011) to adjust the expenditures of the household categories in the SAM. I also use information on total annual maize consumption and production from the survey to impute total annual maize purchases. Summary statistics in Table 10 show the distribution of net sellers and net buyers of maize across household groups based on this information. The only group of households that on average were net sellers in the 2008/09 season is the land-rich households in the Central region. The

[22]Monthly expenditures multiplied by 12.

indicator for trade position takes the value 1 for net seller, 2 for self-sufficient and 3 for net buyers. As expected, there is a larger share of net buyers among female-headed households and land-poor households, while the land-rich in the Central region have a mean value below 2, indicating a large share of net sellers. About half of the surveyed households sell at least some of their output in the market, as shown by the summary statistics of the dummy variable for selling maize. This is slightly lower than the estimate in World Bank (2007) at 54 per cent at the national level, based on data from the Second Integrated Household survey from 2004/5. Fewer female-headed households sell maize, but there are no significant differences between the remaining household categories.

Table 10: Distribution of net sellers and buyers of maize

	1	2	3	4	5	6	Total
Maize produced (kg)	386.9	636.6	732.1	339.5	536.3	1034.1	651.3
	(321.2)	(561.9)	(895.6)	(196.0)	(414.1)	(818.4)	(652.4)
Maize consumed (kg)	744.2	680.6	821.8	832	776.3	903.1	781.0
	(1197.8)	(346.5)	(829.7)	(805.2)	(493.6)	(513.2)	(697.9)
Net maize sales (kg)	-355.2	-46.40	-94.20	-486.3	-236.4	134.6	-128.5
	(1088.3)	(494.6)	(942.4)	(868.3)	(535.3)	(678.0)	(770.2)
Trade position indicator	2.66	2.26	2.33	2.68	2.43	1.98	2.34
	(0.71)	(0.89)	(0.85)	(0.75)	(0.84)	(0.91)	(0.87)
Sells maize, dummy var.	0.37	0.54	0.52	0.31	0.5	0.61	0.5
	(0.49)	(0.5)	(0.5)	(0.47)	(0.5)	(0.49)	(0.5)
Observations	62	90	65	26	58	70	371

Mean of variable with standard deviation in parentheses. Source: 2008/09 survey data.
1: female-headed , 2: male-headed land-poor, 3: male-headed land-rich Southern region
4: female-headed , 5: male-headed land-poor, 6: male-headed land-rich Central region

Households also pay taxes and save in the SAM. I use tax rates from a 2007 SAM of Malawi, described in Douillet et al. (2012), where the rural households in the 4th and 5th income quintiles pay direct taxes to the government, at rates of 0.3 per cent and 4.2 per cent, respectively. Since our SAM includes more informal income, I apply the lowest tax rate to the land-rich households in both regions. The survey data on net purchases of assets and livestock is used to impute savings rates for each household category.

In addition to consumption goods, the household groups also demand leisure. The consumption of leisure is based on the time use data in the 2008/09 survey, as well as the detailed survey of time use in Holden (1993). In line with Holden et al. (1998), household labor and the demand for leisure is valued at the household group specific shadow wage for households that do not participate in the labor market.

2.4.4 Government, transaction costs and the rest of the world

Regional or village SAMs differ from national SAMs in their treatment of imports, exports and the exchange rate. There is no separate currency, and the "rest of the world" with which the regional economy trades refers to all areas and sectors not captured by the SAM (Taylor and Adelman, 1996), in this case both in Malawi and abroad. This means that exports from the SAM should not be interpreted as exports in the traditional sense, it could also refer to demand from a sector outside the SAM, but in the same geographical area. The government account does not refer to the national government of Malawi, but rather the government activities that take place within the economy captured by the SAM. There is no available data on local government activities in the survey. It is therefore assumed that the only activity undertaken by the government in the SAM, in addition to collecting income taxes, is to subsidize inputs through the input subsidy program.

Transaction costs are captured through three accounts in the SAM: the export transaction costs account, the import transaction costs account and the domestic transaction costs account. For each good that is traded domestically, exported or imported, the difference between the purchase price and the sales price of the good is paid to the appropriate account. For instance, when a household sells maize, the difference between the farm gate price and the market price of maize is the transaction cost. When a good is imported, the transaction cost is the difference between the lower "international" price and the higher price of the imported good when bought domestically. For exported goods, the transaction cost is the difference between the lower price the exporter receives, and the higher price at which the good is sold abroad. The difference between the farm gate price recorded in the survey and retail prices from Ministry of Agriculture and Food Security (MoAFS) data is used as an indicator of transaction costs. Jayne et al. (2010) compare retail prices from MoAFS with farm gate prices obtained from focus groups in 2008 and 2009. The marketing margins they find are used as controls for the marketing margins used in this SAM.[23] The same marketing margins are assumed for goods that are exported and imported to the SAM economy.[24] The payment to transaction cost accounts is assumed to be returned to traders outside the SAM,

[23]For the non-crop commodity, for which I do not have prices, I use the same ratio of farm gate to retail price as for tobacco, which has the lowest marketing margin.

[24]For goods that are exported, I use the same transaction costs as for domestic trade (implicitly assuming that the ROW retail price is the same as the domestic retail price). For goods that are only imported, I assume that the import transaction cost is the difference between the retail price at which the imported good is bought and the farm gate price.

since our sample only includes rural households that do no report trading as an important activity.

2.5 Balancing and aggregation

The column sums and row sums of the SAM must be equal, meaning that expenditures equal incomes for every account. Balancing of the SAM to ensure that this holds takes place both before and after aggregation. The survey data is disaggregated to the household group level, and used to create separate tables that in the end are combined as the complete SAM. Each of these sub-tables is balanced before aggregation. For instance, the input-output table is balanced to make gross activity outputs from crop activities match the value of reported harvest, as discussed above. I assume that the harvest data is more reliable than the input data, because the input data is recorded at the plot level rather than the crop level. The SAM does not take into account inter-cropping and mixed cropping systems, but rather assumes that all inputs used on a plot are used as input into the primary crop planted. This creates imbalances that are particularly evident in the maize cropping activity input levels. All adjustments are made so that the relative differences between the household groups are maintained.

The SAM is a snapshot of an entire agricultural year, and does not capture seasonality. This means that any "cross trade" within the year is netted out to represent the average trade position of the household group.[25] For instance, 13 per cent of the households in the 2008/09 survey report both hiring and supplying *Ganyu* over the past 12 months, and poor households may sell maize right after harvest, when prices are low, to obtain cash, but then rely on purchasing maize before the next harvest, when maize stocks have run out and prices are higher (World Bank, 2007). This type of cross trade is eliminated by subtracting the quantity sold from the quantity purchased, revealing the household as a net seller, net buyer or self-sufficient of each good. This balancing is not trivial, as it removes any heterogeneity in trade positions within the household category.

Because of the poor quality of the consumption expenditure data, I choose to adjust this data rather than the income data to balance income and expenditures at the household group level. After all other adjustments are made, expenditures are still high compared to incomes for all household groups. Since the expenditure data was collected just after harvest, a downward adjustment of non-food expenditure seems reasonable, and is here used to balance the data rather than an ad-hoc downward adjustment before balancing.

[25] The same holds for the trade position of the entire economy relative to the outside world.

The basic approach to creating the SAM is to multiply average values for each household group in the data by the number of households in each group. National Statistical Office (2010) contains data on the number of households at the district level. From this data, I use the shares of households in each category (1-3 in each of the Southern districts, and 4-6 in the two Central districts) to allocate the households in each of the sampled districts to a household category. This is based on the assumption that our sample is representative at the district level.

2.6 Stuctural characteristics of the economy

Aggregate production (valued in 2009 Malawi Kwacha) and net sales/purchases are described in Table 11.

Table 11: Aggregate production and trade flows in SAM (million MWK)

	Southern districts	Central districts	Total
Number of households	456 357	395 747	852 104
Production			
Local maize	5 154	2 905	8 059
Improved maize	4 465	7 405	11 870
Total maize	9 619	10 310	19 930
Legumes	1 131	3 607	4 738
Tubers	836	557	1 393
Other crops	2 693	343	3 035
Tobacco	2 354	7 003	9 357
Non-crop	4 892	4 757	9 649
Total agriculture	21 524	26 577	48 101
Business	4 929	4 127	9 056
Total	26 454	30 704	57 157
Net sales (purchases)			
Maize	-1 586	-132	-1 719
Legumes	-164	458	294
Tubers	-28	181	153
Other crops	346	-741	-395
Tobacco	2 354	7 003	9 357
Non-crop	3 636	3 526	7 162
Business	4 929	4 127	9 056
Labor	150	966	1 116
Rental land	-270	-315	-586

Source: 2008/09 Regional Malawi SAM.

The less populous districts in the Central region produce more improved maize, more legumes and more tobacco. The districts in the Southern region produce more local maize, tubers, and other crops (such as rice, sorghum and millet). Part of the net sales of legumes and tubers from the Central region flow to the Southern region, while crops in the "other crops" category flow in the opposite direction. The economy described by the SAM is a net importer of maize, other crops, rental land, seeds and fertilizer, as well as agricultural and non-agricultural goods that are not produced domestically. The economy exports tobacco, legumes, tubers, output from livestock and forestry activities, informal business output, as well as labor. The labor exports could be interpreted as demand for labor from large-scale farms or sectors that are not captured by the SAM, and not necassarily as long distance labor migration.[26] The land "imports" similarly have to be interpreted as renting in land from larger farms or estates that were not covered by the survey.[27]

Table 12 shows the production activities and trade flows of the household categories in the SAM.

The male-headed land-rich household category in the Central region stands out as a major producer of improved maize, legumes, tobacco and livestock and forestry output. The group sells maize, legumes and tubers, in addition to non-crop and business output, and is a major tobacco supplier for export. The group is self-sufficient in land and labor, but buys some food crops in the "other crops" category, in addition to imported agricultural and non-agricultural goods. The rest of the household categories are net buyers of maize, in addition to the maize they produce and consume on their own farm. The female-headed group in the Central region is a net seller of legumes, and both male-headed categories in the Southern region sell "other crops", but they are either self-sufficient or net buyers of all other food. All tobacco, non-crop, and business output is sold, and provides household groups with cash to buy food and other consumption goods. In addition, the male-headed land-poor in both the Southern and Central region and the female-headed in the Central region are net suppliers of informal farm labor (*Ganyu*). The labor-constrained, but land-rich male-headed group in the Southern region rent in labor, while both land-poor categories rent in land.

Table 13 shows the composition of supply and demand for the production activities in the SAM, and reveals that a large share of demand is for home consumption, and that transaction costs constitute a large share of supply for traded goods.

The share of transaction costs in total supply is particularly large for sectors where a large share of production is traded, like tobacco, which is a pure export crop in the SAM. 86 per cent of the

[26]Unfortunately, the survey respondents were not asked about where they worked, only how much they worked and the pay they received.

[27]The literature on the emerging land rental markets in Malawi is limited, and the survey respondents were not asked about sources or destinations of their land market transactions. Holden et al. (2006) find some evidence of land being rented in from neighboring estates.

Table 12: Household production and trade flows in SAM (million MWK)

	South			Central		
	Female-headed	Male land-poor	Male land-rich	Female-headed	Male land-poor	Male land-rich
Number of households	120 073	192 778	135 506	59 875	166 616	169 256
Production						
Local maize	1 575	1 426	2 154	284	1 005	1 616
Improved maize	699	2 449	1 317	899	2 053	4 453
Total maize	2 274	3 874	3 471	1 183	3 058	6 069
Legumes	248	464	419	370	721	2 516
Tubers	104	252	480	54	135	369
Other crops	157	826	1 710	0	140	203
Tobacco	321	1 183	850	369	2 365	4 269
Non-crop	1 823	1 490	1 579	284	1 171	3 301
Total agriculture	4 927	8 089	8 508	2 260	7 589	16 728
Business	0	2 390	2 539	202	974	2 951
Total	4 927	10 479	11 047	2 462	8 563	19 679
Net sales (purchases)						
Maize	-1 048	-228	-310	-301	-847	1 016
Legumes	-118	0	-46	198	-19	279
Tubers	-17	-10	0	-23	0	203
Other crops	0	222	125	-46	-211	-484
Tobacco	321	1 183	850	369	2 365	4 269
Non-crop	1 550	981	1 104	166	849	2 510
Business	0	2 390	2 539	202	974	2 951
Labor	0	279	-129	288	677	0
Land	0	-270	0	-113	0	0

Source: 2008/09 Regional Malawi SAM.

Table 13: Shares of sectoral supply and demand

	Maize	Tobacco	Rest of crops	Non-crops and business	All sectors
	Shares of sectoral supply				
Domestic production	92.37	69.96	92.68	92.02	87.71
Transaction costs	4.80	30.04	6.47	7.98	11.25
Imports	2.84	0.00	0.85	0.00	1.04
Total sectoral supply	100.00	100.00	100.00	100.00	100.00
	Shares of sectoral demand				
On-farm consumption	86.02	0.00	71.92	12.24	44.12
Domestic market consumption	12.58	0.00	14.44	0.00	6.65
Exports	0.00	100.00	7.02	87.76	47.53
Intermediate consumption	1.41	0.00	6.62	0.00	1.70
Total sectoral demand	100.00	100.00	100.00	100.00	100.00

Source: 2008/09 Regional Malawi SAM.

maize produced in the SAM is consumed on-farm. However, as discussed above, the inability of the SAM to capture seasonality may exaggerate this share, since some households may participate in the market both as sellers and buyers, but are self-sufficient or net buyers in the SAM. On-farm consumption is also important for the rest of the food crops in the SAM, while the non-crops and business category is mainly exported.[28]

3 Application: Economy-wide effects of droughts and floods

The SAM provides a detailed description of the sectoral composition and composition of demand in the rural economy, but it can also be used as a simple linear model of the economy. In this section, I use the SAM of the Central and Southern regions of Malawi as a basis for SAM multiplier analysis to investigate the economy-wide effects of droughts and floods.

3.1 Methodology: SAM multiplier analysis

Following Pyatt and Round (1979) and Lewis and Thorbecke (1992), the first step to constructing a SAM multiplier model is to categorize the accounts in the SAM as endogenous or exogenous. In the Malawi SAM, the Government, Savings-investment and Rest of the world accounts are classified as exogenous, since government spending, investment demand and export demand are not expected to change in response to changes in income within the rural economy.

The SAM can then be represented as a matrix of endogenous and exogenous income flows, as shown in Table 14. N is an $n \times n$ matrix of payments from endogenous to endogenous accounts, L

[28] This is largely due to the lack of data on sources and destinations of output for these activities.

Table 14: Partition of SAM into endogenous and exogenous accounts

	Expenditures		
Receipts	Endogenous accounts	Exogenous accounts	Totals
Endogenous accounts	N	X	y_n
Exogenous accounts	L	R	y_x
Totals	y'_n	y'_x	

is an $x \times n$ matrix of "leakages": payments from endogenous accounts to exogenous accounts. X is an $x \times n$ matrix of payment flows, or injections, from exogenous accounts to endogenous accounts, and R is and $x \times x$ matrix of transfers between exogenous accounts. y'_n is a row vector of total endogenous expenditures, and y'_x is a row vector of total exogenous expenditures. Dividing each element in the N matrix by the column total gives the matrix of average expenditure shares, A_n, where

$$A_n = N y_n'^{-1} \tag{3}$$

since $y'_n = y_n$ (column and row totals are equal), we have that

$$N = A_n y'_n = A_n y_n \tag{4}$$

and since $y_n = N + X$, we have that

$$y_n = A_n y_n + X \tag{5}$$

or

$$y_n = (I - A_n)^{-1} X = M_a X \tag{6}$$

M_a is called the accounting multiplier matrix (Pyatt and Round, 1979), and equation 6 shows that given a change in exogenous payments to endogenous accounts (e.g. increased export demand or remittances to households), the effect on endogenous incomes, y_n depends on the multiplier matrix. The underlying assumptions of this simple model are that any increase in demand is met by a corresponding increase in supply (i.e. there are no supply constraints, and prices are fixed), and that average expenditure shares equal marginal expenditure shares. As an example, consider an increase in export demand. Since we assume excess supply capacity, this would increase supply in export sectors, and increase demand for intermediate inputs, value-added to factors and transaction costs by fixed shares. The corresponding increase in household incomes (depending on factor ownership) would lead to an increase in consumption demand by fixed shares (the average expenditure shares from A_n.) This implies that the income and expenditure elasticities of households are equal to one for all goods (Pyatt and Round, 1979). One remedy to this problem is to replace average expenditure shares by estimated marginal expenditure shares where it is unreasonable to assume that these are the same, giving the "fixed price multiplier matrix" (Pyatt and Round, 1979). The survey data from 2008/09 is used to estimate household consumption expenditure elasticities for the commodity groups in the SAM. As expected, these elasticities are generally less than one for the food crops, but greater than one for imported foods and non-agricultural goods.[29] The marginal expenditure propensity is calculated as the average expenditure propensity times the expenditure elasticity (Subramanian and Sadoulet, 1990), and replaces the average expenditure propensities for the household groups in the accounting multiplier matrix. The remaining expenditure shares are unchanged, with the implicit assumptions of fixed factor income shares to households and fixed commodity supply shares from activities and imports (Subramanian and Sadoulet, 1990). Payment shares from production activities to intermediate inputs and factors are also fixed, implying Leontief production technologies (Pyatt and Round, 1979).

However, the problem of assuming that any change in demand can be met by a corresponding change in supply remains. In the context of the Malawi SAM, this seems like a particularly problematic assumption when it comes to crop production. Given limited access to land, it does not seem likely that supply from the agricultural sector is perfectly elastic. As in Subramanian and Sadoulet (1990), I therefore assume that crop production in the short run is determined by supply side factors such as the weather. However, demand is still assumed to be endogenously determined, and the export (imports) of food crops serves to balance total supply and demand when there are exogenous supply changes in agricultural output (Subramanian and Sadoulet, 1990).[30]

3.2 Climate risk in Malawi

The mixed multiplier model with exogenous agricultural supply makes it possible to investigate direct and indirect impacts of weather induced changes in agricultural supply within the rural economy captured by the SAM. This is particularly relevant in the Malawian context, where the majority of the population relies on rain-fed agriculture, and the impact of weather fluctuations on agricultural output has been an important contribution to volatile economic growth (World Bank,

[29] Expenditure elasticities were estimated following the approach by Massell (1969). The results are available upon request.

[30] The multiplier model with mixed endogenous and exogenous sectors is derived in Subramanian and Sadoulet (1990).

2007). The rainy season in Malawi depends on the Inter-tropical Convergence Zone (ITCZ) and the El Niño Southern Oscillation (ENSO), as well as local topography, which makes it difficult to identify trends and project future trends in rainfall (McSweeney et al., 2010a,b). There is significant local and inter-annual variation, but rains usually last from November to February in the South, but may last until March or April further north (McSweeney et al., 2010a,b). The summary of climate projections based on Global Climate Models in McSweeney et al. (2010a,b) indicates an increase in temperature and frequency of high temperatures, and increased frequency and severity of heavy precipitation events in the rainy season.

Pauw et al. (2011) identify drought events in Malawi based on historical rainfall data from 45 weather stations, and define a drought as a period with less than 75 per cent of average rainfall at the weather station, adjusting for the timing of the drought relative to the growing season of important crops. The further below this threshold the rainfall, the more severe the drought. Based on the historical precipitation data, they estimate a rainfall probability distribution that is used to calculate the probability of drought events of varying severity. It follows that the severity of a drought and the likelihood of such a drought occurring are inversely related, and return periods (RPs) are used to classify the events. The return period of an extreme event is defined as "the expected length of time between the reoccurrence of two events with similar characteristics" (Pauw et al., 2011, p 178), meaning that an RP20 event on average occurs every 20 years, and thus has a 5 percent probability of occurring in any given year. Droughts with a higher return period are thus more severe. Crop losses under droughts of various severity for local, high-yielding and composite maize varieties, where composite varieties include open-pollinated drought resistant varieties, and tobacco are estimated by defining crop losses as the difference between yields in the closest non-drought year and the drought year. Pauw et al. (2011) also estimate the correlation between maize production losses and crop loss in other major crops during drought events. Their findings indicate that improved open-pollinated varieties (OPVs)[31] have an advantage over both hybrid and local varieties, with about 80, 25 and 16 percent losses under an RP 25 drought, respectively.

The estimated crop production losses from Pauw et al. (2011) are used to indicate supply losses during droughts in the mixed multiplier model based on the SAM. Since the production activity for improved maize in the SAM includes both improved OPVs and hybrid varieties, the yield losses for improved maize are weighted by the share of households that report using each variety. The survey

[31] Termed Composite varieties in their paper

Table 15: Percent loss in crop production due to extreme events

Crop	Severity measured by return period (RP)		
Drought	RP 10	RP 15	RP 25
Local maize	28	58	80
Improved maize (HYV and OPV)*	9.3	11.6	24.2
Legumes	5	10	15
Tubers	3	7	10
Other crops	7	14	22
Tobacco	5	6	7
Floods	RP5	RP10	RP20
All crops except tobacco	25	37	48.5
Tobacco	22.5	28.8	36.4

Source: Own calculations based on Pauw et al. (2011).
RP is defined as the expected length of time between each time an event with similar severity occurs, and is inversely related to its severity.
*Average across household categories

data from 2008/09 shows that hybrid varieties dominate, as on average 92 percent of households that grow improved maize varieties report growing HYVs. The share growing OPVs is higher among the female-headed and male-headed land-rich in the Central region (16 and 14 percent of those growing improved varieties, respectively).

Similarly, Pauw et al. (2011) define flood events and their probability of occurrence based on observed flood discharges in the flood-prone Shire river basin in the Southern region of Malawi. Production losses to tobacco and maize due to flooding are estimated in a stochastic flood model based on regression analysis of observed floods and historical production data, taking into account the share of cropped areas in the region that are likely to be affected.[32] The same crop losses are used to simulate production losses due to floods for the crop production activities that take place in the Southern region in the SAM.[33] In line with Pauw et al. (2011), crop losses for legumes, tubers and other crops are assumed to be the same as for maize, due to the lack of better information.

The assumed crop losses under droughts and floods of varying severity are shown in Table 15. Note that the simulated drought losses to improved maize vary somewhat across household groups due to the variation in improved maize varieties grown across the groups.

[32]Crop losses are estimated for all maize together, as the maize varieties do not differ in sensitivity to flooding.
[33]It is thus assumed that the production losses apply to the districts covered by the SAM. The estimated production losses in Pauw et al. (2011) apply to the Southern region as a whole.

3.3 Results

3.3.1 A 10 percent decrease in crop production

To illustrate the linkage effects between household categories in the SAM, I simulate a 10 percent decrease in all crop production. The results for household incomes and total production are shown in the first column of Table 16. The effect of the shock is transmitted through production and consumption linkages created by changes in intermediate- and factor demand, and changes in household income. The use of all intermediate inputs and factors in agriculture decreases, and the decrease in factor incomes depends on how much of the factor is used in crop production sectors. The return to land decreases by 10 per cent, since land is only used in crop production. Decreased demand for intermediate inputs that are imported (such as fertilizer and seeds) does not create any further linkages to the rest of the economy - the effect is "leaked" to the outside economy. An exception is the use of subsidized inputs, which generates a profit for households that use them, and similarly, the use of rented in land. Decreased use of these inputs affects household income through reduced profits.

The male-headed land-rich group in the Southern districts hires labor for crop production, and reduced demand for farm labor has a negative impact on all households that supply *Ganyu*. This affects the two male-headed land-poor household groups and the female-headed group in the Central districts. How much the income of each household category is reduced depends on the importance of crop production in their income, as well as the additional effects through reduced labor demand. Not surprisingly, the largest absolute income decrease is for the male-headed land-rich group in the Central districts. The smallest absolute income decrease is for the female-headed groups, but the proportional income decrease is similar across groups, ranging from 5.2 per cent decrease for the female-headed in the Southern districts, to 7.6 per cent decrease for the male-headed land-rich in the Central districts. Household consumption of crops does not decrease as much as the production decreases, but is met by increased imports. Decreased demand for imported consumption goods does not create further multiplier effects (import leakage), but decreased demand for non-crop output (livestock and forestry output) creates further production and consumption multiplier effects. After taking into account all multiplier effects, total production in the SAM decreases by 7.2 per cent.

The size and number of linkage effects through factor markets, consumption demand and intermediate demand are reduced compared to a situation without home consumption and transaction costs. The size of linkages is reduced because of leakage through transaction costs, while the number of links is reduced because a number of household groups do not participate in the local markets.

3.3.2 Drought and flood scenarios by Return Period

Next, I show the results from simulating an RP15 drought in the second and third columns of Table 16. The same linkage effects hold as in the previous simulation, but the size of impact varies depending on the drought sensitivity of the crops produced by each household category. The largest relative income decrease due to the drought is for the three household categories in the Southern region, which is because of the importance of the more drought-sensitive local variety for these households. For the households in the Central region, the female-headed and land-poor groups are hit harder than the land-rich, because of the importance of maize production for their incomes. The male-headed land-rich household group in this region has a more diversified income portfolio, deriving a significant share of income from tobacco production, which is less drought-sensitive, and forestry- and livestock activities. However, consumption linkages lead to reduced demand for maize, legumes and tubers sold by this group, adding to the initial drought impact.[34] This also holds for the legume sales of the female-headed category in the same region and sales of "other crops" for the male-headed categories in the Southern region – reduced household income leads to reduced consumption, which negatively affects net sellers. Production linkages reduce labor demand by the male-headed land-rich group in the Southern region, which has an additional negative impact on the land-poor in both regions, and on the female-headed in the central region.

Since flooding predominately occurs in flood-prone areas of the Southern region (Pauw et al., 2011), the flood scenarios are introduced for the three household categories representing the districts in the Southern region. The agricultural production in the three remaining household groups remains fixed (still assuming perfectly inelastic agricultural supply). The simulation shows that a flood in the south affects households in the Central region as well, through the consumption and production linkages described above. Reduced labor demand from the male-headed land-rich in the Southern region has a negative impact on labor suppliers in the Central region as well as in the Southern region, which creates further consumption linkages. Reduced consumption for households affected by floods means reduced demand for goods sold by all net selling households. The total effect on household income and production in the SAM is shown in Table 16.

[34] As previously discussed, the consumption multipliers have been adjusted to take into account relatively inelastic demand for food, which reduces these consumption linkages.

Table 16: Percent change in household incomes and total production

Outcome	Simulation		
	Universal 10 percent crop loss	RP15 drought	RP10 flood
Southern region			
Income female-headed	-5.22	-18.03	-17.51
Income male-headed land-poor	-7.18	-16.28	-22.87
Income male-headed land-rich	-7.30	-18.59	-25.4
Central region			
Income female-headed	-7.74	-13.9	-2.4
Income male-headed land-poor	-7.45	-13.4	-2.02
Income male-headed land-rich	-7.64	-11.9	-1.14
Total production	-7.3	-15.45	-12.71

Source: Own calculations based on 2008/09 Regional Malawi SAM.

In the simulations above, it is assumed that any decrease in supply due to a drought or a flood leads to a proportional decrease in intermediate input demand and value added to factors. As discussed in Subramanian and Sadoulet (1990), it may be that purchased inputs have already been applied, such that the costs of these inputs have been incurred before the drought or flood, depending on the timing of the weather shock, and the timing of input use. If a flood destroys the harvest just before harvesting, hired labor for planting and weeding, rented in land, as well as purchased seeds and fertilizer have already been paid for and used.[35] This means that the loss in profits for the farmers will be more than proportional to the production loss, but the effect on households that rely on *Ganyu* may be smaller if they have already been paid.[36] This would imply larger direct impacts on household groups that purchase inputs, but smaller indirect impacts through decreased demand for labor.

3.4 Discussion and limitations

In a rural economy where markets are imperfect or missing, multiplier effects are limited. There is less interaction between households through factor- and product markets, and thus smaller multiplier effects through markets. The demand for home-produced goods can be seen as leakages, since increased consumption of home-produced goods, or increased use of on-farm factors (labor and land) reduces the multiplier effect on other household groups through production and consumption linkages. Increased demand for exports will only affect households that are linked to the export

[35] Most of the land rental in the survey data is based on fixed rent contracts, and not sharecropping.

[36] In case studies of informal labor contracts in Malawi, Takane (2008) reports several incidences of payments for labor being renegotiated if harvests are poorer than expected, and in general, payments for hired labor being made after the harvest is sold as a type of risk-sharing contract between the employer and the worker.

sector through production or factor markets. On the other hand, the results in this paper illustrate that economy-wide effects are still potentially important. Many households rely on the rural labor market for off-farm income in the lean season, and as an income diversification strategy in times of crop failure (Whiteside, 2000). The land rental market may also be a potential way of coping with shocks through distress land rental (Holden et al., 2006).

The results also demonstrate the importance of taking into account market imperfections when assessing the effects of shocks or policies in rural developing economies. Ignoring home-consumption and use of on-farm factors may overestimate the impact of policies – for instance a top-down policy to reduce poverty may not have the expected "trickle down" effect. Arndt et al. (2012) demonstrate this by comparing Vietnam and Mozambique, and state that "The high trade margins associated with Mozambique thus act as a leakage from the rural economy, and reduce the benefits accruing to rural households from an expansion in agricultural demand" (Arndt et al., 2012, p. 760).

These results are in line with the findings of Benson and Clay (1998), who argue that there is an inverted U-shape relationship between economy-wide impacts of drought and the level of complexity of the economy. Their results point to another important caveat of the results from the multiplier analysis above. Since economies are not static, the impact of droughts and floods are time-dependent. As a simple economy, with few links between households and sectors, evolves, it may if fact become more vulnerable to weather shocks because of increased inter-sectoral linkages. However as the economy evolves to what Benson and Clay (1998) call a complex economy, forward and backward linkages from the agricultural sector are expected to decline, again confining the impact of shocks to the directly affected sectors, and reducing the overall drought impact as the importance of the agricultural sector declines.

On the other hand, impacts of production fluctuations due to climate variability may have severe impacts on food-security if markets for buying food are missing or characterized by large transaction costs, or if there is little scope for income diversification through factor markets. This reveals a major limitation of the simple mixed multiplier model employed above, since it is assumed that any production shortfall within the economy can be compensated for by increased imports to meet demand. A related major limitation is that prices are fixed in the model. Historical evidence shows that food prices in rural markets in Malawi are volatile and likely to react to production shortfalls due to droughts or floods (Harrigan, 2008). On the one hand, production cannot react to a price change in the short run, and it may therefore be reasonable to assume little endogenous adaptation to changes in product and factor prices in the case of a drought. This means that it would not be appropriate to use a model with fully endogenous prices and flexible production response in this case, since it would underestimate the production impact. On the other hand, increased food prices due to a drought or flood are likely to have a large impact on net food buyers.[37] An obvious extension of this analysis would be to calibrate a computable general equilibrium model to the SAM, taking into account the market imperfections discussed in this paper.

The fact that the SAM is constructed based on limited and imperfect data should also be kept in mind when interpreting the model results, as well as the descriptions of the economy based on the SAM. The SAM focuses on the rural economy, and other sectors that the households interact with are simplified and aggregated. The aggregation of heterogeneous rural households to household groups that aim to represent typical households is of course also a gross simplification. The modeled impacts should therefore be seen as illustrations rather than predictions.

4 Conclusion

This paper demonstrates an approach to incorporating characteristics of rural households and markets in Central and Southern Malawi into a social accounting matrix framework. The SAM depicts a detailed composition of production activities undertaken by six typical household groups that represent households with varying endowments and market access. The status of each household group as net buyer, net seller or self-sufficient in factor and product markets is taken into account by introducing separate production activities for each household group, and household-specific factors. The SAM shows that the majority of crops produced by the households is consumed on-farm, and that for traded goods, transaction costs constitute a significant share of supply. The SAM is used as a simple linear model of the rural economy to investigate impacts of droughts and floods on the household groups. A drought that on average occurs every 15 years is shown to affect households in the Southern region more than households in the Central region. This is because households in the south of Malawi rely more on local maize production, which is more drought-sensitive than improved maize and tobacco, which are more important crops in the Central region. Reduced demand for labor from households that hire in labor has an additional negative impact on the land-poor households in both regions because they rely on labor for cash income. A flood that affects the

[37] Harrigan (2008) states that it was high food prices and not lack of available food that caused huger-related deaths during the 2002/03 food crisis in Malawi.

Southern region similarly affects the Central region through decreased labor demand, and decreased consumption demand for crops sold by households in the Central region. The production and consumption multiplier effects due to weather shocks are constrained by the use of family labor in farm production and the large share of consumption of own produce. The results indicate that the type of crops grown by households may be more important for impacts of climate variability than indirect effects through consumption and production multipliers in a setting with missing and imperfect factor and product markets. A potential policy implication of the results is to provide information about the characteristics of improved, drought-tolerant crop varieties, and make them available to households. If the characteristics of existing drought tolerant varieties are not suitable for local conditions and preferences, there should be continued investment in crop research to improve these varieties. Also of relevance to policy makers is the finding that despite the importance of family labor in production for many farm households, the adverse impacts of climate variability may be disseminated through the rural labor market, affecting households that depend on the labor market for cash income in addition to home production.

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Appendix A

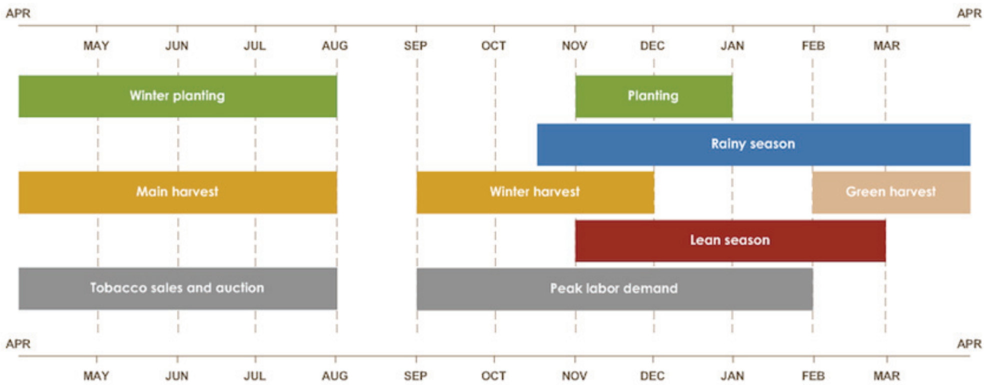

Figure A1: Timeline of typical agricultural year. Source: FEWS Net (2014)

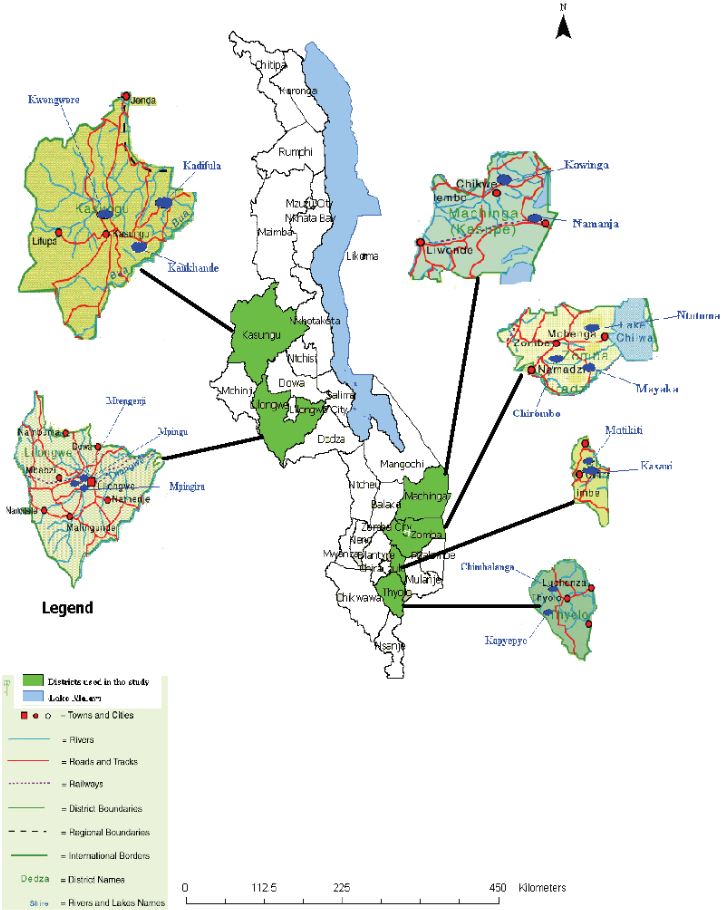

Figure A2: Districts and sites sampled in 2008/09 survey. Source: Lunduka (2009)

Appendix B

As discussed above, when markets are well-functioning, decisions regarding the supply and demand of factors such as land and labor should be made independently of each other. This means that, controlling for the wage, factors that affect labor supply decisions should not affect labor demand (Benjamin, 1992, p. 287). For instance, family size should not matter for the amount of labor used on the household's farm when markets are well functioning, rather all households apply the optimal labor input and any labor surplus or deficit is dealt with through the labor market. Optimal labor input only depends on the production technology and the (exogenous) wage. This result can be used to test whether the separability property holds for the households observed in the data. Benjamin (1992) proposes the following test of separability:

$$H_0 : \text{Separability} \;\rightarrow \frac{\delta F(L; A)}{\delta L} = w$$

where w is the exogenous market wage and $F(L; A)$ is the agricultural production function which depends on labor input L and a fixed amount of land A. The output price is normalized to one. The alternative hypothesis is non-separability, or

$$H_1 : \text{Non-separability} \;\rightarrow \frac{\delta F(L; A)}{\delta L} = w*$$

Where $w*$ is the household shadow wage which depends on demographic factors. The implicit assumption is that the deviation from the equalization of the marginal product of labor to the exogenous wage depends on family size in the non-separable case. When labor supply and demand decisions are no longer separable, labor demand depends on an endogenous shadow wage, which depends on household composition. Benjamin (1992) presents three alternative sources of non-separability: a binding constraint on off-farm employment, rationing on the labor demand side and differing returns to labor on– and off-farm. The first two seem most relevant in the rural labor market of Malawi. Binding constraints on off-farm employment is likely to be the case in the low-season for labor surplus households, while a binding constraint on access to labor could be the case for labor deficit households wishing to rent in labor during the high season. It may well be that there are differing returns to family and hired labor when used on the farm, or that there are better-paid off-farm opportunities, but either case is likely to be combined with labor shortages in the high season, and constrained access to off-farm employment in the low season.

An empirical problem that is also met by Benjamin (1992) is that we do not observe labor use separately for the peak season and the low season, but rather total labor use over the year. Whether the test is able to detect non-separability then depends on the share of labor that is employed during the peak season. An additional problem is the potential endogeneity of demographic variables. For instance, unobservable or omitted variables such as land quality may affect both household size and labor demand on farm. Land quality (as assessed by the farmers) and district dummies are included as an attempt to control for this potential source of endogeneity. The demographic variables included are household size, measured in male equivalent labor units[38] and the gender composition of the household labor. In line with Benjamin (1992), I estimate the following empirical labor demand function:

$$logL_h^D = \beta_0 + \beta_1 logw_h + \beta_2 logA_h + \beta_3 \sum_{i=1}^{G} \delta_i a_{h,i} + u_h \tag{7}$$

where L^D are days of labor used on the farm (both family labor and hired labor), w is the average wage reported by the household,[39] A is the amount of land used (hectares of land used for crop production), and G is the number of demographic variables, a_i. β_3 is then interpreted as the effect of the shadow wage on labor demand, while δ_i is the effect of demographic variable i on the shadow wage. Summary statistics are shown in Appendix B. The partial effect of the demographic variable on labor demand is thus $\beta\delta_i$. If there is a statistically significant association between any of the demographic variables and labor demand, we have to reject the null hypothesis of separability. The regression results are presented in Table A1.

The amount of household labor available is positively and significantly associated with the amount of labor demanded in all three specifications, which indicates a rejection of the separability hypothesis. Households with more labor available use more labor on their own farm, perhaps because of limited off-farm employment opportunities or high transaction costs related to off-farm employment. There is no significant association between the share of women in household labor and labor demand. The next section proceeds by estimating the shadow prices of potentially non-traded inputs, specifically land and household labor.

[38] Male=1, female=0.8 and child younger than 16=0.5. Children younger than 8 are not included

[39] As discussed by Benjamin (1992), we cannot estimate a wage elasticity for households with incomplete wage observations, however the test of separability is still applicable.

Table A1: Dep. var.: Days of labor employed on farm (log)

	(1)	(2)	(3)
Log hectares of land cultivated	0.429***	0.437***	0.417***
	(0.080)	(0.088)	(0.089)
Log average Ganyu wage per day of labor	-0.060	-0.027	-0.013
	(0.044)	(0.042)	(0.042)
Log male equivalent labor units in household	0.518***	0.529***	0.442***
	(0.113)	(0.111)	(0.121)
Female labor share of total labor units in household	0.019	-0.041	-0.033
	(0.267)	(0.264)	(0.264)
Mean fertility of plots operated by household		0.024	0.040
		(0.077)	(0.077)
Age of head of household			0.027
			(0.019)
Age of head of household squared			-0.000
			(0.000)
Years of schooling of head of household			0.018
			(0.011)
Number of Obs.	242	242	242
Mean of Dep. Var.	5.35	5.35	5.35

Robust standard errors in parentheses. Sample of households from 2008/09 survey with wage observations. District dummies included but not reported in regressions (2) and (3)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2: Summary statistics for variables in separability test and estimation of shadow prices

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Land used for crop production, ha	0.9	0.73	0.03	8.9	371
Average Ganyu wage per day of labor	305.57	341.35	2	2800	242
Male equivalent labor units in household	3.1	1.35	0.8	7.9	371
Female labor share of total labor units in household	0.49	0.2	0	1	371
Plot fertility index (avg)	2.08	0.52	1	3	371
Gross value of agricultural output, 2009 MWK	48533.06	60212.04	0	569670	371
Hours of family labor used as input in crop production	1417.15	1387.08	0	9855	371
Hours of hired labor used as input in crop production	89.10	306.88	0	2895	371
Kgs of manure used as input in crop production	1453.63	6671.86	0	75000	371
Value of tradable inputs (MWK)	11549.88	20996.97	2	246600	371
Age of head of household	46.17	15.87	1	85	371
Age of head of household squared	2382.53	1606.35	1	7225	371
Years of schooling of head of household	5.13	4.03	0	24	371

Source: 2008/09 survey. Plot fertility index: 1=very fertile, 2=average, 3=not fertile

Table A3: Disaggregation of SAM accounts

Account category	Accounts	Contents	Number
ACTIVITIES	AMzLocH1-6	Local maize varieties, hh group specific	69
	AMzImprH1-6	Hybrid and OPV maize, hh group specific	
	ALegH1-6	Beans, peas, groundnuts, pigeon peas, soy	
		hh group specific	
	ATubH1-6	Cassava, sweet potato, potato	
		hh group specific	
	AOcropH1-6	All other crops, rice, millet, sorghum	
		cabbage, sugar cane, hh group specific	
	ATobH1-6	Tobacco, hh group specific	
	ALandRH2,5	Land rental activity, hh group specific	
	AGanyuH2,4,5	*Ganyu* activity, hh group specific	
	ANoncropH1-6	Livestock and forestry activities	
	ABusH2-6	Household business activities and formal employment	
		hh group specific	
	ASubsH1-6	Use of subsidized fertilizer	
	ASecH1-6	Use of secondary market fertilizer	
	ATimeH1-6	Household time use, hh group specific	
COMMODITIES	CMaizeH1-6	Hh group specific maize commodity	66
	CMaize	Aggregate traded maize commodiy	
		Local and improved maize varieties	
	CLegH1-6	Household group specific legume commodity	
	CLeg	Aggregate traded legume commodity	
	CTubH1-6	Household specific tuber commodity	
	CTub	Aggregate traded tuber commodity	
	COcropH1-6	Hh group specific other crop commodity	
	COcrop	Aggregate traded other crops commodity	
	CTob	Aggregate traded tobacco commodity	
	CLandRH2,5	Household group specific rented land commodity	
	CLand	Land available for rental	
	CLab	Aggregate traded labor commodity	
	CNoncropH1-6	Household group specific non crop commodity	
	CNoncrop	Aggregate traded non crop commodity	
	CBus	Aggregate traded business commodity	
	CSeeds	Traded seed commodity	

Continued on next page

Table A3 – *Continued from previous page*

Account category	Accounts	Contents	Number
	CSubs	Subsidized fertilizer	
	CSec	Secondary market fertilizer	
	CFertprim	Commercial market fertilizer	
	CFertsecH1-6	Secondary market fertilizer, household group specific	
	CFertsubH1-6	Subsidized fertilizer, household group specific	
	CAGoods	Imported agricultural goods	
	COGoods	Other imported goods	
	CLeisH1-6	Household leisure commodity	
	CTrad	Transaction service commodity	
FACTORS	FTimeH1-6	Household specific time endowment	20
	FLandH1-6	Household specific land endowment	
	FCapH1-6	Household specific capital endowment	
	SubProfit	Profits from fertilizer subsidy and secondary market	
	LandProfit	Profits from land rental	
CAPITAL	S-I	Savings and investment account	1
INSTITUTIONS	HH1	Female-headed, South	7
	HH2	Male-headed land-poor, South	
	HH3	Male-headed land-rich, South	
	HH4	Female-headed, central	
	HH5	Male-headed land-poor, central	
	HH6	Male-headed land-rich, central	
	GOV	Government	
TRANSACTION COSTS	TRNSC-E	Transaction costs for exports	3
	TRNSC-M	Transaction costs for imports	
	TRNSC-D	Transaction costs for domestic trade	
ROW		Outside SAM	1
TOTAL			167

PAPER 4

Economy-wide effects of input subsidies in Malawi: Market imperfections and household heterogeneity

Sofie Waage Skjeflo* and Stein Holden†‡

Abstract

The potential benefits of providing subsidized inputs to farm-households in developing countries may reach well beyond the targeted households. More specifically, increased food production and demand for rural labor may benefit poor households through lower food prices and higher rural wages. However, two recent studies of a large input subsidy program in Malawi find that these effects are smaller than expected based on anecdotal evidence and previous studies using simulation models. In this paper we provide a potential explanation for this finding by using six farm-household programming models to show how market imperfections limit households' ability to take advantage of cheaper inputs. Our findings suggest that input subsidy programs could be combined with improved market infrastructure and market access in order to increase non-beneficiary households' benefits from input subsidies.

Keywords: Input subsidies, Malawi, Farm-household models

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1 Introduction

Over the past years there has been renewed emphasis on input subsidies as a tool to increase agricultural productivity and food security in developing countries. In 2011, input subsidy programs were in place in 10 African countries, providing inputs such as fertilizer and improved seeds at highly subsidized prices to rural households (Jayne and Rashid, 2013). Malawi's Farm Input Subsidy Program (FISP) is at the forefront of this trend, and has been praised as a model program that could inspire other African countries to replicate its success (Jayne and Rashid, 2013). The program was introduced in 2005, and has since then grown considerably to become a large-scale, national subsidy program. For instance, in 2008/09, 202 000 metric tons of fertilizer were distributed to about 65 percent of rural households[1] at about 10 percent of the commercial price of fertilizer (Dorward and Chirwa, 2011). Contrary to previous, smaller-scale subsidy programs, the goal of the current program is to increase national food security, as well as vulnerable households' food security (Dorward and Chirwa, 2011), through increased access to fertilizer and improved seeds for targeted households, allowing them to boost maize production and increase household incomes (Denning et al., 2009). Due to the large scale of the program, it is also expected to generate economy-wide impacts that affect non-beneficiary households through indirect effects on maize prices and rural wages (Dorward and Chirwa, 2011). Increased maize production may lead to lower maize prices, which would benefit the majority of poor households in Malawi who are net food buyers (Ricker-Gilbert, 2014). Increased maize production may also decrease the off-farm labor supply of poorer subsidy beneficiary households,[2] and increase the demand for on-farm labor among less poor subsidy recipients, leading to an increase in rural wage rates, also benefiting poorer households (Dorward et al., 2008; Ricker-Gilbert, 2014).

Ricker-Gilbert (2014) and Ricker-Gilbert et al. (2013) are the first to quantify these indirect effects empirically and they find that there are relatively small general equilibrium effects from the input subsidy program in Malawi. Specifically, Ricker-Gilbert (2014) estimates that an average increase in access to subsidized fertilizer by 10 kg per household in a community increases the median wage in that community by 1.4 percent.[3] Ricker-Gilbert et al. (2013) find that doubling the amount of subsidized fertilizer in the program only reduces the maize price by 1.2 - 2.5 percent.

[1] The program aimed to provide a package of two 50 kg bags of fertilizer and a bag of improved seeds to targeted households. Targeting was based on land access and poverty/vulnerability (Dorward and Chirwa, 2011).

[2] For instance through increased demand for on-farm work to increase maize production, or through decreased need for off-farm income to cover food deficits.

[3] 10 kg is about 17 percent of the average amount received per household in 2006-2009.

On the other hand, Dorward et al. (2008) simulate access to 50 kg of fertilizer with a 70 percent subsidy and 2 kg of free improved maize seeds for all households, using farm-household models, and find 20-30 percent higher wages and about 25 percent lower maize prices. Similarly, economy-wide impacts estimated using a computable general equilibrium model of Malawi indicate significant spillover effects to non-recipients due to lower maize prices and higher rural wages (Arndt et al., 2013). Qualitative evidence from interviews with recipients also suggest large impacts of the subsidy program at the household level, which were expected to lead to significant economy-wide effects of the subsidy program (Dorward et al., 2008; Chirwa et al., 2011). Dorward and Chirwa (2013) support this, claiming that the indirect effects of the program in terms of reducing poverty could be larger than the direct effects. Similarly, Denning et al. (2009) interpret observed price declines in Malawi during the first years of the program as being caused by the program, and thus evidence of the positive effects of input subsidies on net maize consumers.

We are interested in understanding why the empirically observed general equilibrium effects of the Malawi Farm Input Subsidy Program seem to have been lower than expected, based on previous simulation studies and anecdotal evidence. In particular, we are interested in potential explanations for what appears to be only a modest maize price decrease and a moderate increase in rural wage rates, despite the size of the program, both in terms of the amount of fertilizer distributed and the number of households reached. Our hypothesis is that market imperfections limit households' ability to respond to the subsidy. To investigate this hypothesis, we run a series of simulations using six farm-household programming models representing typical household groups in the Central and Southern regions of Malawi. We show how a combination of market imperfections and variations in household endowments constrain households' response to the input subsidy, and how these constraints may explain why the observed economy-wide impacts of the subsidy program may be small. The contribution of the paper is thus to present potential explanations for the apparent discrepancy between the large impacts described in anecdotal evidence and the small estimated maize price and wage effects based on empirical studies.

We use the farm-household programming models to examine the maize supply response and labor supply- and demand decisions of households to varying levels of access to subsidized fertilizer. The models represent households in an environment with missing and imperfect markets, taking into account transaction costs related to input and output markets, missing land rental markets, constrained access to off-farm employment, seasonality in labor demand and informal (secondary) markets for input coupons and cheap inputs. In line with previous literature on agricultural households in environments with missing and imperfect markets, we find non-linear household supply responses to price changes and access to subsidized inputs. We also find large variations across household groups in their response to input subsidies, and that the response is sensitive to the constraints that the different household groups face as well as their endowments.

Our findings suggest that the size of general equilibrium effects of input subsidies depends on the level of market integration and the heterogeneity of household types to which the subsidy is targeted. Because of constrained market access and large transaction costs related to market participation, even large impacts at the household level may not translate into observable wage- and price effects. A possible policy implication is that input subsidies should be combined with efforts to improve access to input and output markets through investment in infrastructure and market integration in order to increase benefits for poor non-recipient households.

In the next section we present the study context and the motivation for developing the farm-household programming models that are described in detail in Section 3. The simulations and the results are presented in Section 4. We discuss the results and limitations to the analysis in Section 5, and Section 6 concludes the paper.

2 Study context

Malawi is among the poorest and most densely populated countries in Sub-Saharan Africa (World Bank, 2014). Poverty is most severe in rural areas, and particularly in the more populous Southern region where the population density is highest.[4] The majority of the population lives in rural areas and produces maize, which is the most important crop in terms of both production and consumption.[5] Female-headed households are more likely to be poor than male-headed households, with 57 percent of female-headed against 49 percent of the male-headed households living below the poverty line in 2011 (National Statistical Office, 2012). Tobacco, the most important cash crop in Malawi, is cultivated on about 10 percent of male-headed plots, compared to about 3 percent of female-headed plots (National Statistical Office, 2012), which demonstrates the stronger subsistence orientation of female-headed households.

[4]The Southern rural region has about 38 percent of the total population and 63 percent of the poor while the Central rural region has about 36 percent of the population and 49 percent of the poor (National Statistical Office, 2012).

[5]Cereals constitute two thirds of energy consumption and maize represents 93 percent of the cereal consumption World Bank (2007).

Agricultural production in Malawi is strongly seasonal, due to predominately rain-fed agriculture and a single rainy season between November and April.[6] This leads to widespread underemployment during the lean season, while labor-poor households in particular may face labor shortages in peak seasons, especially during planting time in December/January (Wodon and Beegle, 2006). Supplying informal farm labor (*Ganyu*[7]) is an important source of cash income for poor households, and is mainly done out of necessity when food stocks have run out (Whiteside, 2000). Whiteside (2000) also notes that there is a potential conflict between doing *Ganyu* and own farm production, since the time when food stocks normally run out coincides with peak labor demand.

Only a small share of Malawian households have access to formal credit (Diagne and Zeller, 2001), and in 2010/11 about 8 percent of households borrowed for production purposes, and less than half of these from formal lenders (National Statistical Office, 2012). The seasonality in production combined with imperfect credit markets also leads to seasonal food shortages that coincide with high food prices (Ellis and Manda, 2012). Households often sell food crops at harvest time at low prices to obtain cash for other needs, and buy food when stocks run out and food prices are higher before the next harvest (World Bank, 2007). In addition to large seasonal variation in food prices, in particular maize prices, crop markets are characterized by large transaction costs (Jayne et al., 2010).

The land sales and rental markets in Malawi are restricted. Holden et al. (2006) report large transaction costs related to land sales (almost 70 percent of the price), and our survey reveals that there are few sales transactions in the land market among the respondents. The land rental market is somewhat more active, but often influenced by traditional norms for land borrowing that contribute to high transaction costs (Holden et al., 2006). Our survey data indicates that the land rental market is less active in the Southern region where land is scarcer.

2.1 The Farm Input Subsidy Program (FISP)

Input subsidies have been present in Malawi since the 1970s, but were removed in the 1980s under the Structural Adjustment Programs of the World Bank (Harrigan, 2003). In the late 1990s, subsidies were reintroduced under the Starter Pack program, consisting of universal distribution of a small pack of fertilizer and maize and legume seeds (Harrigan, 2008). The program was since scaled

[6] A seasonal calendar of a typical agricultural year is shown in the appendix.

[7] *Ganyu* is often piecework such as weeding or ridging that is paid in kind or in cash. It is traditionally seen as a social obligation for farmers with sufficient food stocks to provide food for work (Whiteside, 2000).

down after donor critique, but following a particularly poor maize harvest in 2004/05, a large-scale input subsidy program, later known as the FISP, was introduced (Holden and Lunduka, 2012). The program aims to target about 50 percent of farmers to receive vouchers that can be exchanged for fertilizer and improved maize seeds (Dorward and Chirwa, 2011).[8] The composition of subsidized inputs has varied over the years of the program, including subsidies for tobacco fertilizer and legume seeds in addition to the "standard" package of two vouchers for 50 kg bags of fertilizer and a voucher for 2 kg of improved maize seeds (Dorward and Chirwa, 2011).

Several studies have assessed the farm-level impacts of the subsidy program in Malawi, including impacts on fertilizer use and displacement of commercial fertilizer purchases (Ricker-Gilbert et al., 2011), cropland allocation (Chibwana et al., 2012),[9] use of organic manure (Holden and Lunduka, 2012), seasonal demand for fertilizer (Holden and Lunduka, 2014), targeting (Holden and Lunduka, 2013) and welfare effects of access to improved maize seed (Bezu et al., 2014). Lunduka et al. (2013) summarize empirical studies of farm-level impacts of the FISP, and conclude that impacts on maize production and yields were small but statistically significant, and that better off households benefited more than poorer households.

Fewer studies have assessed the economy-wide effects of the subsidy program, including the indirect impacts on non-recipient households through maize prices and wages. Dorward et al. (2008) report results from focus group interviews that indicate strong indirect effects of the subsidy program in 2005/06. A combination of good rains and access to subsidized inputs is said to have turned net buyers of maize to become net sellers, resulting in lower maize prices. The seasonal labor surplus when maize stocks normally run out switched to a labor deficit situation where workers became wage setters, leading to higher *Ganyu* wages. Likewise, Chirwa et al. (2011) find decreasing maize prices and increasing *Ganyu* wage rates from 2009 to 2010, leading to an average increase in maize purchasing power by 47 percent, which is supported by statements from focus group interviews. They conclude that this is suggestive evidence of strong indirect impacts of the subsidy program.

Dorward et al. (2008) simulate direct and indirect impacts of the subsidy program in a set of household models, representing household groups in two areas of the Central and Southern regions

[8]The targeting rules have been unclear and subject to local adjustments, and the number of rural households has been debated due to a large discrepancy between the population census data and the household rosters used by the subsidy program (Holden and Lunduka, 2013).

[9]Chibwana et al. (2012) investigate the impact of the FISP on the allocation of land to crop types in Kasungu and Machinga districts through a two-step instrumental variables approach. They find that recipient households on average allocated respectively 16 percent and 46 percent more land to maize and tobacco, and that they allocated less land to other crops.

of Malawi. They find that the poorer households benefit from selling their input vouchers to obtain cash,[10] while less poor households replaced at least some regular fertilizer purchases with subsidized fertilizer. The authors also use these models combined with a partial equilibrium model of the rural economy to simulate the maize price- and wage changes resulting from a universal subsidy, where all households have access to one bag of fertilizer at 70 percent subsidy, and 2 kg of free seeds. They find that the supply of labor from poorer households contracts, because of increased maize production and income from reselling fertilizer, and that there is a small increase in labor demand from land-rich households who have saved input expenses by replacing commercial fertilizer purchases with subsidized fertilizer. The tighter labor market implies 20-30 percent higher wages and increased maize production reduces maize prices by just over 25 percent.

Arndt et al. (2013) investigate impacts of the farm input subsidy program in a computable general equilibrium model of Malawi. They simulate access to the full package of subsidized inputs (2 kg of improved seeds and 100 kg fertilizer) for half of farmers in 2005/06, and find that maize prices decrease as maize supply increases, due to marketing and demand constraints (i.e. export constraints and inelastic domestic demand). The real maize price index decreases by between 2.6 and 4.3 percent, depending on how the subsidy is financed, and the average farm wage increases by about 7 percent. They conclude that the indirect effects of the subsidy constitute as much as two-fifths of total benefits from the subsidy. [11]

Ricker-Gilbert et al. (2013) investigate the impact of input subsidies in Zambia and Malawi on maize prices, using market- and district level panel data. They use price-data from two seasons each year from 2000 to 2011 from 72 markets in 26 districts in Malawi, and estimate the average impact of access to subsidized fertilizer on the maize price using the Arellano-Bond estimator. They estimate the same model using district level data from Zambia. Their results indicate statistically insignificant, or significant but very small effects on maize prices in both countries; doubling the amount of fertilizer to a district decreases maize prices in the district by on average 1.2-1.6 percent. The authors conclude that there is minimal effect of input subsidies on maize prices, and that there is little evidence supporting the claim that large-scale subsidy programs may have large poverty-reducing effects for non-targeted households through reduced food prices. They also conclude that the results are as expected based on previous empirical findings of significant displacement of com-

[10]This finding is not supported by their survey data, where there is little reselling of vouchers, nor by the survey data in Holden and Lunduka (2013) or household fertilizer demand experiments in Holden and Lunduka (2014).

[11]Benefits are measures as change in total real absorption (private and public consumption and investment).

mercial fertilizer purchases, and small household level increases in maize production in response to subsidies, combined with increasing integration of domestic maize markets with international markets.

Ricker-Gilbert (2014) examines the wage and employment effects of the subsidy program. He uses three waves of nationally representative survey data from 2003, 2006 and 2008 from Malawi, and estimates the labor supply and demand decisions of households, controlling for household fixed effects, and a community-level wage equation, controlling for community-level fixed effects. On average, receiving 100 kg more of subsidized fertilizer (i.e. two more vouchers, or doubling the standard package) reduces the number of days of *Ganyu* labor supplied by a household by about 3 days. The author concludes that this is in line with previous empirical findings of small, but significant increases in maize production and welfare for recipient households, and that the reduction in labor supply could be due to a relaxed credit constraint. Ricker-Gilbert (2014)'s findings also suggest a small positive impact of subsidy receipt on the probability of hiring labor. This falls in line with the community level wage results, which show a small, positive effect of increasing household level access to subsidies on the community wage rate. Giving each household access to 10 kg more fertilizer on average increases the wage by 1.4 percent. The author also notes that although there has been a large increase in real wages over the three years of the panel survey, a relatively small share of this increase can be attributed to the subsidy program.

The discrepancy between the findings of the two empirical studies and the predicted economy-wide impacts based on anecdotal evidence and partial- and general equilibrium models requires further investigation. In particular, it is necessary to investigate potential causal mechanisms underlying the indirect impacts of the FISP.

3 Model description

In order to investigate household-level responses to an input subsidy program in a setting with imperfect and missing rural markets, we use a set of partial equilibrium linear programming household models that represent six typical household groups in Malawi. We attempt to take into account important characteristics of rural Malawian households, first by creating a household typology based on survey data, and secondly, by incorporating the constraints we expect to be relevant for household response to an input subsidy.

Table 1: Basic characteristics of household groups

	Southern districts			Central districts		
		Male-headed			Male-headed	
	Female -headed	Land -poor	Land -rich	Female -headed	Land -poor	Land -rich
Share of households in sample (percent)	16	20	22	10	8	24
Land owned (ha)	0.94	0.61	1.37	1.39	0.78	1.97
Household size (median)	4	6	4	5	6	5
Per capita owned land (ha)	0.27	0.10	0.44	0.35	0.13	0.41
Household labor (adult equivalents)	2.6	3.0	2.8	3.2	3.2	3.1
Male labor/ha	2.2	3.5	2.8	1.1	2.8	1.2
Female labor/ha	2.9	2.8	2.1	2.0	2.6	0.9
Share receiving subsidized inputs	0.43	0.53	0.49	0.27	0.54	0.50
Subsidized fertilizer received (kg)	32.6	48.5	45.5	23.0	51.7	62.0
Total fertilizer use (kg)	59	82	114	87	88	153

Adult equivalence weights: male=1, female=0.8 and child younger than 16=0.5
Children younger than 8 are not included.
Source: 2005/06 survey

3.1 Household typology

We base our models on three rounds of survey data collected in 2006, 2007 and 2009. The panel survey covers a random sample of rural households in two districts in Central Malawi (Kasungu and Lilongwe) and four districts in Southern Malawi (Chiradzulu, Machinga, Thyolo, and Zomba), as shown in Figure A2. The sampling strategy and survey design is described in detail in Lunduka (2009). The households differ in their access to land and household labor, and a significant share are female-headed. We categorize households by region, sex of household head, and by land availability for the larger group of male-headed households. More specifically, households with less than median land owned per household member are categorized as land-poor, while those with more than median land available per household member are categorized as land-rich. This categorization of households captures land scarcity when consumption needs and labor scarcity are taken into account. This gives us six household groups, with summary statistics of basic characteristics described in Table 1.

3.2 Mathematical representation

Households are assumed to maximize utility subject to a set of technology and resource constraints. We build on Holden (1993) who models household utility as a weighted income-leisure goal in a Chayanovian (drudgery averse peasant) spirit (Chayanov, 1966). We assume that households derive

utility from what can be seen as a hierarchical utility function, with basic food needs at the first level of preferences, and net income at the second level. The model does not explicitly account for consumption of other goods and non-staple foods, beyond the basic food needs, and we therefore assume that households maximize net income available to purchase such goods. This net income is then weighted against the disutility of labor (drudgery aversion) to reach a "subjective equilibrium" (Nakajima, 1986), capturing the trade-off between labor and leisure. Drudgery is assumed to be increasing in total time use within each seasonal time period. Basic household taste preferences for foods, and subsistence requirements in terms of calories and protein, are captured by a set of separate constraints. Drudgery aversion is captured by seasonal constraints on labor availability and labor requirements across production activities, reflecting the timing of crop production as well as seasonal labor shortages and surpluses. The model is essentially static, but it is time-recursive in the sense that input decisions and initial liquidity constraints affect production decisions. The seasonal disaggregation allows us to take into account missing credit markets, as input purchases must take place before the revenue from crop sales is realized. The model is "non-separable", in line with previous literature on agricultural households with market imperfections (see for instance Singh et al. (1986)), since production decisions are affected by food needs, drudgery aversion and constrained access to cash, seasonal employment and subsidized inputs.
The expression to be maximized is:

$$\sum_{i=1}^{N}(p_i^c q_i^c + p_i^s q_i^s - \mathbf{p^x x_i}) + w^m(l^s - l^h) - \sum_{t=1}^{T} w_t^f(l_t^f + l_t^s) \tag{1}$$

where q_i^c is the amount consumed of crop i, p_i^c is the price at which consumption is valued, q_i^s is the quantity sold, p_i^s is the sales price of crop i, and $\mathbf{p^x}$ is a vector of input prices for the vector of purchased inputs, $\mathbf{x}$. Consumption is valued at a price below the sales price, i.e. $p_i^c < p_i^s$ to reflect a higher weight in the utility function on cash income than on consumption of staple crops, once subsistence constraints are satisfied. w^m is the market wage of labor, l^s is the total amount of labor supplied off-farm and l^h is the amount of labor hired. There are $T = 11$ sub-seasons in the agricultural year described in the model, and the total labor supply of the household in each sub-season, t, is the sum of labor used on the farm, l_t^f and the labor supplied off-farm, l_t^s. w^f is the shadow wage of family labor, defined in equation (10) below.

Equation 1 is maximized subject to a number of constraints. To reflect consumption needs and preferences, we have included constraints on minimum protein and calorie consumption per household member, as well as taste preferences for minimum and maximum consumption of specific crops. A simplified[12] representation of the subsistence and taste constraints is

$$\underline{Q}_i \leq q_i^c \leq \overline{Q}_i \qquad \forall i \tag{2}$$

where $\underline{Q}_i$ is the lower bound on consumption of crop i, and $\overline{Q}_i$ is the upper bound on consumption. For each crop, the following resource balance must hold:

$$q_i + q_i^b - q_i^c - q_i^s = 0 \qquad \forall i \tag{3}$$

where total production and purchases equals the combined consumption and sales. Thus, consumption of crop i consists of consumption of own farm output, (quantity produced of crop i, q_i, minus quantity sold) and quantity purchased, q_i^b. The production technology for each crop is described by

$$q_i = F_i(l_i, \mathbf{x_i}; A_i) \qquad \forall i \tag{4}$$

where l_i is labor input, $\mathbf{x_i}$ is a vector of purchased inputs and A_i is the amount of land allocated to the production of crop i. Variation in input use and access is captured by specifying multiple activities (technology sets) for each crop. We have assumed that the amount of land available for cultivation is fixed, i.e. there is no land rental or sales market.

$$\sum_{i=1}^{N} A_i \leq \bar{A} \tag{5}$$

Total labor input in the production of crop i is the sum of family labor and hired labor in each sub-season, t:

$$l_i = \sum_{t=1}^{T} (l_{it}^f + l_{it}^h) \qquad \forall i \tag{6}$$

l^f is total family labor supplied on-farm in the production of all crops:

$$l^f = \sum_i \sum_t l_{it}^f \tag{7}$$

[12]The nutritional requirements are shown in detail in Holden (2014).

and l^h is the total amount of hired labor

$$l^h = \sum_i \sum_t l^h_{it} \tag{8}$$

Total labor supply (on-farm and off-farm) in each sub-season is constrained by the time available in each sub-season, $\bar{L}_t$:

$$l^f_t + l^s_t \leq \bar{L}_t \tag{9}$$

The shadow value of household labor is increasing in the share of total time used in each sub-season:

$$w^f_t = f\left(\frac{l^f_t + l^s_t}{\bar{L}_t}\right) \tag{10}$$

where $f'(\cdot) > 0$. There is constrained access to off-farm employment in each sub-season:

$$g^s_t \leq \bar{G}_t \tag{11}$$

and constrained access to purchased inputs, including subsidized seeds and fertilizer:

$$\sum_{i=1}^{N} \mathbf{x_i} \leq \bar{\mathbf{x}} \tag{12}$$

In addition, households face a cash constraint,

$$Y + w^m(l^s - l^h) = \sum_{i=1}^{N}(p^b_i q^b_i + \mathbf{p}^x \mathbf{x_i}) \tag{13}$$

where the amount of cash available is defined by an exogenous cash endowment, Y, and net income from labor supply (off-farm labor income net of expenses for hired labor). This covers expenses on crop purchases and purchased inputs for all crops. We assume that the purchasing price of crops is higher than the sales price, due to transaction costs. Note that income from crop sales does not enter the cash constraint, since this income is not available until after inputs and most of the food purchases are already made (see the timeline of a typical agricultural year in Figure A1). Further, to account for seasonality in off-farm employment, income from off-farm employment after the main harvest does not enter the cash constraint. The implicit assumption is thus that there is no credit market.

Table 2: Crop production activities

Monocropping activities	Intercropping activities
Improved maize varieties	Improved maize varieties + beans
Local maize	Improved maize + cassava*
Groundnuts	Improved maize + pigeon peas*
Tobacco	Local maize + beans
Cassava	Local maize + cassava*
Sweet potato	Local maize + pigeon peas*
Pigeon peas	

* Southern districts only

3.3 Model calibration

Plot level data from the household surveys is used to calibrate the production activities by region. The variation in production technologies are captured by introducing multiple activities that may produce the same crops, but vary in terms of fertilizer use, intercropping and use of subsidized inputs. Fertilizer use is varied from zero to relatively high levels, based on the observations in the survey data.[13] Maize production activities include the possibility of intercropping with beans, pigeon peas or cassava. Finally, the use of subsidized inputs was included in separate activities to account for lower fertilizer use efficiency on plots where subsidized fertilizer is used.[14] We allow for some systematic differences between the Central and Southern regions in terms of what crops and crop combinations (intercropping activities) that are grown, in line with findings from the survey data. The crop production activities are as shown in Table 2.

An important aspect of the production technologies included in the model, is that they take into account the seasonality of labor demand in the production of each crop. We divide the year into 11 sub-seasons, with more detailed disaggregation of the peak season. Households are constrained by the total amount of labor available in each sub-season, as shown by equation (9), but also timing of input purchases with respect to income from off-farm labor and crop sales, as shown by the cash constraint in equation (13). The model only explicitly includes consumption of crops that are typically both produced and consumed by the households, which includes maize, beans, groundnuts, pigeon peas, sweet potato and cassava. We further assume that storage loss implies 80 percent utilization of production when crops are consumed on-farm.[15] Any other foods or goods consumed

[13]Details of the calibration are provided in Holden (2014).

[14]Holden (2014) found significantly lower output per kg fertilizer on plots using subsidized fertilizer, which could be due to a number of factors, for instance delays in the distribution of subsidized fertilizer, or less experience with fertilizer use among farmers receiving subsidized fertilizer.

[15]This implies a modification of the resource balance in equation (3), which is omitted for simplicity. Jayne et al.

Table 3: Crop prices used in the models

Producer price	Malawi Kwacha/100 kg
Beans	9982
Cassava	2640
Groundnuts	5548
Maize	2690
Pigeon peas	6328
Sweet potatoes	2700
Tobacco	12 932

Source: 2005/06 survey

by the households are not explicitly modeled, but we interpret the surplus income maximized by the households to be spent on off-farm goods, including additional food.

Households can undertake off-farm work in the period before harvest to obtain cash, but this also reduces the amount of family labor available for work on-farm. Households may also rent in *Ganyu* labor. Based on the seasonality of the labor market in Malawi, we assume constrained access to off-farm employment, as illustrated by equation (11) in the mathematical model representation. Market access constraints also include constrained access to subsidized inputs as illustrated by equation (12), both through formal and informal channels, based on the access observed in the data.

The prices used in the model are summarized in Table 3. We include transaction costs causing price bands for crops and inputs. For crops, the basic assumption is a 10 percent mark-up on purchased crops, and a 10 percent mark-down on the price of crops sold. These marketing margins represent a lower bound on the margins found by Jayne et al. (2010). They find the ratio of farm-gate to local retail price to be as low as 45 percent in certain areas and times of the year, while farm-gate prices were on average 75 percent of local retail prices. The weight on consumption in the utility function, p^c, is set at 10 percent below the sales price, i.e. 20 percent below the prices in Table 3. We vary the transaction costs in the simulations in order to investigate the importance of these for household supply response.

The market wage, w^m, is set to 200 Malawi Kwacha per day, based on the survey data from 2005/06. The shadow wage of the household is constructed as a step-function of the share used of

(2010) report average storage losses of maize at the farm-level in Central and Southern Malawi of 14 percent.

total time available in each sub-season, representing the function in equation (10) by:

$$w_t^f = \begin{cases} 0.5w^m & \text{if } \frac{l_t^f + l_t^s}{\bar{L}_t} \leq 0.7 \\ 0.75w^m & \text{if } 0.7 < \frac{l_t^f + l_t^s}{\bar{L}_t} \leq 0.9 \\ 1.1w^m & \text{if } \frac{l_t^f + l_t^s}{\bar{L}_t} > 0.9 \end{cases} \tag{14}$$

Lastly, the data on access to subsidized inputs through informal channels is taken from the 2008/09 survey, since we do not have this information from the first survey round.

4 Simulations

We are interested in understanding why the observed general equilibrium effects of the Malawian Farm Input Subsidy Program seem to have been lower than expected, based on previous studies using simulation models and anecdotal evidence. In particular, we are interested in potential explanations for the modest maize price decrease and the limited increase in rural wage rates, despite the size of the FISP and the number of households reached. Our hypothesis is that market imperfections constrain households' ability to respond to the subsidy. To investigate this hypothesis, we run a series of simulations in the six linear programming household models described above, with and without market imperfections. We are primarily interested in the net supply of maize and off-farm labor (*Ganyu*) since these are the outcomes that will affect the maize price and the rural wage rate. We first show how the household groups' supply of maize and labor respond to changes in the maize price and the wage, keeping the amount of subsidized inputs fixed. Second, we investigate the impact of varying the access to subsidized inputs on households' supply of maize and labor. Finally, we investigate the sensitivity of these latter supply responses to market imperfections, specifically the transaction costs related to buying and selling maize, the liquidity constraint, and the missing land rental market. The simulations are summarized in Table 4.

Table 4: Simulations

Simulation	Prices	Subsidy	Market assumptions
Maize price change	-15 to 15 percent change from 2005/06 price	2005/06 level	Baseline assumption
Wage change	-15 to 15 percent change from 2005/06 wage	2005/06 level	Baseline assumption
Varying subsidy access	2005/06 level	0-4 50 kg bags of subsidized maize fertilizer	Baseline assumption
Varying subsidy access and reducing transaction costs	2005/06 level	0-4 50 kg bags of subsidized maize fertilizer	Maize market transaction costs reduced from 20 to 10 percent
Varying subsidy and access to credit market	2005/06 level	0-4 50 kg bags of subsidized maize fertilizer	Access to credit: 10 percent of income from crop sales can be used to buy inputs
Varying subsidy and access to a limited land rental market	2005/06 level	0-4 50 kg bags of subsidized maize fertilizer	Access to land rental market with transaction costs, larger transaction costs in Southern region.

4.1 Supply curves for maize and labor

To illustrate the characteristics of the six typical household groups, we vary the price of maize and labor, and look at the response in marketed surplus (which is negative for net buyers) of maize and labor for each household group. The net sale of maize is calculated as the quantity sold less the quantity purchased, i.e. $q_i^s - q_i^b$ in the mathematical model representation. Net labor supplied to the market is calculated as the amount of labor supplied less the amount of labor hired, i.e. $l^s - l^h$. The supply curves of maize and labor for each of the household groups are presented in Figures 1 and 2.[16]

[16]Southern region household groups: S FH = Female-headed, S MHLP = Male-headed land-poor, S MHLR= Male-headed land-rich. Central region household groups: C FH = Female-headed, C MHLP = Male-headed land-poor, C MHLR= Male-headed land-rich.

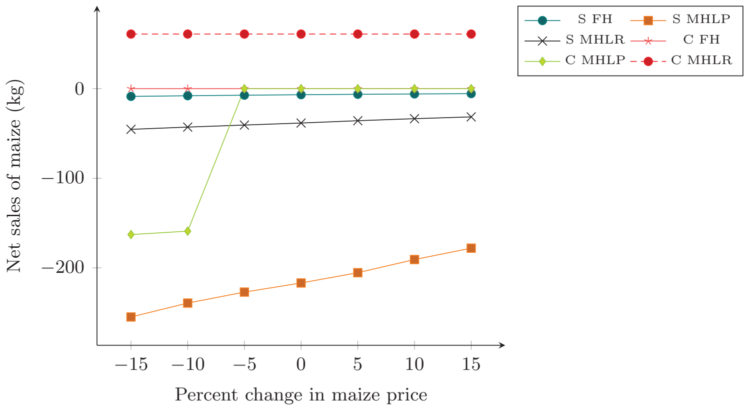

Figure 1: Effect of maize price change on net sales of maize with baseline subsidy level

In the initial situation, calibrated to the 2005/06 data (from now on called the baseline), the three household groups in the Southern region are net buyers of maize, with the largest quantity bought by the male-headed land-poor group. The female-headed group and the male-headed land-poor group in the Central region neither sell nor buy maize, and are self-sufficient. The male-headed land-rich group in this region is a net supplier of maize in the market. The amount of maize purchased by the net buying groups is decreasing in the price of maize, as expected.

As the price drops more than 5 percent below the baseline, the male-headed land-poor group in the Central region switches from self-sufficiency to becoming a net buyer of maize. None of the groups move beyond self-sufficiency and become net sellers over the price range explored in this figure. The amount of maize sold by the net selling male-headed land-rich group in the Central region does not respond to the price variation.

Figure 2 shows that there is little response in labor supply as the wage changes. All household groups except one supply as much labor as possible, under the assumption of constrained access to off-farm employment, and do not rent in any labor. The male-headed land-rich group in the Central region rents in some labor during planting and harvest, and engages in off-farm labor in the lean season. We see that this group's labor demand is decreasing in the wage, as expected, but only marginally. As the wage increases, this group also responds by marginally decreasing net maize sales. The lack of response to the wage change is in line with Goldberg (2010), who finds the labor supply in Malawi to be highly inflexible, while Ricker-Gilbert (2014) finds that a 1 percent increase

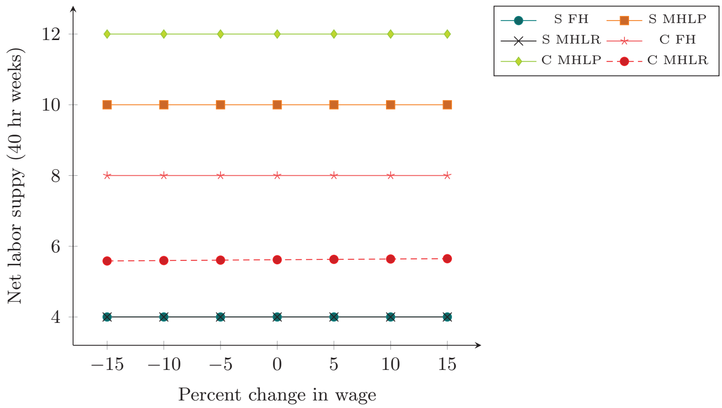

Figure 2: Effect of wage change on net supply of labor to the market with baseline subsidy level

in the median wage in a community decreases the labor supply of *Ganyu*-suppliers, indicating a backward-bending supply curve.

4.2 Effect of access to subsidized maize fertilizer

Next, we study the effect of access to subsidized maize fertilizer (50 kg bags) on the net maize sales of each of the household groups. For simplicity, we have kept access to other subsidized inputs, i.e. seeds and cheap fertilizer through informal sources, fixed at the baseline level. All prices are fixed at the 2005/06 level, not taking into account any price effects of the subsidy. We are thus focusing on the "first round" effect of altering the amount of subsidized fertilizer available to the household groups. Results are reported in Figure 3. We see that giving households the opportunity to buy one bag of subsidized maize fertilizer increases maize purchases for the three household groups in the Southern region, while the remaining household groups are unresponsive to this subsidy level. With access to more than one bag of subsidized fertilizer, both male-headed land-rich household groups and the female-headed group in the Southern region become net maize sellers. However, with 3 or more bags of fertilizer, only the male-headed land-rich group in the Central region is able to take advantage of the subsidy, increasing net sales further. The female-headed category in the Central region is unresponsive to the subsidy, and remains self-sufficient regardless of the amount of subsidized fertilizer available for purchase. Surprisingly, the male-headed land-poor group in this region moves from self-sufficiency to becoming a (marginal) net buyer as access increases beyond two bags of subsidized fertilizer.

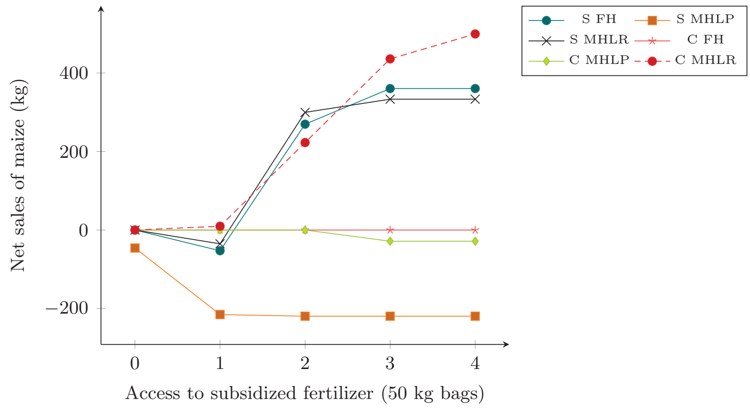

Figure 3: Effect of varying access to subsidized maize fertilizer on net sales of maize with baseline prices

The increase in maize purchases by several of the household groups requires further explanation. As discussed above, giving households access to subsidized inputs may displace commercial input purchases, and thus leave production unchanged. The subsidy would then act as a cash transfer to the targeted households. This could explain why net purchases could increase, reflecting a relaxation of the cash constraint leading to increased leisure or maize consumption (through an income effect) which is in part satisfied through purchasing maize. Further subsidy access allows households to increase maize production and move beyond self-sufficiency.

Based on Figure 4, there does not seem to be much impact of access to subsidized maize fertilizer on labor supply, and no contraction of the labor market. The land-rich household group in the Central region initially hires some labor during peak season, but with access to subsidized fertilizer it decreases its labor demand, i.e. increasing net labor supply to the market. This is despite their increasing maize supply, as they substitute fertilizer for labor in production.[17] The household group thus shifts from more labor-intensive to more fertilizer-intensive maize production. The remaining household groups continue supplying as much labor as possible to relieve their cash constraint. According to this model, these households do not reduce off-farm labor supply, or start renting in labor, rather their adjustment in labor supply is mainly through the amount of family labor employed on-farm.

To understand the mechanisms behind the supply curves above, it is necessary to look at what

[17]The technology set specification facilitates substitution between labor and land through varying the intensity of fertilizer use and choice of improved versus local maize seeds.

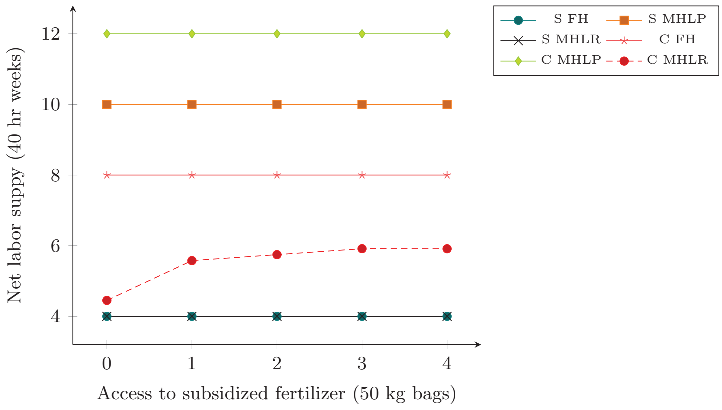

Figure 4: Effect of varying access to subsidized maize fertilizer on net labor supply to the market with baseline prices

happens to total fertilizer use and maize production for each household type. As discussed by Ricker-Gilbert et al. (2011), access to subsidized fertilizer has been found to displace commercial fertilizer purchases, and we do not expect fertilizer use to increase one-to-one with access to subsidized fertilizer.

According to the results presented in Figure 5, total fertilizer use initially decreases or stays constant for the male-headed land-poor groups, while the remaining household groups increase their total fertilizer use. Only the male-headed land-rich group in the Central region increases fertilizer use one-for-one with access to subsidized fertilizer, but not beyond access to three bags of fertilizer. Beyond access to two bags of subsidized fertilizer, there is little change in fertilizer use for the remaining household groups.

If we look at the male-headed land-poor group in the Central region as an example, the effect of access to subsidized fertilizer on relaxing the liquidity constraint of the household seems to be important. Being able to substitute increasingly more of fertilizer purchases with cheap fertilizer relaxes the liquidity constraint such that the household can focus on cash crop production. The household increasingly specializes in tobacco production with increased access to cheap fertilizer, and uses subsidized fertilizer in tobacco production.[18] Since tobacco is relatively more labor intensive than maize, this means increasing on-farm labor use. Access to more than two bags of fertilizer

[18]There is no constraint on the substitutability between fertilizer for maize and for tobacco in our model. The fertilizers distributed through the FISP can be used for tobacco production, while tobacco fertilizer is less suitable for maize.

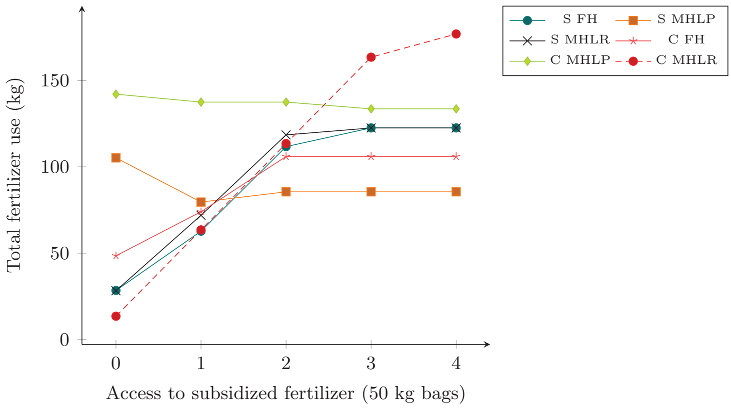

Figure 5: Effect of varying access to subsidized maize fertilizer on total fertilizer use with baseline prices

relaxes the liquidity constraint to the extent that the household can substitute its own maize with purchased maize, and thus decrease fertilizer use marginally, while increasing the area allocated to tobacco.

Looking instead at the male-headed land-poor group in the Southern region, the income effect leads to decreased labor use on-farm and substitution of maize produced on-farm with purchased maize. This response is another example of the impact of relaxing a tight cash constraint. The household spends its extra cash on increasing consumption of leisure, and purchasing maize rather than producing it on-farm with scarce resources. With access to more than one bag, net purchases increase further, but maize production also increases, as the household consumes more maize.[19]

Based on these results, it could be possible for the maize price to increase rather than decrease in response to subsidizing inputs, depending on the targeting and scale of the program. The subsidy could also have impacts on crops other than maize, for instance tobacco. We find that changing the price of fertilizer relative to other inputs, combined with a missing credit market, constrained access to off-farm labor, and transaction costs, create unexpected responses to introducing subsidized inputs for five of the six typical household groups.

[19]The utility function in the models does not give any incentive to increase food consumption beyond subsistence needs, but taste preferences may create incentives for substitution between food crops as long as minimum calorie and protein consumption is satisfied.

4.3 Effect of market imperfections on supply response

To investigate the importance of the market imperfections we have included in our models, we relax the assumptions concerning market imperfections in turn and look at the household groups' response to increased access to subsidized maize fertilizer. The figures below should thus be compared to Figures 3 and 4 above. We focus on three market imperfections that could potentially be mitigated through policy interventions, and that are likely to be important for households' response to the subsidy program: Marketing transaction costs, credit market access and a land rental market.

4.3.1 Maize transaction costs

Figure 6 shows the net supply of maize for each household group when maize transaction costs are removed.[20] The supply response of the female-headed and the male-headed land-rich groups in both regions is stronger than in the case with transaction costs. The net maize sales are larger at all levels of subsidy access, and the female-headed group in the Central region becomes a net seller of maize with access to more than two bags of subsidized fertilizer. As in the case with transaction costs, only the male-headed land-rich group is able to respond to access to more than three bags of subsidized fertilizer. For the male-headed land-poor household groups in both regions, the mechanisms behind their responses are similar to the case with transaction costs, but the lower price on purchased maize makes it possible to increase maize purchases at a lower cost.

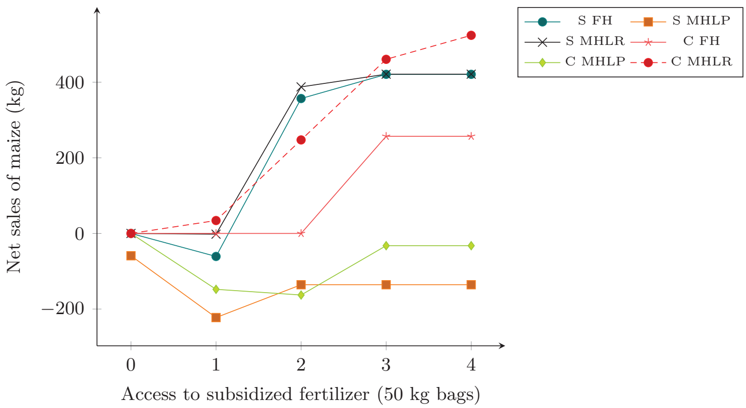

Figure 6: Net maize sales with decreased transaction costs

[20]Compared to the baseline assumption of 20 percent transaction costs.

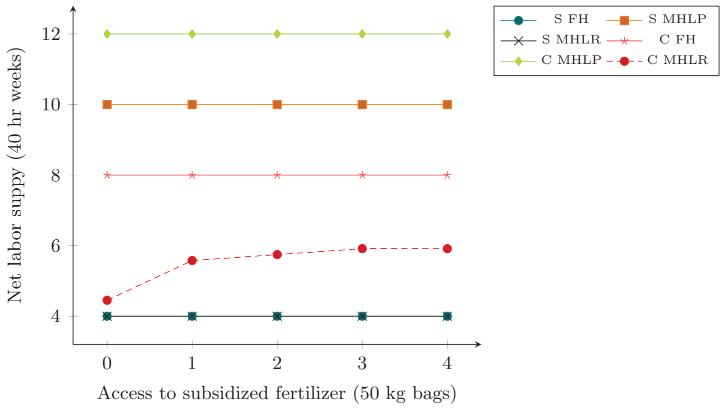

Figure 7: Net labor supply to the market with decreased transaction costs

In Figure 7 we show that there is still no contraction of the labor market in response to varying access to subsidized fertilizer, and that the male-headed land-rich group substitutes its rented in labor with subsidized fertilizer as access to cheap fertilizer increases.

4.3.2 Credit market access

In Figure 8 we show the net supply of maize from each household group with varying access to subsidized maize fertilizer after relaxing the assumption of no credit market. We now assume that households can spend up to 10 percent of their crop sales revenue from harvest time to relax their cash constraint at planting time. The response of the male-headed land-rich groups and the female-headed group in the Southern region is stronger than in the case without a credit market, and both land-rich groups are able to increase net maize sales with access to more than three bags of subsidized fertilizer. The land-poor groups and the female-headed group in the Central region, however, take advantage of access to credit by becoming net maize buyers. The male-headed land-poor group in the Southern region does so to increase maize consumption, while the land-poor group in the Central region increases tobacco production in addition to increasing maize consumption.

An interesting result from relaxing the credit constraint is that all household groups except the male-headed land-poor and the female-headed in the Southern region respond to the subsidy by decreasing their net labor supply, either by reducing their off-farm labor supply or by renting in labor in the peak-season. This is shown in Figure 9, and indicates that the household groups had to work at a high labor cost (drudgery) to meet their basic needs before the constraint was relaxed.

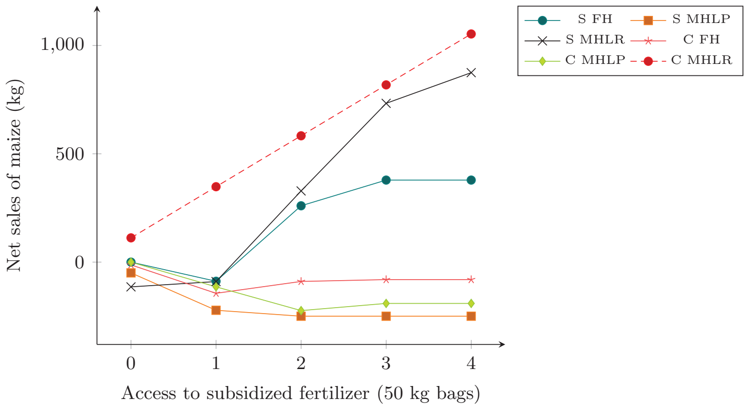

Figure 8: Net maize sales with "borrowing"

The land-rich group in the Central region rents in labor, and more so as the access to subsidized maize fertilizer increases, but it still works off-farm in the off-season.

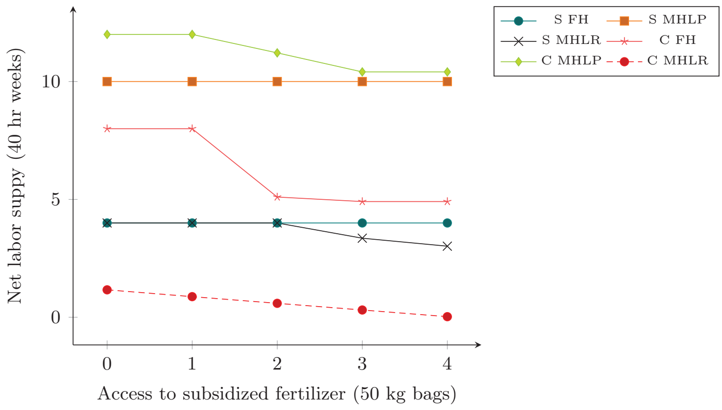

Figure 9: Net labor supply to the market with "borrowing"

4.3.3 Introducing a land rental market

As discussed above, the land rental market in Malawi is limited and largely informal. Heterogeneity in access to land, combined with seasonal labor shortages may constrain households' response to access to subsidized inputs. We relax the assumption of no land market by introducing a land rental market with transaction costs, where the land rental price and transaction costs are assumed to be

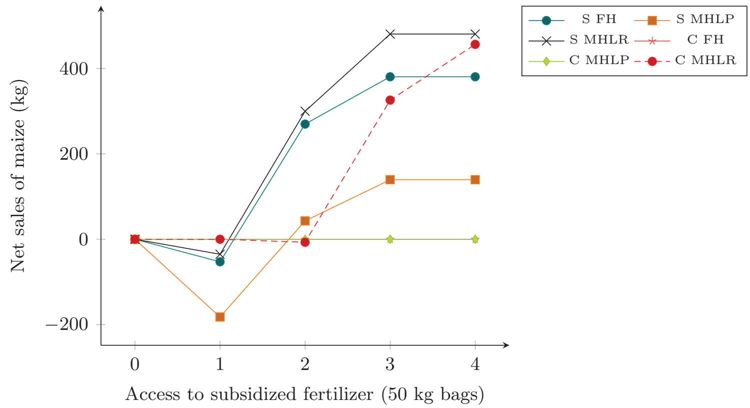

Figure 10: Net maize sales with land rental market

larger in the more land scarce Southern region than in the Central region.[21] We first investigate how this affects net maize sales. As shown in Figure 10, access to a land rental market and more than two bags of subsidized fertilizer turns all household groups, except the female-headed and male-headed land-poor groups in the Central region, into net sellers of maize. The two remaining household groups in the Central region remain self-sufficient when introducing land rental. The land-rich male-headed group in the Central region, however, is less responsive to access to subsidized fertilizer in terms of increasing maize supply when we introduce a land rental market. The household group prefers to rent out land rather than to rent in labor to cultivate their relatively large land area, given the binding cash constraint, and thus remains self sufficient with access to less than two bags of subsidized fertilizer.

Next, we look at the combined effect of land rental and subsidized fertilizer on the labor market. According to Figure 11, the labor market contracts, as the male-headed land-rich group in the Central region starts renting in labor when given access to more than one bag of fertilizer and a land rental market. A similar reduction, albeit marginal, holds for the male-headed land-poor group in the Central region when given access to more than two bags of subsidized fertilizer, but this group is instead reducing its own labor supply.

[21]The assumptions regarding transaction costs and prices in the land rental market are discussed in Holden (2014).

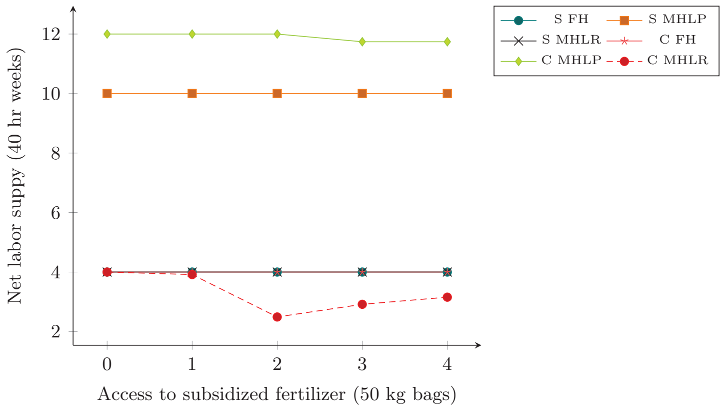

Figure 11: Net labor supply to the market with land rental market

5 Discussion

To summarize the results, both land-rich groups respond strongly to credit market access, indicating that this is an important constraint to expanding maize production for these groups. On the other hand, the land-poor in the Southern region become net sellers only when they gain access to a land rental market and have access to at least two bags of subsidized fertilizer. Relaxing the three market imperfections does not induce the land-poor household group in the Central region to become net sellers of maize, which may be due to the incentives for tobacco production, given that we have kept access to subsidized tobacco fertilizer fixed in the simulations. Both female-headed household groups respond most strongly to the incentives provided by removing transaction costs related to maize trade. For the female-headed group in the Southern region, removing transaction costs is the only measure that induces net maize sales in response to subsidy access, and only with access to more than two bags of subsidized fertilizer.

Our purpose is to investigate potential mechanisms that may explain the small empirically estimated price effects resulting from the subsidy program in Malawi. We will not attempt to aggregate our results to the market level and calculate an equilibrium price resulting from the supply responses observed in our model. That would require a more detailed model of rural markets, while we are mainly concerned with the behavior of typical household groups. However, based on the shares of the population represented by each household group we would not expect a large increase in maize supplied to the market, and thus not a large maize price decrease resulting from the program at the current levels. Likewise, our results on household net labor supply to the market suggest that the rural wage rate is unlikely to increase, they could even indicate the opposite. An important observation from our results is that the supply response of each household group is highly heterogeneous and non-linear. Moving beyond the observed level of the subsidy program, responses are even more diverse and depend on the market characteristics facing the household groups. The empirically estimated wage- and maize price impacts of the program in Ricker-Gilbert et al. (2013) and Ricker-Gilbert (2014) are estimates of the average impact of marginally increasing access to subsidized fertilizer. Based on the model results shown in this paper, extrapolating from these average marginal effects to predict wage- and price effects of a larger scale program could be problematic.

There are several limitations to using farm-household linear programming models to analyze the response to input subsidies. The models represent "average" or typical household groups, based on average characteristics of a large number of heterogeneous households in the survey data. This implies aggregating away much of the heterogeneity across actual households. It also means that it is important to create household groups that have similar characteristics in terms of responding to the input subsidy program, at the same time as being representative. We have not aggregated the behavior of our household groups to predict impacts on the rural maize and labor market. Rather, we consider each household type as an example of a Malawian rural household providing an illustration of potential limits to responding to subsidized inputs in the presence of market imperfections that are prevalent in the rural economy in Malawi.

The models are based on imperfect survey data, which was not collected for the purpose of creating these models. The data on labor supply and demand are particularly weak, as well as the data on food consumption. We have had to make simplifying assumptions, and external data sources were consulted where needed. These assumptions and sensitivity of the models with regards to them are discussed in Holden (2014).

Several assumptions are made in order to create tractable models that are sufficiently detailed to capture important household- and market characteristics, as well as detailed crop production technologies. For instance, we have not included any non-farm income sources or non-farm economic activities. The demand for non-farm foods and goods is treated as a desire to maximize cash income in the utility function of the households. Moreover, there is no uncertainty in the household models, which is obviously a simplification. Exposure to for instance weather risk and price risk is likely to affect household production decisions. For instance, according to Alwang and Siegel (1999), the risk of high maize prices induces subsistence orientation among Malawian smallholders. Incorporation of climate risk is one important area for future expansion of these models.

Nevertheless, the paper shows that this type of household models may be a useful tool to investigate the mechanisms behind results from reduced-form econometric models. Although the models are based on linear programming, they can be used to explore potential non-linear relationships derived from household heterogeneity in ways that econometric models are unable to. While the models have clear limitations in terms of predicting individual household behavior, they allow assessment of plausible responses to specific heterogeneity and to changes in exogenous factors. The results show how multiple market imperfections combined with the characteristics of typical household groups interact to create complex responses to access to subsidized farm inputs. These insights can be combined with the empirical findings on economy-wide effects of input subsidies to explain observed behavior.

6 Conclusion

We have showed in this paper that the maize and labor supply response of households to access to subsidized maize fertilizer is non-linear and dependent on heterogeneity in household groups' resource endowments and market imperfections. Depending on the targeting of the input subsidy and the amount of subsidized inputs received by households, this may explain why the observed general equilibrium effects of a large-scale subsidy program in Malawi are small. First, transaction costs related to buying and selling maize may be too large for households to participate in the market, preventing any impact of increased production on the retail price of maize. Furthermore, households may have constrained access to cash, and thus complementary inputs, preventing them from taking advantage of the subsidized inputs to increase production. Finally, subsidized inputs may serve to relax the cash constraint of households rather than increasing production. This final effect may, as we have seen, induce households to increase purchases of maize rather than supply. All these effects reduce the impact of the subsidy program on maize prices.

We find that relaxing the credit constraint and reducing transaction costs related to maize marketing could increase the supply response to input subsidies. This means that combining input subsidies with credit arrangements for smallholders, and improving infrastructure to reduce transaction costs could contribute to indirect effects that would benefit poor non-targeted households. The results also indicate that an improved land rental market could increase the supply response of some households.

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Appendix A

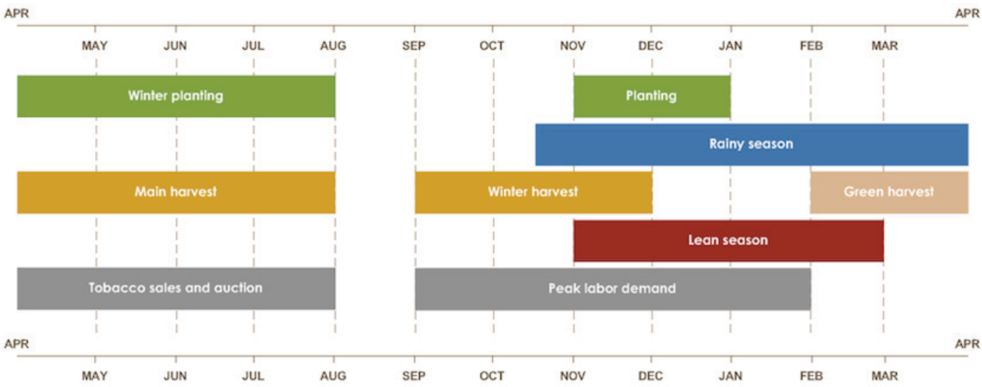

Figure A1: Timeline of typical agricultural year. Source: FEWS Net (2014)

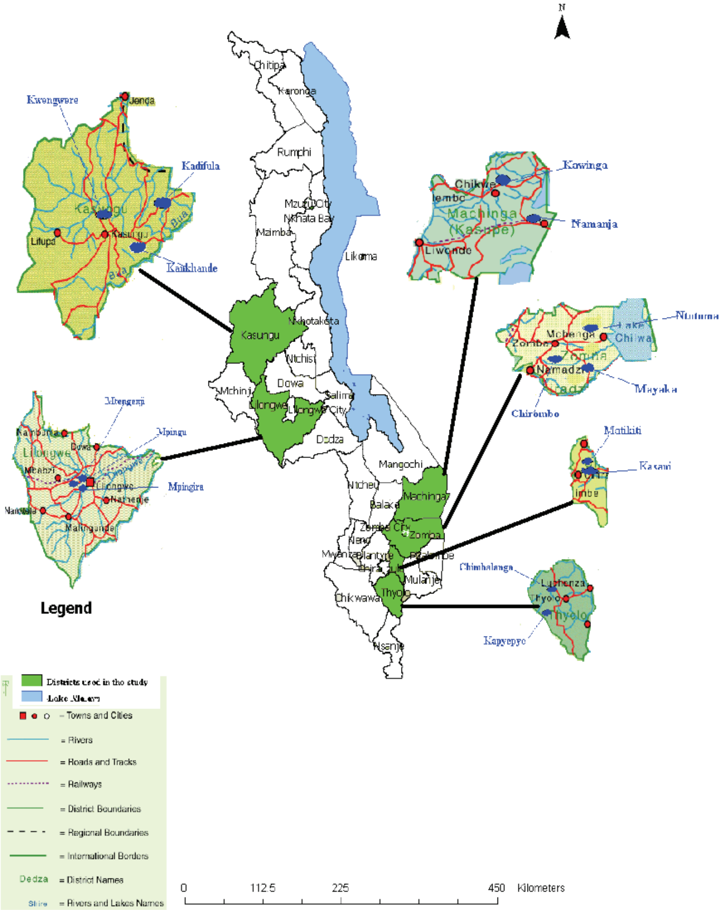

Figure A2: Districts and sites sampled in 2008/09 survey. Source: Lunduka (2009)

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Sofie Waage Skjeflo was born in Hamar, Norway in 1984. She holds a BSc. Degree in Economics from the University of Oslo (2007) and an MSc. Degree in Development and Natural Resource Economics from the Norwegian University of Life Sciences (2009).

The thesis aims to increase our knowledge of how climate change affects agriculture and the welfare of households in developing countries. It consists of an introduction and four independent papers, and adds to the existing literature by developing and applying approaches to modeling welfare impacts of climate change on households in Malawi and Tanzania.

The first paper simulates yield changes by 2030 due to climate change in a computable general equilibrium model of Malawi. The results show that approaches to measuring vulnerability to climate change that do not separate between net sellers and buyers of food, or do not account for impacts of climate change on food prices, are likely to be misleading.

The second paper is an empirical investigation of impacts of droughts on agricultural yields and children's health among Tanzanian farm households. It explores the scope for adapting to climate shocks through learning from previous drought events, and shows that for less severe droughts, households with more previous shock exposure seem to be less affected by current droughts, in terms of agricultural outcomes and impacts on children's nutrition.

The third paper looks at impacts of droughts and floods in Malawi by using a simple economy-wide framework. The contribution of this paper is to further develop economy-wide models to incorporate market failures and characteristics of rural economies.

Finally, the issues of market imperfections are further explored in a paper investigating farm household response to subsidized inputs in Malawi, using linear programming models of households facing liquidity constraints, labor market imperfections and transaction costs related to trade.

Supervisors: Stein T. Holden and Knut Einar Rosendahl.

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