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Essays on Gender Issues, Food Security, and Technology Adoption in East Africa

Simon Wagura Ndiritu

UNIVERSITY OF GOTHENBURG

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To Ndiritu, Wangeci senior, Stellamaris Wagura and Wangeci junior

To all the friends of development, always remember:

"Everybody is a genius. But if you judge a fish on its ability to climb a tree, it will live its whole life believing it is stupid". - Albert Einstein

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Preface

I set to be in the middle spinning the wheel, but as I tried they came to my aid when I was Pulling Heaven Down (PhD).

I want to sincerely acknowledge everyone who has supported me along the way. I am above all Thankful to Almighty God and my friends in Heaven for: answering my prayers, protecting and guiding me; and giving me, peace and joy during my PhD journey which was a leap in the dark. If I tried to list all who helped during my PhD studies, this section might become longer than my papers. However, there are some that I have to mention.

First and foremost, I would like to profoundly thank Katarina Nordblom and Jesper Stage for guiding me in the path of scientific thinking as an economist. As my advisors, they allowed me to wonder with my thoughts and explore research issues. This was through numerous formal and informal discussions that although initially seemed hopeless particularly when I was faced with many dangers, disappointments, inevitable frustrations, illness and dead ends, they constantly offered splendid views and fresh perspective. They saved the day in many occasions. In hard times, they always reminded me that I am not alone; offering encouragement, mentorship, support and guidance. Katarina and Jesper have an amazing ability and commitment to read drafts quickly and provide extremely constructive comments and ideas immediately they finish reading and open their office doors for discussions at my convenience. I owe my timely completion to their unwavering commitment. Thank you both.

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To my classmates: Anna, Claudine, Hailemariam, Haileselassie, Jorge, Kristina, Lisa, Michelle, Qian, and Xiaojun, we met as strangers, grew as classmates, and leave as friends with great memories and many happy hours spent in different settings, especially our academic tour in Ethiopia. Thanks Haile for organizing this trip! Our memories of each other will never be faded. As economists, there is nothing more precious we could have traded. Hailemarium, Yorge, Kristina, Lisa and Xiaojun you gave me special academic and social attention, I am deeply indebted to your generosity.

I would like to express profound gratitude to Swedish International Development Cooperation Agency (Sida) through the Environmental Economics Unit, University of Gothenburg, as well as from the Jan Wallander and Tom Hedelius Foundation for funding my studies. A special thank you to the Sida's Helpdesk: Anders, Daniel, Gunilla, Emelie, Olof, you gave me a fantastic opportunity to learn how to interact with policy makers.

I have spent quite some time with CIMMYT staff, which brought the enormous support from the former director of Social Economic Program, Bekele, Menale and Muricho. I am pleased once again to CIMMYT collaborators particularly for allowing me to join the SIMLESA project and gain from the rare data. My CIMMYT advisor, Menale, your professionalism and the high quality of your work contribute greatly to the value of the paper we produced. Many thanks Muricho for the SPSS classes you generously taught me.

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I also acknowledge my debt to the 'Rex' family (Gothenburg catholic student forum**)**, under the spiritual guidance of Fr. Tomas. I met many committed young people from all over the world, struggling with the usual hassle of a Christian. Many thanks for giving me a home I can share my faith (our index of happiness)! William, Donnesa and Vero made parties and camps in the woods which made unforgettable experiences.

In this journey, many gave me academic and social gifts in different forms and shape; a few are worth to mention: Mumbi, Sr. Jane Kevin, Sr. Juliana, Newton, Jesse, the Mulaehs', Mwaniki, Awiti, Paul, Tony, Sarah, Sussy and "the East African Mafias in Gothenburg".

Lastly but not least my sincere gratitude and thanks to my family. My parents-Ndiritu and Wangeci- your unconditional love, prayers, wisdom, support and spiritual guidance (always reminds me to reflect on Isaiah 43 and Jeremiah 29: 11-14-plans for peace, future and hope) in the city of Volvo! My precious siblings- Wambui, Kariuki, Wanjiru, Nyaruai and Kanyi- your unconditional love, prayers, encouragement and support has been a source of pride, strength and resilience. I am grateful to Uncle Charles Wagura who provided excellent mentorship on the wheel of life. My sweet wife Stella, my love and royal friend deserve special mention for her constant and unwavering love and encouragement and for putting up with my unusual behaviors and mood swings during this period of **P**atiently **h**oping for a **D**egree. Thank you my love for you continues to be the rock to keep my life journey strong and steady. To our daughter, Wangeci it took too long for you to join us in this world; thankfully you are on time to complement this journey! It's not possible to mention by names all those who assisted me, however, to all of you; friends of development, I am deeply grateful and feel honored.

Simon Wagura Ndiritu

Gothenburg, March, 2013

Abstracts

This thesis consists of five self-contained papers:

Paper 1: Are there systematic gender differences in the adoption of joint sustainable intensification practices? Evidence from Kenya

This paper uses household- and plot-level data to test whether there are systematic gender differences in the adoption of joint sustainable intensification practices in Kenya. Using a multivariate probit model, we find that gender differences in the adoption of some technologies do exist. Women plot managers are more likely to adopt maize-legume intercropping, but less likely to adopt minimum tillage and apply animal manure relative to male plot managers. However, we find no gender differences for adoption of maize-legume rotation, improved seed varieties, and application of inorganic fertilizer. The results further show that the adoptions of agricultural technologies are strongly influenced by plot characteristics and household factors such as plot size, plot ownership, soil fertility, extension service, access to credit, and age.

Key words: Complementarity, Gender, Agricultural Technology Adoption, Multivariate Probit, Kenya

JEL classification: O13, Q16

Paper 2: What determines gender inequality in household food security in Kenya? Application of exogenous switching treatment regression

This paper contributes to an understanding of the link between gender of household head and food security using household- and plot-level survey data from 88 villages and five districts in rural Kenya. We use an exogenous switching treatment regression effects approach to assess the gender food security gap. The study establishes that the female food security gap is attributable to observable differences in endowments and characteristics, but also to some extent to differences in the responses to those characteristics. We find that female-headed households (FHHs) could have been more food secure, had they had the male-headed households' (MHHs) observable resources and characteristics. Even if that had been the case, however, our results indicate that FHHs would still have been less food secure than the MHHs. The analysis further reveals that FHHs' food security is influenced by many factors: household wealth, social capital network, land quality, input use, access to output markets, information, and water sources. Policies aimed to reduce discrimination, strengthen local institutions and services, improve the road network, and increase FHHs' access to resources would increase the food security status of female farmers.

Keywords: food security, gender, discrimination, exogenous switching treatment regression, Kenya
JEL classification: O13, Q18

Paper 3: A study of post-harvest food loss abatement technologies in rural Tanzania

This paper focuses on preservation and improved storage technologies as an adaptation strategy to climate change. We also study the tradeoff between preservation techniques and improved cereal storage technologies among rural households in Tanzania. Using a bivariate probit model, we find that preservation measures and modern storage technologies are substitutes. In addition, we find that climate variables influence farmers' choice of preservation methods and improved storage technologies. Extension services increase adoption of improved and modern storage technologies. This finding has strong policy implications as it suggests that solving the present information inefficiency can significantly improve the rate of adoption, and hence reduce storage losses. Since modern technologies are relatively expensive, intervention by the government (through subsidies) and non-governmental organizations can play a significant role in stimulating the adoption of effective post-harvest management practices by poor households.

Keywords: Climate change adaptation, Storage technologies, preservation methods, post-harvest loss abatement, bivariate probit model, Tanzania
JEL classification: C35, O33, Q54

Paper 4: Does Perception of Risk Influence Choice of Water Source and Water Treatment? Evidence from Kenyan towns

This study uses household survey data from four Kenyan towns to examine the effect of households' characteristics and risk perceptions on their decision to treat/filter water as well as their choice of main drinking water source. Since the two decisions may be jointly made by the household, a seemingly unrelated bivariate probit model is estimated. It turns out that treating non-piped water and using piped water as a main drinking water source are substitutes. The evidence supports the finding that perceived risks significantly correlate with

a household's decision to treat/filter unimproved non-pipe water before drinking it. The study also finds that higher connection fees reduce the likelihood of households connecting to the piped network. Since the current connection fee acts as a cost hurdle which deters households from getting a connection, the study recommends a system where households pay the connection fee in instalments, through a prepaid water scheme or through a subsidy scheme.

Key words: Risk perception, water quality, drinking water, water treatment
JEL classification: Q53, Q56

Paper 5: Ndiritu, Simon Wagura and Wilfred Nyangena (2011), "Environmental goods collection and children's schooling: Evidence from Kenya", Regional Environmental Change, 11(3), 531-542

This paper presents an empirical study of schooling attendance and collection of environmental resources using cross-sectional data from the Kiambu District of Kenya. Because the decision to collect environmental resources and attend school is jointly determined, we used a bivariate probit method to model the decisions. In addition, we corrected for the possible endogeneity of resource collection work in the school attendance equation by using instrumental variable probit estimation. One of the key findings is that being involved in resource collection reduces the likelihood of a child attending school. The result supports the hypothesis of a negative relationship between children working to collect resources and the likelihood that they will attend school. The results further show that a child's mother's involvement in resource collection increases school attendance. In addition, there is no school attendance discrimination against girls, but they are overburdened by resource collection work. The study recommends immediate policy interventions focusing on the provision of public amenities, such as water and fuelwood.

Keywords: Environmental goods collection, Fuelwood, Water, Children, Schooling, Kenya

JEL Classification: O13, O15

Paper I

Are there systematic gender differences in the adoption of joint sustainable intensification practices? Evidence from Kenya

Simon Wagura Ndiritu[1]
Department of Economics, University of Gothenburg
email: Simon.wagura@economics.gu.se

Abstract

This paper uses household- and plot-level data to test whether there are systematic gender differences in the adoption of joint sustainable intensification practices in Kenya. Using a multivariate probit model, we find that gender differences in the adoption of some technologies do exist. Women plot managers are more likely to adopt maize-legume intercropping, but less likely to adopt minimum tillage and apply animal manure relative to male plot managers. However, we find no gender differences for adoption of maize-legume rotation, improved seed varieties, and application of inorganic fertilizer. The results further show that the adoptions of agricultural technologies are strongly influenced by plot characteristics and household factors such as plot size, plot ownership, soil fertility, extension service, access to credit, and age.

Key words: Complementarity, Gender, Agricultural Technology Adoption, Multivariate Probit, Kenya

JEL classification: O13, Q16

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[1] The household surveys for this research were supported by the Australian Center for International Agricultural Research (ACIAR) under the CIMMYT led SIMLESA project for Sustainable Intensification of Maize-Legume Cropping Systems in Eastern and Southern Africa. In addition, I gratefully acknowledge support from Sida (Swedish International Development and Cooperation Agency) through the Environmental Economics Unit, University of Gothenburg, as well as from the Jan Wallander and Tom Hedelius Foundation. The author would also like to thank Katarina Nordblom, Jesper Stage, Menale Kassie, Bekele Shiferaw, Måns Söderbom, and seminar participants at the University of Gothenburg and Brown Bag seminar in CIMMYT for helpful comments and suggestions.

1. Introduction

In this study, we examine gender and technology adoption by analyzing adoption of several agricultural technologies across jointly managed as well as female- and male-managed plots in Kenya. We test whether there are systematic gender differences in the adoption of joint sustainable intensification practices in Kenya. Different groups differ in their characteristics, endowments, and technology adoption behavior. For instance, it has generally been observed that female-headed households are resource poor in Sub-Saharan Africa (SSA), and Kenya is no exception. With respect to access to resources, there are gender-specific constraints that female plot managers face in SSA. For example, they are less well informed and have inadequate access to land and low levels of production assets and livestock ownership. Female-headed households face additional constraints such as weaker land tenure security, poorer quality of land, and little access to credit. One would expect that these constraints have direct effects on technology adoption, where women are usually less likely to adopt new technologies that are resources demanding. The study also tests whether the technologies under consideration are complements or substitutes.

The agricultural sector has been evolving over the years. The human population has increased, stimulating food demand and the need for increasing agricultural productivity. However, it has generally been observed that SSA agriculture has very low productivity, especially when contrasted with the green revolution in South Asia (World Bank, 2007). This low productivity is attributed to several factors: declining soil fertility, low or poorly distributed rainfall, slow and limited adoption of yield, and natural resources-improving technologies such as fertilizer, improved seed varieties, and sustainable land management technologies (Binswanger and Townsend, 2000; Pender et al., 2006; Ajayi, 2007; Misiko and Ramisch, 2007). A key strategy to increase agricultural productivity is through the introduction of improved agricultural technologies and better management systems (Doss, 2006).

Gender issues in Africa continue to generate interest among researchers and policy makers. The main proposition underlying this interest is that African women play a key role in farm work where they are responsible for family food security and home production. In an extensive review of gender-related issues in technology adoption, Doss (2001) found that African women farmers are less likely than men to adopt improved crop varieties and management systems. Doss (2001) argues that most farmers in Africa continue to be limited by choices and constraints at the household level, and women often face particularly severe constraints. We know that gender affects farmers' access to agricultural inputs such as labor and land(Meinzen-Dick et al., 2010). International Food Policy Research Institute (IFPRI's 2005) assessment of the impact of vegetable and fishpond technologies on poverty in rural Bangladesh concludes that targeting women in agricultural technology dissemination can have a greater impact on poverty than targeting men.

A fair amount of attention has been paid to the determinants of technology adoption in the economic development literature (Feder et al., 1985). However, from the perspective of gender, little has been done. No account has been taken of who participates in the technology adoption and to what extent, and the studies that do look at gender effects typically look at the gender of the household head rather than of the plot manager. A literature survey by Quisumbing (1995) concludes that there is mixed evidence on technological adoption by gender of the household head. Moreover, earlier studies in the literature show much wider use of chemical fertilizer in male-headed households than in their female counterparts in different countries (FAO, 2011). Similar results are found for improved crop varieties. While a fair amount of attention has been paid to differential adoption of combinations of improved seed varieties and chemical fertilizer (Doss and Morris, 2001; Bourdillon et al., 2002; Chirwa, 2005; Freeman and Owiti, 2003), there is a lack of evidence on gender differences for adoption and combinations of technologies such as maize-legume intercropping, maize-legume rotation, manure application, and minimum tillage.

Sustainable land management technologies and practices, or conservation agriculture, that have been widely studied include soil and water conservation, conservation tillage, cover crops practices, intercropping, and crop rotation (e.g., Pender and Gebermedhin, 2007; Arellanes and Lee, 2003; Rajasekharan and Veeraputhran, 2002; Herath and Takeya, 2003; Lee, 2005: Wollni et al., 2010; Kassie et al., 2009; Kassie et al., 2012). These studies identify the factors that determine adoption of each of these technologies. Notably, there is a missing link with gender aspects of the sustainable land management issues.

The contributions of this paper are threefold. First, unlike many gender studies in the literature, we disaggregate gender at the plot level between female- and male-managed plots. This disaggregation at the plot level is more concrete than is household head gender disaggregation since the gender of the household head is not a clear-cut determinant of who makes decisions about the individual plot (Peterman et al., 2010). This is important since a non-unitary household framework takes into account women plot managers in male-headed households and vice versa. Previous studies that consider only unitary household framework (consider female headship) miss the differences between female management and female headship in technology adoption decisions. The simplification of diverse household decision making in farming systems in Africa neglects the widespread phenomenon of farming behavior by male and female individuals within the same household, whether independently or jointly, and hence potentially leads to the wrong conclusions and policy targets for women in agriculture. In the present study, plot management means making decisions for all activities on that plot including technology adoption choices. If it was not clear-cut whether the decision maker on a plot was the household's man or woman, the plot was categorized as jointly managed.

Second, this is one of very few empirical studies that test the systematic gender differences in the adoption of sustainable intensification practices in Sub-Saharan Africa. This is important because women are resource constrained, which hinders their ability to adopt sustainable intensification practices as such initiatives are expensive and some take longer to become profitable to the farmer.

Third, we used rare data on multiple plot observations (more on the uniqueness of the data will be discussed in the data section) to jointly analyze factors that influence adoption of agricultural technologies. Thus, we consider the complementarity and substitutability among the various technologies studied. Another novelty of this study is that it considers multiple technologies unlike the usual approach to study single technologies. In reality, it is common practice for farmers to adopt several different technologies on their plots simultaneously, as it enables them to obtain the benefits of the nutrient supplementation and moisture retention synergies of different combinations of technologies. Thus, we address a shortcoming of most previous technology adoption studies, since they do not consider the interdependence among the agricultural technologies adopted by farmers (Yu et al., 2008). The insights from joint analysis (cross-technology correlation effects) provide important economic information for designing agricultural extension services. This means that if technologies are complements, extension services can be designed as one package for these technologies, while for technologies that are substitutes, the extension agents should explore the financial gains to the farmers by advocating for the cheap alternatives that are readily available to farmers.

The rest of the paper is organized as follows. Section 2 discusses overall agriculture and technology adoption in Kenya. Section 3 describes the data, sampling procedures, and the descriptive statistics. Section 4 discusses the methodology and Section 5 discusses the results. Finally, section 6 concludes the paper.

2. Agricultural technology adoption in Kenya

The agricultural sector has been evolving over the years. The human population has increased, stimulating food demand and the need for agricultural productivity to increase. A key strategy to increase agricultural productivity is through the introduction of improved agricultural technologies and management systems (Doss, 2006). This has motivated numerous studies to explore the determinants of technology adoption. These studies include adoption of inputs such as chemical fertilizer and high yielding varieties seeds and adoption of sustainable land management technologies and practices, or conservation agriculture.

In Kenya, the agricultural sector directly contributes 24 percent of the Gross Domestic Product (GDP) and 27 percent of GDP indirectly through linkages with manufacturing, distribution, and other service-related sectors. It also employs about 70 percent of the country's labor force and contributes 60 percent of export earnings, making it the highest foreign exchange earner in Kenya (GoK, 2004). Agricultural development is ranked high in Vision 2030 for achievement of food security in Kenya. The vision aims at increasing GDP from agriculture through an innovative, commercially oriented, and modern agricultural sector (GoK, 2007). These interventions are mainly through better yields in key crops such as maize and legumes. However, this can only be achieved if we are able to understand the farming technologies adopted by farmers and the drivers of the adoption behavior.

Land degradation, which contributes to low and declining farm productivity, is common in many parts of SSA, and Kenya is no exception. Efforts to alleviate land degradation in Kenya involves investment in soil and water conservation (SWC) technologies such as *fanya juu* terraces, mulching, Napier grass strips, grass strips, trees on boundaries, and soil and stone bunds. Minimum tillage is a relatively new technology in Kenya, and is slowly being adopted by farmers. All of these technologies prevent the washing away of nutrients by erosion and better retention of soil moisture. Mwangi et al. (2001) claim that soil erosion has caused losses in maize grain yields of up to 83 percent in Central Kenya. They also conducted on-farm trials and found higher maize grain yields in plots with SWC measures. In particular, they found that *fanya juu* terraces increased maize grain yields by 23.1 percent and Napier grass strips by 12.1 percent relative to their control plots. Additional benefits of *fanya juu* terraces and Napier grass strips are the production of fodder for animals. Thus, SWC also complements manure production.

An increasing number of Kenyan farmers report declining soil fertility to be a major constraint to farming. Inorganic fertilizers, which are perhaps the most important technology, and animal manure are widely used to improve soil fertility, but there are challenges with availability, accessibility, and affordability, especially for chemical fertilizers. Animal manure has the benefit of maintaining soil organic matter level, but has insufficient nutrients to maintain soil fertility and needs to be supplemented with chemical fertilizers (Jama et al., 1997). In mixed farming, crop-livestock interaction is a complementary adoption strategy where farmers rely on livestock to produce manure while the crops supply the livestock with fodder. Marenya and Barrett’s (2007) statistics show that manure and fertilizer inputs are complementarities due to the beneficial interactive effects of manure on fertilizer efficiency. Similarly, Jama et al. showed that positive results could be achieved using inorganic fertilizer and manure in western Kenya. In the same region, Duflo et al. (2008) experimented with fertilizer use by farmers on their own farms and found estimated annualized rates of return of 70 percent when using fertilizer. Thus, when fertilizer is used in limited quantities the resulting yield increases, making it a profitable investment even without other complementary changes in agricultural practices. Despite the potential returns to applying limited quantities of top dressing fertilizer, fertilizer use is still low in Kenya. When farmers are asked why they do not use fertilizer, the usual response is that they want to use fertilizer but do not have the money to purchase it.

There are suggestions that fertilizer is complementary with improved seed and other changes in agricultural practice that farmers may have difficulty implementing. Based on experimental farm evidence (see KARI 1994, reported in Duflo et al., 2008), the Ministry of Agriculture recommends that farmers use hybrid seeds, Di-Ammonium Phosphate (DAP) fertilizer at planting, and Calcium Ammonium Nitrate (CAN) fertilizer at top dressing when the maize plant is knee-high. Maize is a stable crop in Kenya, and the Ministry of Agriculture recommends the use of modern maize varieties to increase farm productivity. However, the adoption rates are still low in most of the rural areas: the average maize yield is about 2 t/ha. Potential yields of over 6 t/ha are possible through the increased use of fertilizer, improved seed, and crop husbandry practice (Makokha et al., 2001).

Low soil fertility among small-scale farmers in Kenya is mainly caused by continuous cultivation without a fallow period and insufficient crop rotation due to small farm sizes. Crop rotation enables the plot to replenish lost nutrients and avoid the build-up of soil-borne diseases. For instance, legumes in crop rotations supply biologically fixed atmospheric nitrogen to the soil, which could substitute or complement inorganic nitrogen fertilizer (Muthoni and Kabira, 2010). In the moist savanna agroecological zones of West Africa, Sanginga et al. (2002) found that maize grain yields are generally higher when the crop is planted following soybean than in continuous maize cultivation. Thus, proper crop rotation especially with the inclusion of a legume might help conserve soil fertility and increase cereal productivity in small-scale farms managed by resource-poor farmers in Kenya.

Farmers intercrop maize with legumes such as beans, pigeon pea, groundnuts, cowpeas, and soybeans in Kenya. Maize-legume intercropping has several benefits to the farmer, including an increase in yield per area of land, reduction in farm inputs, diet diversification, increased labor utilization efficiency, and hedging against the risk of crop failure as different crops have different patterns of growth and are affected by different pests and diseases (Willey, 1985; Odhiambo and Ariga, 2001; Kamanga et al., 2003; Tsubo et al., 2005). In western Kenya, Odhiambo and Ariga found that intercropping maize and beans in the same hole had the highest grain yield, with 78.6 percent above the yield in the pure maize strand. The systems of maize-legume intercropping are able to improve soil fertility by reducing the amount of nitrogen nutrients taken from the soil (Adu-Gyamfi et al., 2007). However, farmers might still have to use fertilizer or manure to increase the yield of their maize crop since maize-legume intercropping may not significantly improve the soil nitrogen levels, especially for plots with poor soil fertility. Hence, maize-legume intercropping is a complement to the use of inorganic fertilizer and animal manure. Lastly, combinations of different agricultural technologies are adopted because of their synergies to improve soil fertility and hence higher crop productivity.

Based on the above literature, we hypothesize that fertilizer application is complementary to all technologies under study. Yet, maize-legume intercropping is hypothesized to be a substitute for maize-legume rotation. We also expect maize-legume intercropping to be complementary to improved seeds (maize-legume) and manure application. Minimum tillage and SWC are hypothesized to be complements with other soil fertility-enhancing technologies such as maize-legume intercropping and maize-legume rotation. In general, with the exception of maize-legume intercropping and maize-legume rotation, the study hypothesizes that all the other technologies are complements in plots where they are adopted.

3. Data and descriptive statistics

The data used in this study is part of a baseline survey for a four-year (2010 - 2014) program to intensify the maize-legume cropping systems under rainfed agriculture in the Eastern and Southern Africa (ESA) region. The program targets maize and five main legumes grown in the region (beans, pigeon pea, groundnut, cowpea, and soybean). This study is based on Kenyan data where 613 households farming 2,851 plots were sampled in January-April 2011 in the western Kenya highlands (Siaya and Bungoma districts) and the eastern Kenya highlands (Meru South, Imenti South, and Embu districts) by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Kenya Agricultural Research Institute (KARI). The target sites are considered to have good potential for agriculture with relatively high rainfall (1,100-1,600 mm per year) and well-drained soils. Both regions have a bimodal rainfall pattern and two cropping seasons, i.e., March-April rains and September-November rains.

Before the actual survey a reconnaissance visit to all the study sites in western and eastern Kenya was conducted, during which secondary data was collected. Data on comprehensive crop production and livestock production as well as basic socioeconomic profiles of the households and marketing information concerning for example input and output markets were collected from the Ministry of Agriculture offices and other development organizations working in these two regions. Informal discussions with farmers and key informants were also conducted. Based on the information collected, the sampling strategy was developed.

Purposive sampling methods were used to select two regions (western and eastern Kenya) for the study, taking into account their maize-legume production potentials. A total of five districts were included in the sample: the Bungoma and Siaya districts from the western Kenya region and the Embu, Meru South, and Imenti South districts from the eastern Kenya region. With a target of 600 households (300 in each region), each district in western Kenya was allocated 150 households, while in eastern Kenya each district was allocated 100 households. Multi-stage sampling was employed to select lower level sampling clusters: divisions, locations, sub-locations, and villages. In total, 30 divisions were selected – 17 from western Kenya and 13 from Eastern Kenya. Efforts were made to ensure representation of the sample depending on the population of the study areas. Proportionate random sampling was designed where the total number of households in each division was compiled. The villages to be surveyed were randomly picked from the list prepared. The number of villages surveyed in each division was proportional to its total number of households. Furthermore, a list of households was drawn up for each of the selected villages, and the surveyed households were randomly picked. Thereafter the numbers of the households surveyed in each selected village were randomly picked. The number of households surveyed in each village was proportional to the number of households in that village.

A detailed questionnaire was used to collect the required maize-legume data and probe the socioeconomic characteristics of the households, including gender, age, education level (years of schooling), family size, asset and livestock ownerships, membership in farmers' groups, economic activities, and annual household expenditure. Other variables collected include crop and livestock production and marketing, access to information, and other farm production institutions. In addition to the household- and village-level data, the survey provides detailed information on plot-level characteristics including agricultural technology adoptions and practices, soil fertility, soil depth, plot slope, plot size, plot manager, and distance from the market.

Descriptive statistics

Table 1 reports the sustainable intensification practices considered in this study. For all the plot level information, we split the sample based on who manages the plot (female-managed, male-managed, and jointly managed plots). In this study, we specifically consider the following agricultural technologies: maize-legume intercropping, maize-legume rotation, improved seed (maize and legumes), use of chemical fertilizer, application of animal manure, soil and water conservation, and minimum tillage (conservation or zero tillage). Intercropping is a common technology in the study areas, where maize is usually intercropped together with legumes crops such as beans. About 36 percent of the plots are maize-legume intercropped (female-managed plots 43 percent and male-managed plots 31 percent, with a statistically significant difference). A similar pattern is observed for the maize-legume rotation, as it is applied on about 41 percent of the plots with women dominating the practice. An explanation could be that women need to intercrop in order to attain variety in food crops since they own and manage smaller plots compared to men. Maize is often rotated with legumes such as pigeon peas and haricot beans.

The main SWC methods are: terraces, mulching, grass strips, trees on boundaries, soil bunds, and stone bunds. Of the total plots cultivated, 67 percent received various combinations of SWC practices with a majority being jointly managed. Of the agricultural technologies under consideration, minimum tillage is the least adopted at about 5 percent (only about 2 percent of the female-managed plots). The data indicates that there are no gender differences in the adoption of improved maize and improved bean varieties. About 40 percent and 41 percent of plots have improved maize and improved bean varieties, respectively. On average, 67 percent of the plots grow improved seeds (improved maize and legumes). Female-managed plots have a low application of animal manure and use of chemical fertilizer during planting and/or top dressing. Inorganic fertilizer is used on 52 percent of the plots while animal manure is applied on 46 percent. This could be explained by woman owning few cattle (about 2) compared to men (about 3).

Table 2 reports the plot characteristics. The data suggest that men and women manage plots with differing land qualities. While men dominate in the management of good fertile soil, women are left to manage a majority of the low-fertility soil. The data also suggest that there are significant differences in the mean plot size with women managing smaller plots. We find that 29 percent of the plots are managed by women. Since fewer than 29 percent of households are female headed, some plots must be managed by women though the household head is male. Tabulation (Table 3) of female plot manager and gender of household head reveals that about 18 percent of the female-managed plots belong to male-headed households, while only 6 percent of the male-managed plots belong to female-headed households.

Table 1: Technologies adopted

	Dependent variables	Whole sample N=2851		Male plot manager (u1) N=892		Female plot manager (u2) N=822		Joint plot manager N=1126		t-test for equality of means(u1=u2)	
Variable name	**Variable definition**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t-Value**	**p-value**
mleginter	maize-legume intercrop(1=yes)	0.355	0.479	0.311	0.463	0.428	0.495	0.337	0.473	5.0852	0
mlegrot	maize-legume rotation(1=yes)	0.405	0.491	0.374	0.484	0.467	0.499	0.385	0.487	3.9016	0
improved maize	1=improved, 0=otherwise	0.395	0.489	0.407	0.492	0.375	0.484	0.399	0.490	1.3668	0.1719
improved bean	1=improved, 0=otherwise	0.409	0.492	0.410	0.492	0.398	0.490	0.418	0.493	0.5267	0.5985
improved seed	1=improved maize or legumes, 0=otherwise	0.672	0.470	0.672	0.470	0.657	0.475	0.684	0.465	0.6388	0.523
swc	practice soil and water conservation (1=yes)	0.667	0.471	0.619	0.486	0.644	0.479	0.723	0.448	1.0463	0.2956
mintill	practice minimum tillage (1=yes)	0.046	0.209	0.070	0.255	0.023	0.149	0.044	0.204	4.5508	0
fertilizer	use of fertilizer (1=yes)	0.517	0.500	0.548	0.498	0.461	0.499	0.534	0.499	3.6164	0.0003
manure	use of manure (1=yes)	0.459	0.498	0.502	0.500	0.397	0.489	0.476	0.500	4.4132	0

Table 2: Plot characteristics

	Plot characteristics	Whole sample N=2851		Male plot manager (u1) N=892		Female plot manager (u2) N=822		Joint plot manager N=1126		t-test for equality of means(u1=u2)	
Variable name	**Variable definition**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t-Value**	**p-value**
womanmag	subplot manager (1=woman)	0.289	0.453								
manmag	subplot manager (1=man)	0.314	0.464								
bothmag	subplot manager (1=joint)	0.396	0.489								
tenure	owned plot=1; 0=otherwise	0.865	0.341	0.898	0.303	0.860	0.347	0.845	0.362	2.4157	0.0158
plot size	size of the plot in acres	0.806	0.961	0.944	1.410	0.653	0.557	0.806	0.707	5.5315	0
plotdist	Plot distance in walking minutes	7.195	16.715	6.650	15.347	6.453	13.762	8.197	19.504	0.2799	0.7796
goodsoil	plot has good fertile soil(yes=1)	0.316	0.465	0.520	0.500	0.292	0.455	0.174	0.379	9.8277	0
medsoil	plot has moderately fertile soil(yes=1)	0.542	0.498	0.444	0.497	0.482	0.500	0.662	0.473	1.5884	0.1124
poorsoil	plot has poor fertile soil (yes=1)	0.140	0.347	0.036	0.186	0.226	0.418	0.162	0.368	12.2725	0
flatslope	plot has gentle slope (yes=1)	0.469	0.499	0.557	0.497	0.542	0.499	0.345	0.476	0.6177	0.5368
medslope	plot has moderate slope (yes=1)	0.490	0.500	0.411	0.492	0.412	0.492	0.612	0.488	0.0324	0.9742
steepslope	plot has steep slope (yes=1)	0.041	0.198	0.033	0.178	0.047	0.211	0.043	0.203	1.5006	0.1337
shaldepth	plot has shallow deep soil (yes=1)	0.146	0.353	0.128	0.334	0.166	0.372	0.145	0.352	2.2048	0.0276
meddepth	plot has moderate deep soil (yes=1)	0.651	0.477	0.689	0.463	0.573	0.495	0.679	0.467	5.0053	0
deepdepth	plot has deep soil (yes=1)	0.203	0.402	0.183	0.387	0.261	0.440	0.177	0.382	3.9178	0.0001

Table 3: Plot managers and household heads

Gender of the household head	**Plot manager**			
	Women	Men	Both equally	Total
Female	415 79.65	32 6.14	74 14.2	521 100
Male	407 17.55	860 37.08	1,052 45.36	2,319 100
Total	822 28.94	892 31.41	1,126 39.65	2,840 100

Table 4 reports the socio-economic characteristics for the whole sample and then splits the information into female-headed and male-headed households to test whether there are statistical differences between the means of the various variables under consideration. Out of 613 households, 19.4 percent are female headed. We uncover that there is a gender difference in the ownership of plots between the male and female-managed plots, with a majority (87 percent) owning the plot they cultivate. We observe differences in access to education, cattle ownership, income (proxied by expenditure), salaried employment, and ownership of a mobile phone between male- and female-headed households. However, there are no differences in access to extension visits, asset ownership excluding livestock, and total farm size. A majority (95 percent) of female-heads indicate that their main occupation is farming. The data display rather low average levels of education: the average household head has only primary education (7 years). The figure for women is even lower: the average woman has 4.5 years of education. On average, it takes half an hour to get to the nearest market.

Table 4: Socio-economic characteristics

		Whole sample (N=613)		Male headed (N=494)		Female headed (N=119)		t-test for equality of means	
Variable		**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t-Value**	**p-value**
Gender of hh head	1=female, 0=male	0.194	0.396						
Age	age of hh head	50.313	14.762	49.389	14.594	54.151	14.898	3.183	0.002
Education	years of schooling	7.380	3.974	8.092	3.629	4.445	4.006	9.632	0.000
Hhsize	family size	5.747	2.668	5.978	2.622	4.790	2.658	4.425	0.000
Farming	main occupation is farming	0.742	0.438	0.692	0.462	0.950	0.220	5.913	0.000
Salary	main occupation is salary employed	0.082	0.274	0.095	0.294	0.025	0.157	2.511	0.012
Assets	total value of non-livestock assets	74570.420	185075.0	75768.44	183588.800	69597.140	191836.80	0.326	0.744
Expenditure	family expenditure in 12 months	105145.30	209989.2	113748.4	228078.200	69431.650	98823.570	2.072	0.039
Extension	receive extension services	0.669	0.471	0.673	0.010	0.653	0.021	0.893	0.372
Farmergroup	member of farmers group	0.173	0.378	0.192	0.395	0.092	0.291	2.596	0.010
Frmsize	total farm size (ha)	1.199	3.365	1.279	3.723	0.863	0.702	1.193	0.233
Cattle	number of cattle	2.439	3.064	2.597	3.247	1.782	2.022	2.620	0.009
Phone	owns mobile phone	0.793	0.406	0.828	0.378	0.647	0.480	4.433	0.000
Traders	number of traders farmer knows	6.448	5.896	6.681	5.971	5.475	5.492	2.001	0.046
Relygovt	household can rely on government during crop failure	0.581	0.494	0.569	0.496	0.630	0.485	1.219	0.224
Network	household has relative in leadership position	0.485	0.500	0.507	0.500	0.395	0.491	2.202	0.028
Govtskills	farmers' confidence in local government officials including extension officers' skills	0.711	0.454	0.702	0.458	0.748	0.436	0.994	0.321
Mktdist	walking distance to main market (in minutes)	28.468	28.977	27.906	27.481	30.798	34.529	0.977	0.329
Credit	access to credit (yes=1)	0.117	0.322	0.125	0.331	0.084	0.279	1.253	0.211
Bungoma	Bungoma district=1	0.245	0.430	0.265	0.442	0.160	0.368		
Embu	Embu district=1	0.181	0.385	0.168	0.374	0.235	0.426		
Imentisouth	Imenti south district=1	0.165	0.371	0.168	0.374	0.151	0.360		
Merusouth	Meru south district=1	0.166	0.373	0.176	0.381	0.126	0.333		
Siaya	Siaya district=1	0.243	0.429	0.223	0.416	0.328	0.471		

4. Conceptual and Methodological framework

Adoption behavior is a complex and multidimensional process that can be explained by three paradigms, namely the innovation-diffusion paradigm, the economic constraint paradigm, and the adopter perception paradigm (Roger, 1962; Aikens et al., 1975; Agarwal, 1983; Gould et al., 1989; Biggs, 1990; Adesina and Zinnah, 1993; Negatu and Parikh, 1999). The role of access to information in the process of technology adoption is explained by the innovation-diffusion paradigm. Here extension services play a key role in ensuring that the potential end users are shown that it is rational to adopt the new technology. In addition, information costs are involved in the acquisition of new technology and the learning process itself (Wollni et al., 2010). Factors such as resource endowments that affect the profitability of the innovation fall under the the economic constraint paradigm, which states that the distributions of resource endowments among the potential users in a region could significantly constrain the pattern of technology adoption (Aikens et al., 1975; Adesian and Zinnah, 1993; Negatu and Parikh, 1999). Lack of access to capital, labor, or land could significantly constrain adoption decisions by different groups when the markets for these inputs are imperfect. The additional costs associated with adoption often result from higher input and labor requirements of the new technology or practice. Lastly, the adopter perception paradigm stresses the role of perceptions and attitudes in the farmer's decision-making process.

The decision to apply an agricultural technology is a function of the net benefits that the farmer expects to gain from adoption as compared to non-adoption of a technology or practice. Since farmers in SSA face various constraints, we do not expect them to adopt the technologies that maximize their expected profits. Some of these constraints include slow diffusion of new technologies in rural areas, which makes different groups adopt the new technologies at different times. Some technologies are expensive and access to credit is poor in most of the smallholders' environments. These and other gender-specific constraints have slowed down adoption of the technologies that have been shown to increase productivity and farm incomes in the long run.

Besley and Case (1993) provide a brief review of the empirical approaches taken in modeling agricultural technology adoption studies. They argue that cross-sectional studies are limited in exploring the adoption process but may provide useful insights into the farm and farmer characteristics associated with ultimately accepting the new technology. Farmers are faced with technology adoption alternatives that they may adopt in combination in order to address their specific production constraints. In addition, their choice of technologies today may be partly dependent on earlier technology choices. In this regard, recent studies have started to recognize that conditional on the adoption decision, farmers do consider bundles of technologies that maximize their utility of profit (Dorfamn, 1996; Moyo and Veeman, 2004; Marenya and Barrett, 2007; Yu et al., 2008). The benefits realized when several technologies are adopted simultaneously in a plot may exceed the additive benefits realized when each one is adopted separately.

Given that we investigate several technologies, we will allow for interdependence of the technologies since farmers simultaneously may adopt these technologies as substitutes, complements, or supplements. Because the adoption decisions are simultaneously or sequentially chosen by the farmers and the error terms of the adoption decisions may be correlated, we use a multivariate probit (MVP) specification. MVP allows for systematic correlations between choices for the different technologies. A positive correlation of the error terms indicates that the technologies are likely to be complements, while negative correlations of the error terms imply that the technologies are instead substitutes. Dorfamn (1996) observed that univariate modeling (the estimates of separate probit equations) excludes useful economic information contained in interdependence and simultaneous adoption decisions. Hence, the MVP estimator corrects for this problems by allowing for non-zero covariance in adoption across technologies (Marenya and Barrett, 2007). However, this technique has a caveat of common omitted determinants. For example, a source of positive correlation could be the existence of unobservable household-specific factors such as indigenous knowledge that affect the choice of several technologies but are not easily measurable. Nonetheless, estimating MVP is the only available method for testing important economic information contained in the interdependence of the technologies under study.

Another approach would have been to use a multinomial discrete choice model with seven discrete choice variables where the choice set is made up of all possible combinations of the technologies adopted (2^7 =128 available alternatives). However, since we would end up with many alternatives (128 alternatives), estimating a multinomial logit (MNL) or multinomial probit (MNP) model would be very challenging. Furthermore, the shortcoming of this approach is that interpretation of the influence of the explanatory variables on choices of each of the seven original separate technologies is very difficult. Another shortcoming is that it is not possible to test whether the technologies are complements or substitutes using the multinomial discrete choice model. Thus, this study instead uses the MVP specification.

The basic model is characterized by a set of binary dependent variables (T_i) specified as follows:

$$T_i^* = \beta_{ij} X_j + \varepsilon_i \qquad (1)$$

$$T_i = \begin{cases} 1 \text{ if } T_i^* > 0 \\ 0 \text{ otherwise} \end{cases}, \qquad (2)$$

where i=1…k denotes the type of agricultural technology adopted on a plot. We construct dummy variables for the following technologies: minimum tillage, SWC, maize-legume intercropping, maize-legume rotation, animal manure application, inorganic fertilizer and improved seed varieties (maize and legumes). X_j are the control variables. These are the same for the different agricultural technologies except livestock ownership and plot distance, which are specifically considered for manure adoption. β_{ij} is a vector of parameters to be estimated. ε_i are error terms that may be correlated, otherwise, we estimate the univariate probit model (Greene 2008). Following our sampling procedure, ε_i are multivariate normally distributed with zero means, unitary variance, and an n×n contemporaneous correlation matrix [$Q = \rho_{ij}$].

Following the constraints for women reviewed earlier, the variables hypothesized to influence adoption of agricultural technologies include human capital (proxied by education and age), gender, agricultural extension services, credit facilities, plot characteristics (soil quality, plot slope, plot size, irrigation investments, etc.), social capital, income, family labor, ownership of properties such as land and household assets, infrastructure, culture, and traditional norms (e.g., Bandiera and Rasul, 2006; Wollni et al., 2010; Pender and Gebremedhin, 2007; Arellanes and Lee, 2003, Asfaw and Admassie, 2004; Barrett, 2005; Isham, 2002; Nyangena, 2008). A literature review by Yesuf and Pender (2005) concludes that land tenure; agricultural extension services; access to credit; household endowment of labor, land, physical capital, financial capital and social capital; farm size; and access to markets influence adoption/investment in SWC decisions. However, the authors point out that the empirical evidence is mixed and hence there is a need for more research, especially concerning context-dependent determinants such as agricultural extension services.

Plot characteristics such as plot slope, soil quality, and irrigation do increase the likelihood of adopting improved land management strategies. In Honduras, plots with irrigation, plots farmed by their owners, and plots with steeper slopes were more likely to adopt minimum tillage among resource-poor agricultural households (Arellanes and Lee, 2003). Ownership of properties such as land, livestock, farm equipment, and household assets represents the physical capital of the farmer. A wealthier farmer is more likely to be able to finance and adopt capital-intensive technologies such as fertilizer use and improved seed varieties.

A hypothesis often raised in the literature is that land tenure influences the adoption of agricultural technologies in different ways. First, we have technologies that yield their benefits to farmers in the long term (e.g., minimum tillage and SWC) and technologies that yield benefits in the short term (e.g. fertilizer use, intercropping, and crop rotation). The idea is that a better tenure security will increase the likelihood that farmers will capture the returns from long-term investments without threats of eviction (Kassie and Holden, 2007).

We will use both a simple model and an interacted model, in which key policy variables (education, extension services, and plot ownership) are allowed to have both a main effect (for jointly managed plots and an additive effect (for female plot managers). Since these variables will be entered separately and interacted with a gender dummy, the model allows us to determine the extent to which the effect of the characteristics differs for women and men in the adoption decision. The t-statistic on the interacted coefficient provides a simple test of whether the difference is statistically significant.

Based on previous hypotheses in the literature, we include the following explanatory variables: age, education (years of schooling), family size, distance to market, credit access, participation in farmer's group, assets ownership excluding livestock (log assets), extension and training services, farm size, expenditure (log per capita expenditure-proxy for risk taking ability, assuming the hypothesis that the poor are risk averse), and ownership of livestock (cattle). Plot characteristics include plot size, plot distance from homestead, perceived soil fertility, perceived steepness of the plot, perceived soil depth, and land ownership.

5. Empirical results

The regression results from the MVP model are presented in Table 5. A likelihood ratio test was carried out: the null hypothesis that the correlation coefficients (ρ statistics) are jointly equal to zero against the alternative hypothesis that ρ are not jointly equal zero. The hypothesis of independence between the error terms is strongly rejected; hence, the use of MVP is supported by this test.

All the technologies under consideration have positive correlations indicating that they complement each other when adopted on the same plot. Further probing of the data reveals that only 4 percent of the plots did not receive any of the technologies. In the study areas, about 27 percent of the plots supplement manure with fertilizer, possibly leading to increased fertilizer efficiency. The high correlation coefficient (51%) for improved seed and fertilizer confirms that the two technologies are complements. This is consistent with the efforts of the extension services, which for a long time have promoted the two technologies jointly.

For a robustness check of the complementary results, we run univariate probit[2] analysis for each technology while controlling for the other technologies under consideration. The results are consistent with the MVP correlations and complementarity conclusion.

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[2] The probit results are not reported but they can be provided on request. They should, however, be taken with caution due to the endogeneity and interdependent nature of the sustainable agricultural innovations considered in this study.

Table 5: Multivariate probit

VARIABLES	(1) mleginter	(2) mlegrot	(3) impseed	(4) swc	(5) mintill	(6) fert	(7) manure
			Household characteristics				
Womanmag	0.138*	0.110	0.083	-0.062	-0.509***	-0.042	-0.200***
	(0.072)	(0.071)	(0.072)	(0.071)	(0.144)	(0.069)	(0.070)
Bothmag	0.146**	0.137*	0.131*	0.091	-0.245*	0.041	-0.031
	(0.072)	(0.070)	(0.072)	(0.070)	(0.126)	(0.068)	(0.068)
Lnpercaexp	0.027	-0.082**	-0.060	0.144***	-0.018	0.064*	0.109***
	(0.038)	(0.037)	(0.038)	(0.037)	(0.056)	(0.037)	(0.037)
Lncattle							0.442***
							(0.044)
Lnassets	-0.010	0.011	-0.017	-0.068***	-0.000	-0.004	-0.033*
	(0.019)	(0.019)	(0.019)	(0.018)	(0.027)	(0.018)	(0.019)
Age	-0.008***	-0.009***	-0.011***	0.002	-0.008**	-0.008***	-0.000
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Hhsize	-0.018	-0.039***	-0.019	0.044***	-0.041*	0.005	0.007
	(0.012)	(0.011)	(0.012)	(0.012)	(0.021)	(0.011)	(0.011)
Education	-0.019**	-0.004	-0.006	-0.005	-0.018	0.006	-0.012
	(0.008)	(0.008)	(0.008)	(0.008)	(0.014)	(0.008)	(0.008)
Credit	0.008	-0.099	0.142*	0.249***	0.304**	0.199**	0.108
	(0.081)	(0.085)	(0.084)	(0.091)	(0.123)	(0.082)	(0.082)
Farmergroup	-0.176**	-0.237***	-0.007	-0.167**	-0.178	0.041	0.036
	(0.071)	(0.072)	(0.069)	(0.067)	(0.124)	(0.068)	(0.067)
Extension	0.193***	0.085	0.173***	-0.099*	0.371***	0.218***	0.098*
	(0.059)	(0.059)	(0.058)	(0.059)	(0.104)	(0.057)	(0.057)
Mktdist	0.002*	0.001	0.002	-0.002**	0.002	0.001	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	
			Plot characteristics				
Lnplotsize	0.365***	0.331***	0.283***	0.011	0.351***	0.458***	0.053
	(0.037)	(0.036)	(0.035)	(0.035)	(0.067)	(0.035)	(0.033)
Plotdist							-0.010***
							(0.002)
Goodsoil	-0.089	0.059	0.261***	0.035	0.159	0.278***	0.190*

	(0.102)	(0.100)	(0.100)	(0.107)	(0.196)	(0.102)	(0.102)
Medsoil	-0.106	-0.004	0.269***	0.003	0.087	0.128	0.084
	(0.092)	(0.090)	(0.090)	(0.098)	(0.175)	(0.093)	(0.095)
Flatslope	-0.210*	0.036	0.002	-0.745***	-0.237	-0.389***	0.355**
	(0.126)	(0.151)	(0.139)	(0.163)	(0.230)	(0.146)	(0.139)
Medslope	-0.141	0.090	-0.093	-0.136	-0.126	-0.419***	0.136
	(0.126)	(0.150)	(0.138)	(0.161)	(0.223)	(0.145)	(0.137)
Shaldepth	0.107	0.269***	0.202**	0.068	0.115	0.157	-0.196**
	(0.098)	(0.098)	(0.097)	(0.099)	(0.174)	(0.096)	(0.094)
Meddepth	-0.441***	-0.192***	0.037	0.058	0.025	-0.176**	-0.099
	(0.069)	(0.071)	(0.071)	(0.071)	(0.121)	(0.070)	(0.069)
Ownedplot	-0.333***	-0.240***	-0.373***	0.353***	-0.026	-0.238***	0.306***
	(0.080)	(0.078)	(0.084)	(0.077)	(0.126)	(0.078)	(0.088)
Bungoma	0.644***	0.288***	0.289***	-0.840***	-0.530**	0.373***	-0.477***
	(0.102)	(0.103)	(0.101)	(0.099)	(0.211)	(0.097)	(0.092)
Embu	0.399***	0.445***	0.781***	0.124	0.234*	0.626***	0.362***
	(0.091)	(0.091)	(0.092)	(0.088)	(0.141)	(0.088)	(0.086)
Merusouth	-0.222**	0.110	0.784***	0.220**	0.204	0.254***	0.532***
	(0.097)	(0.091)	(0.092)	(0.087)	(0.129)	(0.086)	(0.085)
Siaya	1.423***	1.159***	0.192*	0.104	-0.196	0.037	-0.071
	(0.108)	(0.108)	(0.107)	(0.106)	(0.190)	(0.105)	(0.099)
Constant	0.689*	1.265***	1.791***	-0.265	-0.380	0.557	-1.680***
	(0.410)	(0.408)	(0.410)	(0.414)	(0.680)	(0.400)	(0.408)
Model chi-square	2311	2311	2311	2311	2311	2311	2311
Observations	2637	2637	2637	2637	2637	2637	2637

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	Correlation coefficient	**Robust std. err**	**P-value**
rho21	0.872	0.012	0.000
rho31	0.655	0.027	0.000
rho41	0.021	0.033	0.529

rho51	0.157	0.050	0.002
rho61	0.593	0.026	0.000
rho71	0.219	0.031	0.000
rho32	0.675	0.024	0.000
rho42	0.014	0.031	0.656
rho52	0.078	0.053	0.140
rho62	0.611	0.023	0.000
rho72	0.236	0.030	0.000
rho43	0.018	0.032	0.572
rho53	0.043	0.059	0.466
rho63	0.505	0.026	0.000
rho73	0.196	0.030	0.000
rho54	0.232	0.059	0.000
rho64	0.053	0.032	0.100
rho74	0.046	0.032	0.145
rho65	0.132	0.045	0.003
rho75	0.102	0.040	0.010
rho76	0.211	0.030	0.000

Likelihood ratio test of rho 21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho65 = rho75 = rho76 = 0: chi2(21) = 2327.71 Prob > chi2 = 0.0000

To check the descriptive results, which clearly show gender differences in access to resources and adoption of maize-legume intercropping, maize-legume rotation, minimum tillage, fertilizer, and use of manure, we run a multivariate analysis. With the exception of maize-legume intercropping, animal manure, and minimum tillage, after controlling for other potentially important factors that differ between men and women, we find no gender differences for improved seed varieties, maize-legume intercropping, maize-legume rotation, SWC, and application of chemical fertilizer technologies relative to male-managed plots. These finding resonate with past studies that found no significant difference between male and female farmers in the adoption of chemical fertilizer and improved seed varieties (Doss and Morris, 2001; Bourdillon et al., 2002).

Women plot managers are more likely to adopt maize-legume intercropping relative to male plot managers. Jointly managed plots are less likely to have minimum tillage practices and more likely to adopt maize-legume intercropping, maize-legume rotation, and improved seeds than are male-managed plots. Our analysis of gender differences reveals that female plot managers are less likely to practice minimum tillage and apply animal manure. Additionally, we find that cattle ownership increases the likelihood of animal manure application. Frequent use of manure highlights the crucial role that livestock play in smallholder farming (Waithaka et al., 2007).

To check the effects of family fixed effects, we interact the female household head dummy with the female manager variable. When we include the interaction of female household head dummy with the female manager variable and the female headship, we do not find any significant difference with the exception of minimum tillage.[3] Female managers who are from female-headed household are less likely to adopt minimum tillage.

We find a significant positive influence of extension services on maize-legume intercropping, improved seed varieties, fertilizer use, manure application, and minimum tillage but a negative effect on SWC. This result supports available evidence on the mixed performance of extension services on technology adoption (e.g., Freeman and Owiti, 2003; Chirwa, 2005). Results further indicate that household income (proxied by expenditure) favors adoption of inorganic fertilizer, animal manure application, and SWC but less likely to influence adoption of maize-legume rotation. Perhaps this is because wealthier farmers are less risk averse and can afford to adopt expensive technologies such as inorganic fertilizer.

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[3] Results not reported but can be provided on request

Plot characteristics are highly significant in determining the choice of agricultural technologies. As the plot size increases, farmers are more likely to adopt improved seed varieties, maize-legume intercropping, maize-legume rotation, minimum tillage, and to use inorganic fertilizer. Plots with good fertile soil are more likely to receive improved seed varieties, fertilizer, and animal manure application relative to poor fertile soils. With regard to plot slope, we find that flat-sloped plots negatively and significantly influence the adoption of maize-legume intercropping, SWC, and chemical fertilizer but positively influence the application of animal manure relative to steep-sloped ones. Regarding soil depth, farmers are more likely to adopt maize legume rotation and improved seeds on shallow depth soil but less likely to use animal manure relative to deep depth soil.

As expected, plots that are further away from the homestead are less likely to receive animal manure, which is heavy and bulky, meaning distance is a significant cost for the adoption of this technology. SWC practices negatively correlate with distance to market. The results further show lack of significance for distance-to-market for inputs such as chemical fertilizer. Similar results were found in western Kenya in Freeman and Owiti's (2003) study on fertilizer adoption.

As expected, technologies that yield benefits after a long period, such as SWC and animal manure, are more likely to be used on owned plots. This is consistent with the finding that better tenure security increases the likelihood that farmers capture the returns from long-term investments without threats of eviction (Kassie and Holden, 2007). On the other hand, farmers are less likely to apply chemical fertilizer, improved seed varieties, maize-legume intercropping, and maize-legume rotation on their own plots. Perhaps this is because farmers prefer to use long-term soil fertility enrichment on their own plots and short-term soil fertility intensifications on rented plots.

We uncover that access to credit is positively and significantly correlated with adoption of improved seeds, SWC, minimum tillage, and chemical fertilizer. Family labor has a significant positive effect on the adoption of SWC but is negatively correlated with maize-legume rotation and minimum tillage. This is in line with agricultural intensification literature that argues for less rotation (shifting cultivation) with high population pressure (Heerink, 2005). Education turns out to be negative and significant in determining the choice of maize-legume intercropping. The results also reveal that older farmers are less likely to adopt improved seeds, maize-legume intercropping, maize-legume rotation, minimum tillage, and chemical fertilizer. SWC, maize-legume intercropping, and maize-legume rotation are negatively influenced by social capital (participation in farmers groups); we do not find evidence of social capital influencing adoption of the other technologies. We also control for regional fixed effects.

Table 6 reports the MVP model with interaction effects. We allow for interaction effects between female plot manager dummy and extension services, education, and plot ownership. We find that if female plot managers have no access to extension services, education, and plot ownership, they are more likely to adopt SWC and less likely to apply animal manure. Female plot manager are more likely to adopt animal manure but less likely to practice SWC and use fertilizer on their plots following exposure to extension services. Well-informed plot managers are less likely to adopt SWC. Female plot managers who own land are more likely to adopt animal manure but less likely to use fertilizer.

Table 6: Multivariate probit (with interactions)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	mleginter	mlegrot	impseed	Swc	mintill	fert	manure
			Household characteristics				
womanmag	-0.113	-0.028	0.054	0.573***	-0.539	-0.242	-0.854***
	(0.205)	(0.209)	(0.214)	(0.218)	(0.405)	(0.210)	(0.238)
womanmedu	0.003	-0.004	0.019	-0.052***	0.030	0.017	-0.003
	(0.014)	(0.014)	(0.015)	(0.015)	(0.032)	(0.014)	(0.015)
womanmowner	0.055	0.107	-0.182	-0.085	-0.095	0.296*	0.411**
	(0.166)	(0.169)	(0.180)	(0.167)	(0.296)	(0.171)	(0.187)
womanmext	0.195	0.040	0.074	-0.264**	-0.151	-0.278**	0.417***
	(0.124)	(0.126)	(0.127)	(0.128)	(0.290)	(0.123)	(0.128)
bothmag	0.102	0.087	0.110	0.090	-0.260**	0.010	-0.056
	(0.072)	(0.070)	(0.072)	(0.070)	(0.127)	(0.068)	(0.068)
lnpercaexp	0.026	-0.062*	-0.047	0.153***	-0.013	0.097***	0.112***
	(0.038)	(0.037)	(0.038)	(0.038)	(0.057)	(0.037)	(0.037)
lncattle							0.438***
							(0.044)
lnassets	-0.017	0.000	-0.027	-0.063***	-0.006	-0.011	-0.043**
	(0.019)	(0.019)	(0.019)	(0.018)	(0.027)	(0.018)	(0.019)
age	-0.007***	-0.006***	-0.009***	0.001	-0.008**	-0.007***	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
hhsize	-0.018	-0.034***	-0.017	0.049***	-0.038*	0.013	0.007
	(0.012)	(0.011)	(0.012)	(0.012)	(0.021)	(0.011)	(0.011)
mktdist	0.002	0.001	0.002	-0.002**	0.002	0.001	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	
education	-0.019*	-0.004	-0.012	0.014	-0.027*	0.001	-0.009
	(0.010)	(0.010)	(0.010)	(0.010)	(0.016)	(0.010)	(0.010)
credit	0.037	-0.081	0.142	0.245***	0.305**	0.218***	0.115
	(0.082)	(0.086)	(0.087)	(0.091)	(0.121)	(0.084)	(0.082)
farmergroup	-0.164**	-0.247***	-0.030	-0.191***	-0.178	0.037	0.046
	(0.070)	(0.072)	(0.069)	(0.068)	(0.126)	(0.067)	(0.068)
extension	0.144**	0.050	0.118*	-0.028	0.386***	0.273***	-0.015
	(0.069)	(0.068)	(0.069)	(0.070)	(0.106)	(0.066)	(0.066)
Plot characteristics							
lnplotsize	0.364***	0.329***	0.292***	0.009	0.346***	0.462***	0.057*
	(0.037)	(0.036)	(0.035)	(0.035)	(0.065)	(0.035)	(0.033)
plotdist							-0.010***
							(0.002)

goodsoil	-0.097	0.102	0.279***	0.078	0.142	0.303***	0.199*
	(0.105)	(0.101)	(0.102)	(0.106)	(0.188)	(0.102)	(0.102)
medsoil	-0.098	0.053	0.302***	0.029	0.093	0.142	0.111
	(0.094)	(0.093)	(0.092)	(0.098)	(0.174)	(0.093)	(0.095)
flatslope	-0.178	0.064	-0.023	-0.733***	-0.177	-0.380***	0.306**
	(0.139)	(0.144)	(0.141)	(0.163)	(0.234)	(0.144)	(0.146)
medslope	-0.130	0.116	-0.106	-0.112	-0.083	-0.411***	0.101
	(0.139)	(0.142)	(0.139)	(0.161)	(0.227)	(0.143)	(0.144)
shaldepth	0.109	0.277***	0.222**	0.070	0.134	0.189*	-0.220**
	(0.097)	(0.097)	(0.100)	(0.100)	(0.175)	(0.096)	(0.095)
meddepth	-0.456***	-0.181**	0.072	0.052	0.050	-0.123*	-0.112
	(0.070)	(0.071)	(0.071)	(0.071)	(0.121)	(0.070)	(0.070)
ownedplot	-0.351***	-0.258***	-0.327***	0.382***	0.011	-0.317***	0.174*
	(0.100)	(0.093)	(0.103)	(0.091)	(0.142)	(0.091)	(0.103)
bungoma	0.631***	0.288***	0.278***	-0.871***	-0.536**	0.338***	-0.470***
	(0.102)	(0.102)	(0.101)	(0.099)	(0.212)	(0.097)	(0.093)
Embu	0.406***	0.462***	0.767***	0.121	0.233*	0.614***	0.349***
	(0.091)	(0.089)	(0.091)	(0.088)	(0.135)	(0.088)	(0.087)
merusouth	-0.191**	0.193**	0.793***	0.262***	0.190	0.268***	0.528***
	(0.096)	(0.091)	(0.092)	(0.087)	(0.133)	(0.086)	(0.086)
Siaya	1.429***	1.164***	0.179*	0.100	-0.215	-0.007	-0.056
	(0.108)	(0.108)	(0.107)	(0.105)	(0.194)	(0.104)	(0.101)
constant	0.782*	1.022**	1.749***	-0.669	-0.445	0.273	-1.440***
	(0.422)	(0.428)	(0.428)	(0.431)	(0.657)	(0.406)	(0.423)
Observations	2,637	2,637	2,637	2,637	2,637	2,637	2,637
Model chi-square	2351	2351	2351	2351	2351	2351	2351

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	Correlation coefficient	Robust std. err	P-value
rho21	0.872	0.012	0.000
rho31	0.629	0.026	0.000
rho41	-0.009	0.034	0.802
rho51	0.130	0.051	0.011

rho61	0.593	0.025	0.000
rho71	0.216	0.031	0.000
rho32	0.652	0.022	0.000
rho42	0.025	0.032	0.427
rho52	0.074	0.051	0.146
rho62	0.602	0.023	0.000
rho72	0.225	0.030	0.000
rho43	-0.005	0.033	0.878
rho53	0.062	0.058	0.288
rho63	0.523	0.025	0.000
rho73	0.198	0.030	0.000
rho54	0.246	0.055	0.000
rho64	0.076	0.033	0.020
rho74	0.060	0.032	0.061
rho65	0.169	0.044	0.000
rho75	0.082	0.039	0.035
rho76	0.208	0.030	0.000

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho
> 43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho65 = rho75 = rho76 = 0:
chi2(21) = 2312.54 Prob > chi2 = 0.0000

6. Conclusions

Using a smallholders' plot-level dataset, this study contributes to the still limited literature on the role of gender on adoption of agricultural technologies. This paper explores the gender differential in the adoption of maize-legume intercropping, maize-legume rotation, improved seed (maize and legumes), use of chemical fertilizer, application of animal manure, soil and water conservation (SWC), and minimum tillage (conservation or zero tillage) in Kenya. The study uses primary plot-level and household data collected from two agricultural zones: western Kenya (the Siaya and Bungoma districts) and eastern Kenya (the Meru South, Imenti South, and Embu districts). A sample of 613 households and 2,851plots are used. From a policy perspective, this research contributes to the ongoing debate on best practices by addressing gender-related challenges in agricultural technology adoption. The paper focuses on testing whether there exist systematic gender differences in the adoption of sustainable intensification practices. Both descriptive and econometric methods are employed. Plots are classified into three groups: jointly managed, managed by women, and managed by men.

The descriptive results indicate that women generally manage plots with lower soil fertility, thus they have a greater need for adopting improved technologies. We also find significant differences in the ownership of plots and mean plot size, with women managing smaller plots. In addition, we observe differences in access to education, cattle ownership, household income (proxied by expenditure), salaried employment, and ownership of a mobile phone between male- and female-headed households. However, there are no gender differences in access to extension visits, asset ownership excluding livestock, and total farm size between the female- and male-headed households.

The econometric results suggest that all technologies under consideration have positive correlations, indicating that the innovations complement each other in plots where they are adopted. The high correlation coefficient (51%) between improved seed and fertilizer confirms that the two technologies are complements, supporting the efforts of the extension services that for a long time have promoted the two technologies jointly. The analysis further shows that there are gender differences in the adoption pattern of some technologies. Female plot managers are more likely than male plot managers to adopt maize-legume intercropping but less likely to apply animal manure and adopt minimum tillage. However, after controlling for household assets and plot characteristics, we find no gender differences for adoption of SWC, maize-legume rotation, improved seed varieties, and application of inorganic fertilizer.

For the chemical fertilizer and improved seeds, our findings corroborate those of Doss and Morris (2001), i.e., that adoption of these technologies depends on access to resources rather than on gender *per se*. From our finding, the same conclusions follow for SWC and maize-legume rotation. Yet we do find gender differences in access to resources, meaning that the driving forces behind the differences in adoption may be explained by these factors. Gender matters for maize-legume intercropping, animal manure, and minimum tillage investments. This study shows that maize-legume intercropping, manure, and minimum tillage are not gender-neutral technologies, with women choosing not to practice minimum tillage and use of manure or they do not have access to manure. Factors explaining these differences are beyond the scope of the current study due to data limitations (this would require panel data enabling the researcher to control for unobserved heterogeneity).

The results of this analysis show that the adoptions of agricultural technologies are strongly influenced by plot characteristics and household factors that differ between men and women, suggesting several policy implications. Provision of credit facilities would significantly increase adoption of improved seeds, SWC, minimum tillage, and chemical fertilizer. The lack of significance of the distance-to-market for inputs such as chemical fertilizer suggests that there is a good access network for these inputs in the study areas. Continued reduction of the cost of accessing farming inputs will induce wider adoption of purchased inputs.

Though older farmers might have more experience with traditional technologies such as animal manure, younger farmers tend to be more innovative and educated and may also have lower levels of risk aversion than older farmers toward technologies such as maize-legume intercropping, maize-legume rotation, minimum tillage, chemical fertilizer, and improved seeds than older farmers. So, efforts to promote maize-legume intercropping, maize-legume rotation, minimum tillage, chemical fertilizer, and improved seeds should target younger farmers who would warmly welcome the complementary role that the technologies play in the plots where they are adopted.

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Paper II

What determines gender inequality in household food security in Kenya? Application of exogenous switching treatment regression

Menale Kassie[1]and Simon Wagura Ndiritu[2,1]
[1]Scientist-Agricultural & Development Economist at CIMMYT (International Maize and Wheat Improvement Center), Nairobi, Kenya; e-mail: m.kassie@cgiar.org.
[2]Department of Economics, University of Gothenburg, Sweden and CIMMYT (International Maize and Wheat Improvement Center), Nairobi, Kenya; e-mail: Simon.wagura@economics.gu.se

Abstract

This paper contributes to an understanding of the link between gender of household head and food security using household- and plot-level survey data from 88 villages and five districts in rural Kenya. We use an exogenous switching treatment regression effects approach to assess the gender food security gap. The study establishes that the female food security gap is attributable to observable differences in endowments and characteristics, but also to some extent to differences in the responses to those characteristics. We find that female-headed households (FHHs) could have been more food secure, had they had the male-headed households' (MHHs) observable resources and characteristics. Even if that had been the case, however, our results indicate that FHHs would still have been less food secure than the MHHs. The analysis further reveals that FHHs' food security is influenced by many factors: household wealth, social capital network, land quality, input use, access to output markets, information, and water sources. Policies aimed to reduce discrimination, strengthen local institutions and services, improve the road network, and increase FHHs' access to resources would increase the food security status of female farmers.

Keywords: food security, gender, discrimination, exogenous switching treatment regression, Kenya
JEL classification: O13, Q18

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1. Introduction

In this paper, we study the food security of male- and female-headed households, using rich household- and plot- level survey data generated by the Kenya Agricultural Research Institute (KARI) in partnership with the International Maize and Wheat Improvement Center (CIMMYT). More specifically, we aim to answer the following questions: Are female-headed households more likely than male-headed households to be food insecure? If so, why? Using better data and more sophisticated econometric techniques than previously applied to this problem, we are able to disentangle the effects of different types of gender inequalities in agriculture to a greater extent than possible in the past.

Gender inequalities and lack of attention to gender in agricultural development contribute to lower productivity, higher levels of poverty, as well as under-nutrition (World Bank, FAO, and IFAD, 2009; FAO, 2011). The 2012 World Development report dedicated to *Gender Equality and Development* warns that the failure to recognize the roles of as well as differences and inequities between men and women poses a serious threat to the effectiveness of agricultural development strategies (World Bank, 2012).

In many countries in Africa, there has been a significant increase in the percentage of female-headed households (FHH) in recent years. Among the main causes are the deaths of male heads, family conflicts and disruption, male migration for work, the woman deciding not to marry, changes in women's roles, and increased empowerment of rural women; these have all increased the importance of women as the breadwinners of their households (IFAD website[2]). In this study, we define households as FHHs if they belong to any of the following categories: de jure FHH (single, widowed, divorced, or separated women) and de facto categories (wives of male migrants).

Although African women are often responsible for providing food to their families both in female- and male-headed households (MHH), they generally have less access to land than men, less access to education, a higher dependency ratio in spite of the smaller average size of FHH households, and a greater history of disruption. They are also expected to carry most of the burden of housework and childcare. There seems to be little controversy over the fact that FHHs are usually disadvantaged in terms of access to land, livestock, other assets, credit, education, health care, and extension services.

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[2] http://www.ifad.org/gender/learning/challenges/women/60.htm accessed 19 December 2012

In addition to such easily observable inequalities, there is prevalent, less easily identifiable, inequality in the form of less secure tenure, more superficial extension advice, rationing out of credit markets, and other subtle forms of social and cultural discrimination. This has implications for technology adoption, food security, and access to markets. Increasing women's access to land, livestock, education, financial services, extension, technology, and rural employment has the potential to boost their productivity and generate gains in agricultural output, food security, economic growth, and social welfare (FAO, 2011; Meinzen-Dick et al., 2010). However, this will only address the effects of the easily observable forms of discrimination discussed above. The more subtle forms of discrimination might well remain, and could continue to cause worse outcomes for FHHs.

Although there is a considerable literature on the relationship between gender and agricultural productivity and technology adoption in Sub-Saharan Africa, gender gaps in food security have received far less rigorous empirical attention.[3] Our paper thus contributes to the literature in several directions. First, we consider the household's own perception of food security, which provides a better assessment of the food security situation throughout the year. The use of subjective measures, including self-reported poverty (see, e.g., Deaton, 2010, who argues for wider use of self-reported measures from international monitoring surveys) and people's subjective perceptions of their economic welfare (see, e.g., Ravallion and Lokshin, 2002, who used subjective economic welfare measures in Russia), is a growing field, and our paper represents one of the first applications to food insecurity.

Second, unlike earlier studies (e.g., Mallick and Rafi, 2010) that used pooled regression, we use an exogenous switching treatment regression effects approach, which allows us to identify the effects of observable and unobservable differences between men and women on their food security status. This allows us to understand the effects of both observable and unobservable gender discrimination on food security. To our knowledge, we are the first to disentangle different forms of discrimination against women and in particular apply impact evaluation methodologies in the context of gender impact on food security. Finally, we use plot-level data, which makes it possible to control for plot characteristics that have a direct impact on crop production and hence affect food security.

The next section presents a survey of selected literature on food security. In Section 3 we describe an exogenous switching regression (ESR) treatment effects approach to evaluate the responses of food security to gender. Section 4 covers the data, the variables, and the

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[3] For a comprehensive review of econometric evidence on gender differences in agricultural productivity and technology adoption in the developing world, see Peterman et al. (2010, 2011).

descriptive statistics. The empirical results and discussions are found in Section 5. Then Section 6 concludes the paper with discussions on policy implications.

2. Food security

Food security is a broad concept that includes issues related to the nature, quality, and security of as well as access to the food supply (Iram and Butt, 2004). The 1996 World Food Summit in Rome stated that "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). Hence, there is no single way of measuring food security.

Food insecurity has a temporal dimension. It is defined as transitory when a person suffers from a temporary decline in food consumption and as chronic when a person is continuously unable to acquire sufficient food (Chung et al., 1997). During transitory food insecurity a household can potentially adopt several coping strategies, yet for poor households one of these strategies is often to deplete productive assets, which may lead to chronic food insecurity in the longer term.

There is a growing literature on food security in developing countries. Using pooled regressions (with a gender dummy used as indicator in the regression) at the household level, Feleke et al. (2005) and Kidane et al. (2005) probed the household food security in rural households of Ethiopia. The studies link food security and adoption of new technologies (adoption of high yield varieties of maize and fertilizer application). They concluded that technology adoption increases household food security. Other factors analyzed include farm size, livestock ownership, education of head of household, household size, and per-capita production of the household. With the exception of household size, all the other factors increase food security. However, these studies only assessed gender differences using a gender dummy; the possibility that gender might affect the impact of the explanatory variables, e.g., that an extra year of education or a slightly larger farm might have different impacts depending on the gender of the household head, was ignored.

Other studies have also found that wealth, ownership of assets such as land or livestock, and income are good predictors of food security (e.g., Iram and Butt 2004; Babatunde et al., 2008). A household with such resources is expected to better withstand shocks in production or prices that could create food shortages. More generally, food insecurity is linked to high food prices, poverty, and low agricultural productivity (Nyangweso et al., 2007; Misselhorn, 2005; GoK, 2008; Dávila, 2010; Lewin, 2011). Dávila found that higher prices for maize affected Mexican households' living standards and food security both in urban and rural areas, with the poorest net buyers of maize being the most affected. Lewin showed that a 25 percent increase in the price of maize flour would increase the likelihood of food insecurity in Northern Malawi by 12 percent, while a similar increase in fertilizer prices would increase food insecurity by 30 percent in the central region of the country. Using dietary diversity among households in a poor Vihiga district in Kenya, Nyangweso et al. found that household income, number of adults, ethnicity, savings behavior, and nutritional awareness are critical when addressing the question of food security from the demand side.

A number of different interventions have been shown to improve the food security situation. For instance, participation in dry lands interventions (e.g., the Makueni District Agricultural Project, Kenya) such as irrigation was shown by Lemba (2009) to have significant impacts on household food security, which was attributable to improved access to resources (mainly for production). Similar results were found for irrigation schemes in Malawi (Lewin, 2011). In Nepal, Tiwari et al. (2010) assessed the effects of maize varietal intervention to improve productivity and food security. They found that food availability increased as a result of the improved varietal intervention, with greater relative benefits to poor than rich farmers. Nyangito et al. (2004) studied impacts of the economic and trade policy reforms introduced in Kenya and found that market access for food imports has improved since the reforms, while at the same time the capacity to import food has declined, making the country more food insecure.

Most of these studies concentrate on objective food security measures at the household level. These measures look at the consumption (converted into calories) or expenditure data. Pinstrup-Andersen (2009) proposes that, conditional on a set of assumptions about household behavior, total household income and food prices can be used to estimate the household food security. He further points out that consumption-based estimates are an outcome of household food acquisition, allocation behavior, and access to food, A food consumption method does not provide a full assessment of food security since it fails to take into account the vulnerability and sustainability elements of food security. Consumption has a large seasonal volatility and most studies use only a single-round survey that frequently focuses on the last month before the survey was run; therefore, consumption data may systematically under- or over-report the true food security, depending on the time of year the survey was conducted.

A recent study, Mallick and Rafi (2010), therefore adopted subjective food security measures to overcome the shortcoming of the food consumption method pointed out above.

Based on all food sources (own production, food purchases, food from safety nets and welfare programs, harvesting from communal resources, etc.), the respondents were asked to assess the food security status of their households over the last twelve months and place it in one of the following four categories: food shortage throughout the year (chronic or severe food insecurity); occasional food shortage (transitory food insecurity); no food shortage but no surplus (break-even); or food surplus. We follow their approach here.

It has generally been argued that, due to various forms of discrimination, FHHs are more vulnerable to food insecurity and non-monetary aspects of poverty. For example, cultural restrictions on women's ability to fully participate in food production activities in some of the poorest areas of South Asia have left them particularly vulnerable in times of economic crisis (Kabeer, 1990). Babatunde et al. (2008) conducted a gender-based analysis of vulnerability to food insecurity in Nigeria and found that FHHs were indeed more vulnerable than MHHs to food insecurity. McLanahan (1985) found that children in FHHs had lower rates of socio-economic attainment than children in MHHs. If FHHs utilize all available resources including engaging school age children in income-generating activities to survive, then they end up with low levels of educational attainment; thus, the risk of transmitting poverty and food insecurity to the next generation is higher. Moreover, Kennedy and Peter (1992) found that the proportion of income controlled by women has a positive influence on household caloric intake.

Although discrimination of women is acknowledged in the literature, little rigorous work has been done to disentangle the various forms of discrimination of women with a focus on their impact on food security. Earlier studies typically used a binary gender indicator to capture all impacts. Thus, for instance, Mallick and Rafi (2010) used a pooled regression where they assume that the same set of covariates have the same impact on the probabilities for MHHs' and FHHs' food status, so that gender shifts only the intercept and not the slope of the coefficients. They found no significant differences in the food security between MHHs and FHHs among the indigenous ethnic groups in Bangladesh.

Yet, women face different forms of discrimination. Some forms of discrimination can be easily captured in surveys; smaller, or poorer quality, plots are easily identifiable, as are lower levels of education, and both are likely to affect agricultural productivity and food security. Petty day-to-day discrimination – such as greater reluctance on the part of input providers to provide credit for fertilizer purchases for FHHs than for MHHs, less scope to borrow money or to buy food on credit, or more superficial advice from extension officers – can also affect food security but can be harder to capture in a survey. This is partly because it is less visible, and partly because it tends not to be seen as worthy of note by respondents who have internalized the social norms associated with these forms of discrimination. Comparing MHHs and FHHs across the board, as earlier studies have done, permits identification of the overall impact of gender discrimination on food security, but not of the effects of specific types of discrimination.

Understanding gender discriminations has implications for policy interventions, especially interventions aimed at improving the food security status of FHHs in particular. If the problem is primarily rooted in the differences in, e.g., access to land or access to education, then explicit policy interventions banning these forms of discrimination are called for. On the other hand, if, e.g., technology adoption is less frequent among FHHs, or if education has less impact on food security for FHHs, e.g., because of poorer extension services or discrimination in small-scale credit for input purchases, then addressing the problem will require long-term changes in social norms rather than outright bans. Identifying the precise causes of FHH food insecurity is therefore important from a policy perspective.

3. Econometric estimation methodology and strategy

In order to overcome the challenges discussed above, we use an exogenous switching regression (ESR) in a counterfactual framework. For the subjective food security measure, we follow Mallick and Rafi (2010) and use a four-category food security assessment (1= chronic food insecurity, 2 = transitory food insecurity, 3 = break-even, and 4= food surplus) made by the household as our outcome variables. In parts of the analysis, we merge the first two and the last two categories into “food insecure” and “food secure” households, respectively.

Exogenous switching treatment regression (ESR) effects

Pooled regression (a dummy regression where a binary gender variable is used) may not be appropriate to assess the effect of gender on food security. This is because pooled model estimation assumes that the set of covariates have the same impact on FHHs and MHHs (i.e., common slope coefficient for both groups). This implies that there is no interaction between the gender variable and other explanatory variables, indicating that gender has only an intercept effect or parallel shift effect, which is always the same irrespective of the values taken by other covariates that determine food security. However, as discussed earlier, numerous variables might have different impacts for FHHs and MHHs; in our sample, the Chow test rejected the assumption of parallel shift (equality of coefficients for MHHs and FHHs) at a 0.1% significance level ($\chi_2(34) = 123.32^{***}$ and $= 142.96^{***}$ for binary food security and ordered food security outcome variables, respectively), giving a strong indication that gender-specific coefficient estimates are likely to be more informative.

The exogeneous switching treatment regression (ESR) framework can capture such interactions between gender and other household characteristics by estimating two separate equations (one for MHHs and one for FHHs), which are specified as follows:

$$(1)\quad \begin{cases} y_{im} = x_{im}\beta_m + u_{im} & \text{if } G = 1 \\ y_{if} = x_{if}\beta_f + u_{if} & \text{if } G = 0 \end{cases}$$

where m and f denote MHHs and FHHs, respectively. The two y variables are the food security outcomes for the two groups, G is a gender dummy variable set equal to 1 for MHHs and zero otherwise, the two x vectors are vectors of household and plot characteristics that determine food security, the two β vectors capture how MHH and FHH food security, respectively, respond to those household and plot characteristics, and u is the error term with zero mean and constant variance.

Equation 1 may not allow us to directly examine the role of gender on food security for both groups of households because their characteristics could be different. Following Carter and Milon (2005) and Di Falco et al. (2011) and the impact evaluation literature, we compute the average food security for both MHHs and FHHs by comparing the expected values of the outcomes of MHHs and FHHs in actual and counterfactual scenarios. The "actual" MHH and FHH scenarios are the ones actually observed in the data. The "counterfactual" scenarios show what the food security status for FHHs would be had they had the same characteristics as the MHHs but continued to respond to those characteristics in the way they do now, and vice versa. Alternatively, they show what the food security status of FHHs would be had the returns (coefficients) to their characteristics been the same as the current returns to MHHs' characteristics, and vice versa. The estimates from ESR allow us to compute the expected values in the real and hypothetical scenarios presented in Table 1 and defined below:

$$(1a)\quad E(y_{im} | G = 1) = x_{im}\beta_m$$

$$(1b)\quad E(y_{if} | G = 0) = x_{if}\beta_f$$

$$(1c)\quad E(y_{if} | G = 1) = x_{im}\beta_f$$

$$(1d)\quad E(y_{im} | G = 0) = x_{if}\beta_m .$$

Equations (1a) and (1b) represent the actual expectations observed from the sample, while equations (1c) and (1d) are the counterfactual expected outcomes. Using these conditional expectations and considering the gender variable as a “treatment” variable, the average gender food security outcome differences are derived as follows.

The change in MHHs’ food security (MFS), had they had the same characteristics as they do now but the same returns to those characteristics as FHHs have now, is given as the difference between (1a) and (1c):

$$(2)\ M\mathrm{FS} = E\left(y_{im} \middle| G = 0\right) - E\left(y_{if} \middle| G = 1\right) = x_{im}\left(\beta_m - \beta_f\right).$$

Similarly, the change in FHHs’ food security (FFS) had they had the same returns to their characteristics as the MHHs have is given as the difference between (1b) and (1d):

$$(3)\ F\mathrm{FS} = E\left(y_{if} \middle| G = 0\right) - E\left(y_{im} \middle| G = 0\right) = x_f\left(\beta_f - \beta_m\right)$$

Equations (2) and (3) are equivalent to the average treatment effect on the treated and on the untreated, respectively, in the impact evaluation literature and the coefficient effects in the literature on wage decomposition. In our study, they indicate what outcomes MHHs would have had if the unobservable factors facing them had been the same as those currently facing FHHs, and vice versa.

Table 1: Conditional expectations, treatment effects and heterogeneity effects

Household types	Male-headed households’ responses to characteristics	Female-headed households’ responses to characteristics	Treatment effects (difference caused by difference in response to characteristics)
Male-headed households’ characteristics	(a) $E\left(y_{im} \middle| G = 1\right)$	(c) $E\left(y_{if} \middle| G = 1\right)$	MFS = (a) – (c)
Female-headed households’ characteristics	(d) $E\left(y_{im} \middle| G = 0\right)$	(b) $E\left(y_{if} \middle| G = 0\right)$	FFS = (d) – (b)
Heterogeneity effect (HE) (difference caused by differences in characteristics)	HE_m = (a) – (d)	HE_f = (c) - (b)	

As shown in Table 1, the above framework can also be used to compute the heterogeneity effects as the difference between (1a) and (1d) and (1b) and (1c). MHHs and FHHs do in fact have different observable characteristics, and this would have had an impact even if their responses to the characteristics had been the same. The heterogeneity effects show, respectively, what the difference would have been had all households had the current MHH responses and current FHH responses to the observable characteristics.

The parameters β_m and β_f are estimated using probit and ordered probit models. Ordered probit regression is used because the response in food security is ordered in nature. However, because some of the categories have few observations relative to others, we also estimate a binary probit model to check robustness of the results. In doing this, as mentioned earlier, the four categories are combined into two: food secure (combining break-even and food surplus) and food insecure (combining chronic and transitory food insecurity).

4. Data and description of variables

We use detailed primary household and plot survey data from 589 farm households and 2,779 plots (defined on the basis of land use) in 88 villages in 5 districts in Kenya where maize-legume systems are predominant. The survey was conducted in January-April 2011 using trained and experienced enumerators who knew the farming systems and spoke the local language.

In the first stage of the sampling procedure, five districts from two regions of Kenya were selected based on their maize-legume production potential: the Bungoma and Siaya districts from the western region and the Embu, Meru South, and Imenti South districts from the eastern region. The two regions were assigned an equal number of sample households. The households in a region were distributed across the respective districts according to the total number of households per district (proportionate sampling). Multi-stage sampling was employed to select lower level sampling clusters: divisions, locations, sub-locations, and villages. In total, 30 divisions were selected – 17 from western Kenya and 13 from eastern Kenya. Efforts were made to ensure representativity of the sample depending on the population of the study areas. Proportionate random sampling was designed where the total number of households in each of the divisions was compiled. The villages to be surveyed were randomly picked from the list earlier prepared. The number of villages surveyed in each division was proportional to its total number of households. Furthermore, a list of households in each selected village was made, and the households to be surveyed were randomly picked from this list. The number of households surveyed in each village was proportional to the number of households in that village.

The survey covered detailed household, plot, and village information. Trained enumerators collected a wide range of information on the households' production activities and plot-specific characteristics, as well as demographic and infrastructure information for each household and village. The enumerators also collected a number of other plot attributes: soil fertility, where farmers ranked their plots as poor, medium, or good (a dummy variable was set equal to 1 for the selected rank and zero for the others); soil depth, where farmers ranked their plots as deep, medium deep, or shallow (a dummy variable was set equal to 1 for the selected rank and zero for the others); and distance of the plot from the household dwelling, in minutes of walking. Other information collected at the plot level was tenure status of plots (participation in land rental markets by renting or renting out land), crop production estimates, and inputs associated with each type of agricultural activity.

Key socioeconomic elements collected about the household include age, gender, and education level of head of households, family size, household wealth indicators (livestock, farm size, and other physical assets), social capital network including membership in farmers' organizations, and number of traders the respondents know in their vicinity. Information at village level was also collected, including distance to nearest output market, extension office, and water source.

The household survey also includes individual rainfall shock variables derived from respondents' subjective rainfall satisfaction, in terms of timelines, amount, and distribution. The individual rainfall index was constructed to measure the farm-specific experience related to rainfall in the preceding three seasons, based on such questions about whether rainfall came and stopped on time, whether there was enough rain at the beginning and during the growing season, and whether it rained at harvest time.[4] Responses to each of the questions (yes or no) were coded as favorable or unfavorable rainfall outcomes and averaged over the number of questions asked (five questions), so that the best outcome would be equal to 1 and the worst to zero.[5]

(a) Descriptive statistics

MHHs and FHHs make up 81 and 19 percent of all the households in the sample, respectively, and 82 and 18 percent of the total plots (2,779 plots) are operated by MHHs and FHHs, respectively.

Definitions of variables used in the analysis and summary statistics and statistical significance tests on equality of means for continuous variables and equality of proportions for binary variables for male- and female-headed households are presented in Table 2.

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[4] We followed Quisumbing (2003) to construct this index.

[5] Actual rainfall data would, of course, be preferable. However, obtaining reliable village-level data in most developing countries, including Kenya, is difficult.

Table 2: Descriptive statistics and description of variables

		Male-headed households		Female-headed households		Mean diff.
		Mean	SD	Mean	SD	
		A		B		(A-B)
Outcome variables						
Food security	Household food security status (1=food secure; 0= food insecure)	0.533		0.412		0.121**
Chronic food insecurity	Household suffers from chronic food security(1=yes; 0=no)	0.056		0.117		-0.062*
Transitory food insecurity	Household suffers from transitory food security(1=yes; 0=no)	0.412		0.471		-0.059
Break-even food security	Household has break-even security(1=yes; 0=no)	0.385		0.319		0.065
Food surplus	Household has food surplus(1=yes; 0=no)	0.148		0.092		0.056
Treatment variable		0.80		0.20		
Gender	Head of household (1=male; 0=female)					
	Independent variables					
Plot characteristics and investment						
Improved seed use	Adoption of any improved seed varieties (1=yes; 0=no)	0.46		0.43		0.03
Fertilizer use	Intensity of chemical fertilizer use (kg/ha)	87.7	124.52	69.4	104.22	18.3***
Manure use	Amount of manure use on a plot('000 Kg)	0.75	1.3	0.64	1.9	0.11*
Plot distance	Plot distance to dwelling (in walking minutes)	6.91	16.2	8.05	19.33	-1.14
Good fertile plot	Farmers' perception that plot has good fertile soil (1=yes; 0=no)	0.33		0.25		0.08***
Moderately fertile plot	Farmers' perception that plot has moderately fertile soil (1=yes; 0=no)	0.54		0.53		0.01
Poor fertile plot (ref)	Farmers' perception that plot has poor fertile soil (1=yes; 0=no)	0.13		0.22		-0.09***
Shallow depth plot (ref)	Farmers' perception that plot has shallow deep soil (1=yes; 0=no)	0.15		0.14		0.01
Moderately deep plot	Farmers' perception that plot has moderately deep soil (1=yes; 0=no)	0.65		0.67		-0.02
Deep plot	Farmers' perception that plot has deep soil (1=yes; 0=no)	0.21		0.19		0.01
Social capital network						
Trader	Number of traders that farmer knows (number)	7	7.57	5.17	4.12	1.74**

Membership	Household belong to a rural institution or farmers’ group	0.74		0.74		0
Household characteristics and endowments						
Education	Education level of household head (years of schooling)	7.99	3.61	4.54	3.96	3.45***
Age	Age of household head (years)	48	12	52	12	-4.0***
Family size	Total family size (number)	5.97	2,61	4.81	2,71	1.17***
Own land (ref)	Own plot (1=yes; 0=no)	0.89		0.87		0.55
Rent in land	Rented in plot (1=yes; 0=no	0.1		0.1		-0.21
Rent out land	Rented out plot (1=yes; 0=no)	0.02		0.03		-0.15
Farm size	Total farm size (acre)	0.78	0.88	0.61	0.52	0.17**
Livestock	Livestock ownership (TLU)	2.37	2.68	1.76	1.65	0.61**
Asset ownership	Asset value of major farm equipment ('000 KSh)	2.51	3.88	2.56	5.97	0.05
Bicycle	Household own bicycle (1=yes; 0=n0)	0.63		0.46		0.16***
Location characteristics						
Rain fall index	Rainfall satisfaction index (1=close to best)	0.58	0.32	0.56	0.3	0.03
Distance to market	Distance to the nearest output market (in walking minutes)	78.59	52.58	84.12	58.81	-5.53
Distance to water sources	Distance to the nearest water source (in walking minutes)	8.39	9.48	9.94	10.35	1.55
Distance to information source	Distance to the nearest extension office (in walking minutes)	67.71	56.89	68	58.50	0.28
Season	Crop production season (1=long rainy season; 0=short rainy season)	0.53		0.52		0.02
Bungoma district(ref)	Bungoma District (1 = yes; 0 = no)	0.26		0.16		
Embu district	Embu district (1 = yes; 0 = no)	0.17		0.24		
Imenti south district	Imenti south district (1 = yes; 0 = no)	0.17		0.13		
Meru south district	Meru south district (1 = yes; 0 = no)	0.18		0.13		
Siaya district	Siaya district (1 = yes; 0 = no)	0.23		0.34		
	Number of plot (household) observations	2274(486)		505(119)		

Note: *, **, and *** indicate significance at the 10, 5, and 1% level, respectively.

The results in Table 2 show that about 11 percent of the FHHs suffer from chronic food insecurity compared to 5 percent of the MHHs. Similarly, 47 and 41 percent of the FHHs and MHHs suffer from transitory food insecurity, respectively. The difference in chronic food insecurity between MHHs and FHHs is statistically significant. On the other hand, 39 (14) percent of the MHHs fall under the categories of break-even (food surplus) compared to 32 (10) percent of the FHHs. Fifty-three percent of the MHHs are food secure (break-even and food surplus are combined into food secure) compared to 42 percent of the FHHs. This difference is statistically significant. FHHs, on average, have smaller farms and less education than MHHs. The differences in farm size and education level are statistically significant. As shown in Table 3, the probability of being food secure increases with farm size and level of education.

Table 3: Food security and food expenditures by land category and education level

Quartiles	Land		Education	
	Food security (%)	Annual food expenditure (Ksh)	Food security	Food expenditure (Ksh)
1 (Lowest)	44	59885	50	62710
2(Lowest middle)	47	72946	48	63498
3 (Upper middle)	52	77437	52	79637
4(Highest)	61	87410	54	88951

Apart from absolute farm size difference, FHHs have lower quality land. Thirteen percent of the cultivated area owned by FHHs falls in the poor soil fertility category, compared to 8 percent owned by MHHs. Forty-nine percent of the total cultivated land owned by MHHs is classified as good to medium fertile land compared to 39 percent of FHH-owned land. This difference may be associated with low use of land quality-enhancing inputs (fertilizer and manure) and the fact that plots managed by FHHs are relatively far from their dwellings. In addition, FHHs rent out more land than MHHs. This may affect the quality of land if tenants do not manage rented land well.

MHHs and FHHs also differ in bicycle ownership; MHHs own bicycle to a greater extent, and the difference is statistically significant. Bicycles are an important means of transportation, not merely for personal transportation but also for transporting produce.

The unconditional summary statistics and tests in the tables above generally suggest that FHHs are more food insecure and that they lack important resources that have repercussions on their welfare, including food security. However, because food security is an outcome of the interaction of several factors, we need to add careful multivariate analysis to study the causal effect of gender of household head on food security.

5. Empirical results and discussion

This section presents results from a probit model, ordered probit model, and exogenous switching regression. Before discussing the causal effect of gender on food security, we briefly discuss the determinants of food security.

(a) Determinants of food security

Estimated parameters for the probability of food security determinants are presented in Tables 4-6.[6] We report both the average marginal effects (AME) and robust standard errors. In the probit model, the dependent variable is a binary food security status variable that equals one if the household is food secure and zero otherwise, while in the ordered probit model we use the ordered categorical food security variables discussed earlier.

Table 4 Determinants of binary food security status: Probit model

Explanatory variables	Female-headed households			Male-headed households		
	AME	SE	P>z	AME	SE	P>z
Social capital network						
Trader	0.020***	0.003	0.000	0.001	0.001	0.340
Group membership	0.101***	0.036	0.005	-0.009	0.022	0.678
Household characteristics and endowments						
Education	0.003	0.005	0.600	-0.003	0.003	0.249
Ln(Household head age)	0.336***	0.052	0.000	-0.193***	0.035	0.000
Family size	0.019***	0.006	0.003	-0.001	0.004	0.835
Livestock	0.005	0.014	0.733	-0.004	0.004	0.276
Ln(Farm size)	0.156**	0.068	0.021	0.186***	0.031	0.000
Asset value	0.005*	0.003	0.070	0.003	0.002	0.228
Bicycle ownership	-0.012	0.036	0.744	0.086***	0.020	0.000
Plot characteristics and investments						
Plot distance	-0.001*	0.001	0.085	0.000	0.001	0.507
Deep fertile plots	0.141**	0.059	0.016	0.257***	0.030	0.000
Medium fertile plots	0.066	0.056	0.236	0.115***	0.029	0.000
Moderately deep soil plots	-0.018	0.055	0.742	0.028	0.032	0.383
Deep soil plots	0.006	0.051	0.914	0.049*	0.026	0.060

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[6] We estimated the models with and without including potential endogenous regressors (fertilizer, improved seeds and manure use, access to credit, membership in groups/associations, and participation in land market); however, we report results *with* potential endogenous variables to save space and because the food security impact results are numerically close. All results are available upon request.

Fertilizer use	0.000*	0.000	0.098	0.000**	0.000	0.016
Improved seeds use	0.072**	0.033	0.030	-0.009	0.019	0.640
Manure use	-0.013	0.013	0.315	0.021***	0.007	0.002
Rented in plots	-0.007	0.054	0.889	0.059*	0.035	0.091
Rented out plots	-0.160	0.129	0.213	-0.075	0.070	0.286
Location characteristics						
Distance to extension office	-0.001**	0.000	0.022	0.000***	0.000	0.006
Distance to output market	-0.001***	0.000	0.000	-0.001***	0.000	0.003
Distance to water source	-0.010***	0.001	0.000	-0.003	0.001	0.000
Rainfall index	-0.028	0.064	0.655	0.035	0.033	0.294
Season	-0.004	0.031	0.894	-0.014	0.018	0.456
Embu district	0.380***	0.052	0.000	0.288***	0.033	0.000
Imenti south district	0.393***	0.048	0.000	0.444***	0.033	0.000
Meru south district	0.429***	0.051	0.000	0.351***	0.032	0.000
Siaya district	0.104	0.065	0.109	0.120***	0.030	0.000
Regression diagnostics						
Wald chi2(28)	502.29***			208.29***		
Pseudo R2	0.197			0.384		
Log pseudo likelihood	-1264			-219.2		
Number of plot (household) observations	2310(486)			521(119)		

Note: *, **, and *** denote significance level at the 10, 5, and 1% level, respectively.

Table 5: Ordered probit model results on the determinants of FHHs food security status

	Chronic food insecurity			Transitory food insecurity			Breakeven food security			Food surplus		
	AME	SE.	P>z	AME	SE	P>z	AME	SE	P>z	AME	SE	P>z
Social capital networks												
Trader	-0.003**	0.001	0.028	-0.005**	0.003	0.037	0.004**	0.002	0.037	0.004**	0.002	0.033
Group membership	-0.024**	0.011	0.037	-0.041*	0.025	0.100	0.035*	0.017	0.042	0.029	0.019	0.127
Household characteristics and endowments												
Education	-0.003	0.002	0.129	-0.005	0.004	0.167	0.004	0.003	0.129	0.004	0.003	0.181
Ln(Household head age)	-0.082***	0.022	0.000	-0.152***	0.039	0.000	0.122***	0.029	0.000	0.112***	0.033	0.001
Family size	-0.001	0.002	0.508	-0.003	0.004	0.528	0.002	0.003	0.515	0.002	0.003	0.527
Livestock	-0.001	0.006	0.922	-0.001	0.011	0.923	0.001	0.009	0.922	0.001	0.008	0.923
Ln(Farm size)	-0.023	0.024	0.345	-0.042	0.045	0.350	0.034	0.036	0.351	0.031	0.033	0.347
Asset value	-0.004***	0.001	0.000	-0.008***	0.002	0.000	0.006***	0.002	0.000	0.006***	0.001	0.000
Bicycle ownership	0.010	0.013	0.455	0.018	0.023	0.424	-0.014	0.019	0.451	-0.014	0.017	0.417
Plot characteristics and investments												
Plot distance	0.001***	0.000	0.086	0.001*	0.001	0.063	-0.001*	0.000	0.077	-0.001*	0.000	0.067
Deep fertile plots	-0.049***	0.015	0.001	-0.103*	0.042	0.014	0.072***	0.023	0.002	0.080**	0.034	0.020
Medium fertile plots	-0.026	0.016	0.108	-0.047	0.036	0.186	0.039	0.026	0.137	0.034	0.026	0.182
Moderately deep soil plots	-0.032*	0.017	0.056	-0.068	0.045	0.134	0.047*	0.025	0.056	0.052	0.037	0.163
Deep soil plots	-0.052***	0.016	0.001	-0.085**	0.034	0.013	0.076***	0.023	0.001	0.061**	0.027	0.023
Fertilizer use	0.000***	0.000	0.003	0.000***	0.000	0.000	0.000***	0.000	0.001	0.000***	0.000	0.001
Improved seeds use	-0.011	0.010	0.280	-0.021	0.022	0.324	0.017	0.016	0.296	0.016	0.016	0.325
Manure use	0.002	0.004	0.692	0.003	0.008	0.697	-0.003	0.007	0.694	-0.002	0.006	0.698
Rented in plots	0.028	0.023	0.221	0.044	0.030	0.137	-0.041	0.031	0.194	-0.032	0.022	0.140
Rented out plots	0.082	0.058	0.158	0.088**	0.035	0.013	-0.107*	0.065	0.100	-0.063**	0.028	0.026
Location characteristics												
Distance to extension office	0.000	0.000	0.684	0.000	0.000	0.686	0.000	0.000	0.682	0.000	0.000	0.688
Distance to output market	0.001***	0.000	0.000	0.001***	0.000	0.000	-0.001***	0.000	0.000	-0.001***	0.000	0.000
Distance to water source	0.002***	0.000	0.000	0.004***	0.001	0.000	-0.003***	0.001	0.000	-0.003***	0.001	0.000
Rainfall index	-0.050***	0.025	0.042	-0.094**	0.040	0.020	0.075**	0.034	0.028	0.069**	0.031	0.028

Season	0.006	0.011	0.572	0.012	0.020	0.550	-0.009	0.016	0.567	-0.009	0.014	0.549
Embu district	-0.087***	0.015	0.000	-0.241***	0.056	0.000	0.105***	0.021	0.000	0.223***	0.063	0.000
Imenti south district	-0.089***	0.015	0.000	-0.250***	0.051	0.000	0.106***	0.021	0.000	0.232***	0.062	0.000
Meru south district	-0.097***	0.016	0.000	-0.308***	0.069	0.000	0.114***	0.031	0.000	0.291***	0.089	0.001
Siaya district	-0.034**	0.021	0.096	-0.066	0.046	0.153	0.045*	0.026	0.086	0.055	0.041	0.178
Regression diagnostics												
Wald chi2(28)	209.73***											
Pseudo R2	0.181											
Log pseudo likelihood	-485.4											
Number of (plot) household observations	521(119)											

Note: *, **, and *** denote significance level at 10, 5, and 1% level.

Table 6: Ordered probit model results on the determinants of MHHs food security status

	Chronic food insecurity			Transitory food insecurity			Breakeven food security			Food surplus		
Explanatory variables	AME	SE	P>z	AME	SE	P>z	AME	SE	P>z	AME	SE	P>z
Social capital network												
Trader	0.000	0.000	0.562	0.000	0.001	0.560	0.000	0.000	0.561	0.000	0.001	0.560
Group membership	-0.010	0.005	0.038	-0.026	0.014	0.059	0.014**	0.007	0.033	0.023*	0.012	0.067
Household characteristics and endowments												
Education	0.000	0.001	0.597	0.001	0.002	0.598	0.000	0.001	0.597	-0.001	0.002	0.598
Ln(Household head age)	0.012	0.008	0.146	0.032	0.021	0.139	-0.016	0.011	0.147	-0.028	0.019	0.138
Family size	0.000	0.001	0.879	0.000	0.002	0.879	0.000	0.001	0.879	0.000	0.002	0.879
Livestock	0.001	0.001	0.144	0.004	0.002	0.143	-0.002	0.001	0.144	-0.003	0.002	0.143
Ln(Farm size)	-0.044***	0.008	0.000	-0.115***	0.020	0.000	0.058***	0.010	0.000	0.101***	0.017	0.000
Asset value	-0.001***	0.001	0.017	-0.004**	0.002	0.017	0.002**	0.001	0.016	0.003**	0.001	0.018
Bicycle ownership	-0.025***	0.005	0.000	-0.06***	0.014	0.000	0.033***	0.006	0.000	0.054***	0.013	0.000
Plot characteristics and investments												
Plot distance	0.000	0.000	0.200	0.001	0.001	0.193	0.000	0.000	0.197	-0.001	0.000	0.193
Deep fertile plots	-0.047***	0.005	0.000	-0.142***	0.022	0.000	0.056***	0.005	0.000	0.133***	0.023	0.000
Medium fertile plots	-0.027***	0.006	0.000	-0.068***	0.019	0.000	0.036***	0.007	0.000	0.060***	0.018	0.001
Moderately deep soil plots	-0.016***	0.006	0.009	-0.047**	0.021	0.024	0.021***	0.007	0.004	0.043**	0.020	0.033
Deep soil plots	-0.008	0.006	0.165	-0.021	0.016	0.200	0.011	0.008	0.158	0.018	0.015	0.209
Fertilizer use	0.000***	0.000	0.001	0.000***	0.000	0.001	0.000***	0.000	0.001	0.000***	0.000	0.001
Improved seeds use	0.000	0.005	0.966	0.001	0.012	0.966	0.000	0.006	0.966	0.000	0.011	0.966
Manure use	-0.003*	0.002	0.055	-0.008*	0.004	0.051	0.004*	0.002	0.055	0.007*	0.004	0.050
Rented in plots	-0.026***	0.006	0.000	-0.085***	0.023	0.000	0.031***	0.005	0.000	0.080***	0.024	0.001
Rented out plots	-0.016	0.016	0.327	-0.048	0.057	0.404	0.019	0.017	0.265	0.044	0.056	0.429
Location characteristics												
Distance to extension office	0.000***	0.000	0.000	-0.001***	0.000	0.000	0.000***	0.000	0.000	0.001***	0.000	0.000
Distance to output market	0.000**	0.000	0.010	0.000***	0.000	0.008	0.000***	0.000	0.009	0.000***	0.000	0.009
Distance to water source	0.000*	0.000	0.045	0.001*	0.001	0.048	-0.001*	0.000	0.050	-0.001**	0.000	0.045

Rainfall index	0.016*	0.008	0.047	0.042*	0.021	0.046	-0.021**	0.010	0.044	-0.037**	0.019	0.047
Season	0.005	0.005	0.282	0.013	0.011	0.259	-0.006	0.006	0.287	-0.011	0.010	0.253
Embu district	-0.044***	0.005	0.000	-0.149***	0.025	0.000	0.047***	0.004	0.000	0.146***	0.029	0.000
Imenti south district	-0.054***	0.005	0.000	-0.230***	0.023	0.000	0.049***	0.009	0.000	0.235***	0.030	0.000
Meru south district	-0.051***	0.005	0.000	-0.185***	0.022	0.000	0.052***	0.005	0.000	0.184***	0.026	0.000
Siaya district	-0.015***	0.007	0.024	-0.039*	0.020	0.046	0.017**	0.007	0.017	0.036*	0.019	0.054
Regression diagnostics												
Wald chi2(28)	577.98***											
Pseudo R2	0.098											
Log pseudo likelihood	-2469											
Number of plot (household) observations	2310(486)											

Note: *, **, and *** denote significance at the 10, 5, and 1% level, respectively.

As indicated in Table 4, the average marginal effects of covariates are different for MHHs and FHHs. This supports the Chow test result, and thus further supports running separate food security regressions for the two groups. In addition, some of the covariates that explain the food security status of MHHs do not explain that of FHHs and vice versa.

The results reveal that both household- and plot-level factors conditioned the food security status of MHHs and FHHs. The probabilities of FHHs falling into the different food security categories are influenced by access to social capital networks (grain traders and membership in rural institutions), physical capital (farm size and farm equipment ownership), natural capital (soil fertility), access to services (markets, information, and water), human capital (age), access to labor[7] (family size), distance from plot to dwelling, input use (chemical fertilizer and improved seeds), and geographic location variables (district dummies). Similarly, MHHs' food security status is significantly affected by human capital (age), physical capital (farm size, farm equipment, and bicycle ownerships), access to services (markets, information, and water), input use (manure and chemical fertilizer), natural capital (soil fertility), participation in land rental markets, and geographic location variables (district dummies).

The number of traders that FHHs know is positively correlated with the likelihood of FHHs being food secure. On average, an FHH knows 5.17 traders; knowing an extra trader significantly reduces the probability of chronic and transitory food insecurity by 5.8 and 9.7%, respectively, and increases the probability of break-even food security and food surplus, respectively, by 7.7% each. Traders can improve market access through a regular supply of inputs and outputs as well as through provision of credit (interlinked contract). At the same time, causality is not certain here; it could of course also be the case that more food-secure FHHs know more traders simply because they have food to sell more frequently and, hence, have a greater need for such contacts. However, there appears to be no such link for MHHs, as the variable has no significant effect on any of the MHH food security indicator outcome variables. Membership in rural institutions or farmers' groups increases the probability of FHH food security as well as break-even food security and food surplus. This is probably because social capital networks may serve as an important resource that FHHs can use to help mitigate the impact of adverse shocks (Quisumbing, 2003). However, social capital network variables only affect break-even and food surplus MHHs. Distance to the nearest output

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[7] One might expect that FHHs have fewer income earners and limited farm labor capacity, as some FHHs are female headed due to deaths or divorces, so it might seem more informative to control for adult labor. However, in this study, there is no statistically significant difference between MHHs' and FHHs' access to adult labor; therefore, we control for family labor, which allows for children to be involved in household activities.

market, water, and information significantly decreases the probability of food security for both FHHs and MHHs.

Use of chemical fertilizer improves the food security for both FHHs and MHHs (measured using both the binary food security variable and the categorical variable). Use of improved seeds has a positive impact on FHH food security, while use of manure has a positive impact for MHHs. These results suggest that improving access to inputs can play a significant role in increasing the food security condition of rural households.

Soil quality indicator (soil fertility and depth) variables have a positive effect on the likelihood of food security, indicating that increasing the productivity of land can contribute to reducing food insecurity in rural areas of Kenya. Finally, farmers in the Embu, Imenti south, Meru south, and Siaya districts seem more food secure than do farmers in the Bunguma district.

(b) Impact of gender of household head on food security

The switching regression results were used to estimate the conditional probability of food security expectations and to evaluate the treatment effects of gender. Results on the average causal effect of gender on food security are provided in Tables7-8.[8] The results reveal that FHHs could have been more food secure had they had the resources and characteristics of MHHs. However, the results also indicate that there is some sources of unobserved heterogeneity that makes FHHs less food secure than the MHHs.

Table 7: Average probability of food security, treatment, and heterogeneity effects (dependent variable: binary food security)

Household type	MHH responses	FHH responses	Treatment effect
MHH characteristics	(a) 0.575	(c) 0.542	0.033(0.009)***
FHH characteristics	(d) 0.517	(b) 0.429	0.088(0.018)***
Heterogeneity effects	0.058(0.012)***	0.114(0.017)***	

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[8] The food security difference results obtained from the models with and without the potential endogenous variables are numerically close, so the results from the regressions without endogenous variables are not reported but are available upon request.

Table 8. Average probability of food security, treatment and heterogeneity effects (Dependent Variable: ordered food security)

Household type	Chronic food insecurity			Transitory food insecurity			Break-even food security			Food surplus		
	Male headed	Female headed	Treatment effect	Male headed	Female headed	Treatment effect	Male headed	Female headed	Treatment effect	Male headed	Female headed	Treatment effect
Male headed	0.050	0.068	-0.018 (0.002)***	0.374	0.428	-0.054 (0.005)***	0.406	0.387	0.019 (0.004)***	0.170	117	0.053 (0.004)***
Female headed	0.066	0.096	-0.030 (0.007)***	0.402	0.481	-0.079 (0.010)***	0.390	0.348	0.042 (0.009)***	0.143	0.076	0.067 (0.007)***
Heterogeneity effect	-0.016 (0.003)***	-0.028 (0.005) ***		-0.027 (0.007)***	-0.053 (0.009)***		0.016 (0.004)***	0.039 (0.008)***		0.027 (0.006)***	0.042 (0.007)***	

Considering cells (a) and (b) in Table 7 which show the observed expected probability of food security, the probability of food security of FHHs is 14.6 % less (0.575 versus 0.429), on average, than the MHHs'. However, with the counterfactual condition (d), i.e., if the FHHs had the response coefficients of MHHs, this difference would be reduced to about 5.8% (0.575 versus 0.517). Similarly, with the counterfactual condition (c), i.e., if the MHHs had the characteristics of FHHs, the probability of FHHs being food secure would still be 11.4% lower. Under both counterfactual conditions, the FHHs thus, still, have less probability of food security, indicating that there are some important sources of heterogeneity that make the FHHs less food secure than the MHHs regardless of their observed characteristics. The last column of Table 7 presents the "treatment effects" of gender on the probability of food security. In the counterfactual case (d), i.e., if the FHHs had the characteristics of MHHs, their average probability of food security would be 8.8% higher than it is now. Similarly, in the counterfactual case (c), i.e., if MHHs had the characteristics of FHHs, the mean probability of food security would be 3.3% lower.

The results of the ordered probit model (Table 8) also tell a similar story, where the probability of chronic and transitory food insecurity could have been significantly lower for FHHs had they had the characteristics of MHHs, but nonetheless higher than those of MHHs. Unobserved heterogeneity has also contributed to differences in chronic and transitory gender food insecurity. The probability of break-even food security and food surplus of FHHs would increase by 4.2% (0.390 versus 0.348) and 6.7% (0.143 versus 0.076), respectively, had they had the characteristics of MHHs.

These results imply that differences in observed resource endowments, and unobservable discriminations against women, are both important in explaining the difference in food security between the genders.

6. Conclusions and policy implications

Using recent household and plot survey data from maize-legume systems in rural Kenya, we examine the reasons why female-headed households (FHHs) are more likely to be food insecure than male-headed households (MHHs). All farmers in our dataset reported their perceived food security. This gives us an opportunity to explore the subjective measure of food security. This measure provides a full assessment of the food security situation throughout the year where households consider their vulnerability.

Both the descriptive statistics and the statistical tests suggest that FHHs are more food insecure; they are less well endowed with several important resources, which has repercussions on their welfare including food security. About 12 percent of the FHHs suffer from chronic food insecurity, compared to 6 percent of the MHHs. The difference in chronic food insecurity between MHHs and FHHs is statistically significant. With a statistically significant difference, about 53 percent of the MHHs are food secure (break-even and food surplus are combined into food secure), compared to only 41 percent of the FHHs. Tabulation of food security and food expenditures by land and education level shows that food expenditures and the probability of being food secure increase with farm size and level of education.

The econometric results confirm that FHHs are, in general, more likely to be food insecure than MHHs. However, we find that this cannot be explained by the differences in observable endowments alone; the exogenous switching regression shows that even under the counterfactual conditions where MHHs and FHHs are made more similar, the FHHs still have less probability of food security. This indicates that there are important additional gender-specific sources of food insecurity that make the FHHs less food secure than the MHHs, regardless of their observed characteristics.

These results have important policy implications: They imply that although some of the gender differences in food security could be addressed through policy interventions of various kinds, important differences – presumably linked to gender-specific social norms and differences in the way male and female farmers are treated by others – would still remain. Nonetheless, our study does identify several openings for policy interventions that could address some of the gender imbalances in fairly short order. The determinants of food security form parametric results suggesting that FHHs' food security increases with land quality, farm size, and the quality of extension workers, while distance to the market has the opposite effect.

As for the quality of extension staff, policy makers should focus on improving the skills of extension staff for efficient and effective dissemination of technologies and other important information that has an impact on food security. Since area expansion is infeasible due to land scarcity in Kenya, policy makers focusing on land augmenting practices can help farm households to escape food insecurity. Although little can be done with respect to distance to markets, policy interventions could improve road quality and traffic by improving existing road networks and maintaining existing ones. Such investments are likely to have a positive impact on market integration, productivity, and food security.

Finally, future analysis using repeated observations (or panel data) may be needed to examine the relationship between gender and food security in order to control for unobserved specific heterogeneity and to see whether the MHH-FHH food security gap persists over time. To the extent that gender-specific norms drive part of the difference in food security, as our results suggest, panel data analysis would help show whether these norms are changing over time or not.

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Paper III

A study of post-harvest food loss abatement technologies in rural Tanzania

Simon Wagura Ndiritu [1] and Remidius Ruhinduka [2]

Abstract

This paper focuses on preservation and improved storage technologies as an adaptation strategy to climate change. We also study the tradeoff between preservation techniques and improved cereal storage technologies among rural households in Tanzania. Using a bivariate probit model, we find that preservation measures and modern storage technologies are substitutes. In addition, we find that climate variables influence farmers' choice of preservation methods and improved storage technologies. Extension services increase adoption of improved and modern storage technologies. This finding has strong policy implications as it suggests that solving the present information inefficiency can significantly improve the rate of adoption, and hence reduce storage losses. Since modern technologies are relatively expensive, intervention by the government (through subsidies) and non-governmental organizations can play a significant role in stimulating the adoption of effective post-harvest management practices by poor households.

Keywords: climate change adaptation, storage technologies, preservation methods, post-harvest loss abatement, bivariate probit model, Tanzania

JEL classification: C35, O33, Q54

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[1] School of Business, Economics and Law, Department of Economics, University of Gothenburg (email) simon.wagura@economics.gu.se

[2] School of Business, Economics and Law, Department of Economics, University of Gothenburg (email) Remidius.Ruhinduka@economics.gu.se

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Introduction

In this paper we study the factors influencing the choice of preservation techniques and improved cereal storage technologies among farming households in rural Tanzania. First, we use farm-level climate data to investigate the role of climate variables (rainfall, temperature, and altitude) on the adoption decision of storage and preservation measures across households. Climate change does affect the already produced cereals by increasing storage losses, something that has often been overlooked in the climate change literature. Hence, proper storage and preservation methods could become useful adaptation measures for farmers. Second, we study the tradeoff farmers make when choosing which storage and preservation technologies to use for post-harvest food storage. We thus estimate the joint adoption decision using a bivariate probit model, for improved storage technologies (and preservation), where traditional storage is the base category. In addition, we test the tradeoff between the preservation practices and modern storage solutions, where the base category is traditional and improved traditional storage technologies. Since the different technologies have different efficacy rates (i.e., fraction of pests that can be treated), we group the technologies as low efficacy (traditional technologies), medium efficacy (improved traditional technologies), and high efficacy (modern technologies), and estimate an ordered probit model.

Poor post-harvest management of cereals is one of the major challenges to food security in Sub-Saharan Africa (SSA), accounting for 15-30% of annual grain losses (World Bank 2011). Assuming minimum losses, World Bank (2011) estimates a monetary value of more than USD 4 billion a year out of an estimated annual value of grain production of USD 27 billion. This loss is estimated to exceed the total value of food aid (USD 6.1 billion) that SSA received from 1998 to 2008. In addition, the loss is equivalent to the annual caloric requirement of at least 48 million people (at 2,500 Kcal per person per day) (World Bank 2011). Thus, there is potential for great gains in food security and significantly reducing the food aid dependence through improved post-harvest cereals management.

The cereals production in SSA has been very low compared with the rest of the world (World Bank 2008). Low agricultural production has been blamed for food problems in SSA, an argument that has motivated hundreds of studies on the adoption of improved and production-enhancing technologies in the region (see Feder, Just, and Zilberman,1985; Sunding and Zilberman, 2001; and Foster and Rosenzweig, 2010 review in technology adoption). Consequently, significant amounts of financial aid and support have been extended to these countries to address production/related issues. But can we continue to emphasize only production problems when 20-30 % of the yields of the cereals harvested never reach the consumers? Post-harvest losses continue to worsen food insecurity by contributing to high food prices, by removing part of the food supply from the market (Tefera 2012). Although adoption of sustainable intensification practices is a promising step in making SSA food secure, existing post-harvest losses can reduce the benefits to be gained from such improved technologies. Reducing food losses from storage can be more environmentally sustainable than a corresponding increase in production.

Moreover, climate change and variability have continued to worsen food security problems both in Africa and in the world at large. In response, huge efforts and a great deal of research have focused on how farmers respond to such challenges on the production side (e.g., Di Falco et al, 2011; Mendelsohn et al, 1994; Deressa and Hassan, 2009). However, the post-harvest responses to such climatic shocks have largely been overlooked. Climate variables, i.e., temperature, moisture content, and relative humidity, are asserted as principal physical factors that affect stored grain as they influence insect and mold development, which causes deterioration and loss of grain (USAID, 2011; Tefera 2012). Higher (or very low) temperatures and low humidity levels are less likely to support the growth and development of most of the pests and insects.

Some studies have literally argued that certain modern storage technologies are so effective that if adopted, one does not necessarily need any additional preservation techniques to protect the crops (see, e.g., the metal silos discussion in Gitonga et al. 2012, Tefera 2012). Nonetheless, experience shows that some farmers still adopt both improved storage technologies and some preservation methods. If some technologies are scientifically proven to be substitutes but are still adopted jointly by farmers, then it is important to understand why they do this as there is a potential to help them reduce a significant fraction of storage costs by choosing only one of the options.

The current study contributes to the literature in two ways. First, to the best of our knowledge, this is the first study to exploit farm-level climate data (temperature and rainfall) to estimate the effect of these variables on the adoption of storage technologies and preservation methods. Second, Unlike Adegbola and Gardebroek (2007), we study the tradeoff farmers make when choosing preservation techniques and improved cereals storage technologies. We relax Adegbola and Gardebroek's (2007) assumption that the two adoption decisions are made separately. We do this because modern storage technologies (e.g., metal silos) do not require preservation measures as they work hermetically (Tefera 2012), and thus the decision to adopt modern storage is likely to affect the decision on whether to use preservation measures. Surprisingly, relatively few empirical studies in the peer reviewed journals (from which Tanzania can learn) assess the adoption of agricultural storage technologies in developing countries, and to the best of our knowledge none have explored the role of climate variables and the joint adoption decision.

To answer our research questions, we exploit a very recent and rich data set, the Tanzanian national panel survey (TNPS), collected in 2010/2011. The main findings of the study contribute to a new tweak in the climate change literature implying that climate variables (mainly rainfall and temperature) do influence the choice of improved storage technologies and preservation methods. The study adds to a thin literature on the role of extension services in increasing the adoption of improved storage technologies. We also find that modern storage technologies and preservation techniques are substitutes.

The rest of the paper is organized as follows: Section 2 discusses the issues of post-harvest losses and storage practices in SSA. The conceptual and methodological framework is presented in Section 3, while Section 4 presents the data and descriptive statistics. Section 5 discusses the results and Section 6 concludes the paper.

2. Post-harvest losses and storage practices in Sub-Saharan Africa

Post-harvest cereal loss is the loss of grains between harvest and consumption (Proctor 1994, USAID 2011). These losses could be in terms of economic loss, quality deterioration, and quantity damage. Qualitative deterioration refers to the damage or contamination of food, which includes nutritional loss while quantitative loss is the reduction in weight that can be quantified and valued (Tefera 2012). Economic loss is the reduction in monetary value of the crops that arise from the failure to sell in higher-value markets due to quality or quantity reduction (FAO 2010). Farmers reduce losses primarily by adopting post-harvest storage facilities (e.g., open drums, metal silos, airtight, i.e., hermetic, bags/drums) or one of various preservation methods. For a long time, cereal storage in SSA has relied on traditional methods (e.g., traditional granaries) of grain storage. However, these methods do not effectively protect the grain from climate change, pests, and diseases, resulting in huge losses and threatening food security. This has resulted in the introduction of several improved post-harvest technologies and/or other preservation techniques to minimize losses. However, empirical information on the determinants of adoption of such technologies is scanty (Tefera et al., 2011), and a good fraction of SSA farmers continue to practice their traditional methods.

In 2008, the International Maize and Wheat Improvement Center (CIMMYT) implemented a project on effective grain storage for the sustainable livelihood of African farmers. The project was implemented in two pilot areas, Kenya and Malawi, and included an economic analysis of the viability of modern storage technologies, specifically metal silos. CIMMYT argues that metal silos last for more than 15 years (with very low or no maintenance costs) and thus the farmer will save all the money normally spent on pesticides as long as he/she retains the storage facility. In the Kenyan project (Kenya was the first country in Africa to experiment with metal silos), CIMMYT estimates that a silo generates an annual benefit of USD 20 (through the avoidance of 10% storage loss) per year for 15 years. Given that the total fixed cost of a 900 kg silo is some USD 60, plus fumigation costs, the cost of the silo is quickly recovered (CIMMYT, 2011 p.21).

Agriculture is the foundation of the Tanzanian economy and a major hope for food security in the country. Like in many other countries in the region, it accounts for a significant share of the national income (about 45% in 2005) and provides employment opportunities to about 74% of all Tanzanians (NBS, 2012). About 74.2% of the country's poor depend mainly on this sector for their daily livelihood (NBS, 2008). Food insecurity is a serious concern in the country with approximately 23% of the rural population estimated to have unsatisfactory access to food (WFP, 2010). The slow growth in agricultural productivity (mainly due to use of poor production technologies) has been blamed for the localized food insecurity and hunger that continue to affect a majority of the country's farming households (URT, 2001). Consequently, efforts to enhance higher productivity (e.g., through promoting the adoption of improved production technologies) have always been perceived as roadmaps to increased food security and poverty reduction. Related to this is the World Bank's recent approval of a total of USD 55 million to boost agricultural productivity in the country through increased access and usage of improved inputs.[3]

However, like many other countries in SSA, Tanzania is not immune to post-harvest loss of cereal crops or the negative shocks of climate change. It is estimated that up to 40 percent of the harvested cereals does not reach the final consumer due to poor post-harvest

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[3] News posted on the local blog and media on 29 October, 2012 and can be accessed from http://issamichuzi.blogspot.se/2012/10/the-world-bank-boost-for-tanzanias.html

management (Maunya 2002 as cited in Rugumamu, 2003; USAID^{b}, 2011). World Bank (2011) estimates that lack of or poor storage facilities account for up to 38% of the country's post-harvest losses. This type of loss generally refers to either qualitative or quantitative measurable decreases of the foodstuff mainly caused by insects, molds, bacteria, rodents, birds, sprouting, and rancidity (USAID, 2011). Considering the low agricultural productivity by many poor subsistence farmers in the country, such huge losses can have adverse effects on the food security both of the farmers and of the country at large.

Tanzania is a large country with many different agro-ecological zones and hence a great range of climatic characteristics. The diverse climatic conditions, corresponding to the country's varied topology, (other factors held constant) put different farming households at different risk of storage losses. For example, farmers in humid and relatively less warm tropical temperatures are at larger risk since such conditions favor the reproduction and growth of pests, insects, fungus, and other cereal destructive organisms. In effect, households in different climatic zones are affected differently by climate change. There is already strong evidence that climate change is an issue in the country, as indicated by the drastic change in the annual mean rainfall from 1,067mm in 1960-1990 to 767 mm in 2001-2009. Rowhani et al. (2011) predict that a temperature increase of 2^{0}C by 2050 will reduce the average maize, sorghum and rice yields in the country by 13%, 9%, and 8%, respectively. Although nothing is known about the impact on storage losses, they are likely to increase and therefore worsen the situation. Understanding how farmers adopt storage technologies and preservation methods in response to these climatic factors is important. In the current situation of climate change, where less humid and relatively cold areas become wet and warm, adoption of relevant storage technologies could be a useful adaptation strategy.

A growing body of literature has shown that African farmers' adaptation to climate change is crucial in order to improve food security and the farmers' overall wellbeing (Di Falco, 2011; Deressa and Hassan, 2009 and Rowhani et al, 2011). Proper storage technologies and preservation methods could become useful adaptation measures by farmers.

The government of Tanzania acknowledges that post-harvest losses due to poor storage technologies pose a major challenge to the agricultural sector and overall food security in the country. For example, the Tanzanian Agricultural Sector Development Program (URT, 2001) postulates that low adoption of improved storage technologies by poor farmers (due to either lack of knowledge or poor delivery, hence access) is a major source of the problem, and is therefore planning to increase awareness and access to these technologies as a potential solution to the post-harvest losses. In addition, Pillar 7 and 9 of the KILIMO KWANZA (a Swahili acronym for *Agriculture First*) policy strategy underscore the central role of storage methods as a way of managing the post-harvest losses in the agricultural sector. In line with maintaining agriculture first, a special unit known as *National Food Security – Post-Harvest Section* has been established under the Ministry of Agriculture, Cooperatives and Food Security to specifically deal with different related storage matters[4].

Storage technologies and preservation methods that farmers use can have a significant effect on the amount of loss attributable to post-harvest storage. In Tanzania, farming households use a wide range of technologies, from the very traditional to improved traditional and modern methods. While traditional technologies vary from storing on the floor to storing in cribs, improved/modern methods vary from using small drums and bags to storing in complex silos (USAID, 2011). It is important to point out that the types of traditional storage technologies used differ significantly across societies as they represent age-old experiences and traditions that have become perfectly suited to local conditions, with some undergoing gradual improvements over time. In addition, some farmers choose to complement their storage practices with the use of preservation methods (such as spraying or smoking) for better results.

What drives adoption of storage technologies and preservation methods and the relationship between the two is still unknown. Despite the fact that the government of Tanzania aims at promoting the diffusion and adoption of improved storage technologies, it is unclear whether adoption of preservation methods and improved storage technologies is a joint decision.

3. Conceptual and methodological framework

After harvesting the crops, cereal farmers have to decide how much of the harvest to store for future household food consumption, how much to store for seeds, and how much to store to sell at higher market prices.[5] The farmers also have to determine which storage technologies and preservation methods will maximize the value of the stored cereals, at least in the current period. The household faces a storage technology choice set comprising

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[4] Visit http://www.kilimo.go.tz/Organization%20structure/NFS/post%20harvest.htm

[5] This study only focuses on the decisions farmers make once they have decided to store a certain amount of their harvest.

traditional methods, improved traditional methods, and modern methods, where the latter is assumed to be the most effective (i.e., to have the highest efficacy rate), and this feature is common knowledge. The household also has to decide whether to preserve the stored crops as well as the amount of the given preservative to use.

Farmers can reduce the storage losses attributable to pests by simultaneously choosing between adopting a different pest management measure, i.e., type of storage technology, and changing the level (or intensity) of pesticide to apply to the stored cereals. The smaller the damaged fraction of stored cereals, the more is available for sale (or consumption) at a higher market value. We assume that there are standard pesticides for a given cereal grain and alternative types of storage technologies from which farmers can choose. We further assume that the efficacy rates (i.e., fraction of pests that can be treated) of different pesticides and storage technologies are known to farmers (through experience, learning from others, and extension services). The problem facing a farmer is to choose preservation methods and storage technologies given the costs.

The storage handbook by USAID (2011, p33) classifies farm-level storage facilities as traditional or modern based on some physical characteristics of the structures. Informed by this report, we classify these facilities into three groups: traditional, improved, and modern storage technologies. While traditional technologies include locally made traditional structures, improved locally made structures, and unprotected piles and ceiling; improved technologies include sacks/open drums, modern stores and airtight drums, and modern technologies only include airtight drums and modern stores (i.e., exclude sacks/open drums).

Following the discussions above, the econometric specification of this paper consists of two parts. In the first part, we test if adoptions of improved/modern technologies and preservation methods are interdependent by estimating a bivariate probit model; in the second part, we analyze the determinants of the three possible groups of storage technologies (i.e., traditional, improved traditional, and modern technologies) by estimating an ordered probit model.

Bivariate probit model

The choice of the storage technology is likely not independent of the decision to adopt preservation measures. When households decide on storage technologies, we assume that they also decide what preservation method (if any) to adopt. To estimate the bivariate model, first we consider the broad category of improved technologies (i.e., improved traditional and modern), where the base is traditional technologies. In the second bivariate estimation we consider only the modern technologies, and the base is traditional and improved traditional. Following Greene (1998; 2008), we model simultaneously the choice of storage technology and preservation measures. Thus, we adopt the following bivariate probit model:

$$(1)\quad \begin{array}{l} \mathrm{y}_1^* = X_1^{'}\beta_1 + \varepsilon_1, S = 1, if \\ \mathrm{y}_1^* > 0; \mathrm{S} = 0, otherwise \end{array}$$

$$(2)\quad \begin{array}{l} \mathrm{y}_2^* = X_2^{'}\beta_2 + \varepsilon_2, P = 1, if \\ \mathrm{y}_2^* > 0; \mathrm{P} = 0, otherwise \end{array}$$

$\varepsilon_1, \varepsilon_2, \rho$ ~ Bivariate normal (BVN),

where S=1 for the choices of improved/modern storage technologies and zero otherwise, and P is the decision to preserve. y_1^* and y_2^* are the unobserved latent variables from which the two decisions are defined; X_1 and X_2 are the vectors of independent variables for both decisions; ε_1 and ε_2 are the error terms, which may be correlated (given by the correlation coefficient, ρ statistics), otherwise, univariate binary probit model is appropriate (Greene, 2008).

Ordered probit model

Because the different technologies have different levels of efficacy, we group the technologies as low efficacy (traditional technologies), medium efficacy (improved traditional technologies), and high efficacy (modern technologies). Given the different efficacy rates, the storage technologies used have ordinal meaning: modern storage technologies are better than improved traditional, which are better than traditional storage technologies. In the literature, a standard way of modeling ordered response variables like our dependent variable is by means of ordered probit or ordered logit (for details of the model estimation see Greene 2008). These two models are very similar, but we opt for an ordered probit in this paper because of its greater flexibility and ease of estimation. The model assumes a normally distributed cumulative density function (cdf). For the model probabilities to be positive, we define two threshold parameters, U_1 and U_2, with $U_1<U_2$. We do not observe the efficacy rate, but we do observe choices made by respondents. Assume y_i = (1, 2, and 3) for traditional, improved traditional, and modern storage, respectively. Then the interval decision rule is:

$y_i=1$ if $y_i^* \le U_1$ (Traditional technologies)

$y_i=2 \quad \text{if} \quad U_1 < y_i^* \leq U_2$ (Improved traditional technologies)

$y_i=3 \quad \text{if} \quad y_i^* > U_2$ (Modern technologies),

where y_i^* is the latent index of the efficacy rate. To estimate this model we apply the usual maximum likelihood estimation to obtain both the threshold parameters and the model parameters.

The choice of control variables for both the bivariate probit model and the ordered probit model is mainly informed by the existing post-harvest loss literature (e.g., Adegbola 2010, Adegbola and Gardebroek 2007, USAID 2011, World Bank 2011, Tefera 2012). The decisions made by farmers depend on a number of factors including amount harvested, household size, short-term climate variables (rainfall, temperature, and altitude, with terms for rainfall and temperature squared in order to capture any nonlinearities), humidity (i.e., as measured by the interaction term between rainfall and temperature), amount of rainfall in the previous season, crops grown, marketing infrastructure, and assets, which is a proxy for wealth. Since storage facilities are more expensive the higher the efficacy rate, we expect assets to positively influence adoption of modern technologies. We also control for regional variation, which captures the long-run climatic conditions as well as other regional fixed effects.

4. Data and descriptive statistics

We employ a very recent, rich, and nationally representative household survey data set from Tanzania collected in 2010-2011 as part of the Tanzanian National Panel surveys.[6] The data was collected based on a stratified, multi-stage cluster sample design using the national master sampling frame constituting a list of all populated enumeration areas in the country (NBS, 2012). Information was collected from a total of 3,846 households, of which 2,121 (55 percent) were from rural areas. Among other information available in the

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[6] At this point, it is worth pointing out two major reasons for not employing both rounds of the Panel in our analysis, despite the well founded merit of the Panel in controlling for the unobservable time invariant confounding factors. First, a majority of the farmers changed the types of cereals they cultivated and stored between the two rounds. Trying to retain a subgroup of farmers who cultivated similar crops between the two rounds reduces our sample to fewer than 180 households. Despite the econometric advantages, we find this loss of information hard to justify. Second, the interval between the two rounds is too short to observe any dynamics on the adoption of storage technologies, which are considered to have large fixed costs (especially the modern ones) and are attached to long-lived cultural traditions (especially the traditional ones). Consequently, we try to take advantage of the richness of our dataset to control most of the relevant observable variables (both at a household and community level) in our estimations as a means to minimize any potential estimation bias.

data set include, detailed plot level agricultural information: types of crops cultivated, plot characteristics, agricultural inputs, harvests, storage and preservation methods, output, and sales. In addition, a set of geospatial variables (including temperature, rainfall, and humidity) were included by using the georeferenced plot and household locations in conjunction with various geospatial databases that were available to the survey team. We also include other information gathered at the household level (such as socioeconomic characteristics, asset ownership, and consumption) and community level (governance and access to basic services).

From this dataset, we select those rural cereal farming households who reported storing at least a portion of their crops, giving us a sample of 927 cereal storage (and/or preservation) observations for 557 rural and cereal farming households.[7] The final data shows that 56% of households cultivate maize, 23% cultivate rice, and the remaining 21% cultivate other cereals, mainly millet, sorghum, and beans.

Table 1a: Major types of storage facilities used, disaggregated by gender of household head

	% of female-headed households	% of male-headed households	% of total population	Efficacy rate
Traditional storage	**21.24**	**24.70**	**24.10**	**LOW**
Locally made traditional structures	16.58	16.90	16.85	
Improved locally made structures	0.52	1.84	1.61	
Unprotected pile	1.55	1.84	1.79	
Ceiling	2.59	4.12	3.85	
Improved storage	**69.95**	**67.61**	**68.01**	**MEDIUM**
Sacks/Open drums	69.95	67.61	68.01	
Modern storage	**8.29**	**5.96**	**6.36**	**HIGH**
Airtight drums	8.29	5.42	5.91	
Modern stores	0	0.54	0.45	
Others	0.52	1.73	1.52	

Notes: Others not included in the analysis.

Table 1a provides a detailed distribution of storage technologies by gender. One can note that gender differences are very small. The main types of farm-level storage technologies used in Tanzania are: traditional storage (i.e., locally made traditional structures, improved locally made structures, unprotected pile and ceiling) adopted by 24% of our

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[7] Households are likely to adopt different types of storage technologies/preservation methods for different cereal crops. Following this we use observations for cereal storages or/and preservation as our primary unit of analysis other than households. This also enables us to retain the highest number of observations in our dataset. However, for robustness checks, we shall also do the models estimation using household as unit of analysis.

sampled households; improved storage (i.e., sacks/open drums), adopted by 68%; and modern storage (i.e., airtight drums or modern store), adopted by 6%. Since modern storage is a subset of improved storage, in the subsequent analyses, improved storage refers to both the improved-only and modern storage (i.e., sacks/open drums, airtight drums, and modern store), whereas the modern storage category does not include the improved-only one (i.e., sacks/open drums).

Table 1b: Proportion of households preserving, disaggregated by storage type

	Traditional storage	Improved storage	Modern storage	Whole population
Whether preservation (% of sample)	29.0%	31.6%	18.3%	30.7%
Distribution by category of preservation measure				
Spraying	18.6%	29.2%	16.9%	26.3%
Smoking	4.5%	2.2%	0.0%	2.8%
Other	5.6%	0.2%	1.4%	1.5%

We consider a household to have adopted a preservation measure (preservation) if it reported doing something to protect the stored crops. In our sample (as presented in Table 1b), only 30.7 % of the households reported preserving their stored crops, with a vast majority using spraying (26.3 %). We record a very small difference between those using improved and those using traditional storage methods in the proportion of households who report using preservation measures (32% versus 29%, respectively). Yet a much smaller share of households that adopt a modern storage technology (i.e. 18.3 %) also preserve. This suggests that the storage solution with the highest efficacy and preservation are substitutes.

Table 2 provides descriptive statistics of other major variables by type of storage technologies adopted. Adopters of modern storage technologies live is areas with lower temperatures and less rainfall, have more access to extension services, and are more educated and wealthy than those adopting traditional storages. However, when we look at the share of households that live in humid regions (good environment for pests, insects and other microorganisms), we find that a larger share of modern storage adopters (90%) than of traditional storage adopters (71%) live in these regions. The mean annual temperature for the whole sample is 22.8^{o}C, with the value ranging from 15.4^{o}C in some areas to 27.8^{o}C in others. Average rainfall is 754mm, varying from 359mm to 1,652mm. These statistics confirm that there is indeed a significant climatic variability across households from different geographical locations, and that these variables are likely to partly explain the differences in storage technology adoption behavior.

Table 2: Descriptive statistics of key variables

Storage technology	Traditional		Improved		Modern		Whole sample
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
share of household that have adopted preservation method	29%	-	32%	-	18%	-	31%
Mean annual temp.	22.56	2.295	22.81	2.797	20.81	2.446	22.8
Mean annual rainfall(mm)	778.7	177.840	745.3	221.802	571.0	228.816	754.4
Households living in a humid region	71%	-	75%	-	90%	-	74%
Access to extension services	14%	-	15%	-	21%	-	15%
Number of years hhld has lived in the village	40.6	21.208	38.0	19.099	30.2	19.751	38.5
Distance to the nearest major road (km)	22.624	20.255	20.594	23.516	11.755	14.529	20.9
Share of households that sold any of the harvested crops	47%	-	39%	-	58%	-	41%
Maize farming hhld (dummy)	58%	-	52%	-	83%	-	54%
Proportion of heads without any formal education	57%	-	44%	-	24%	-	47%
Female-headed households	15%	-	18%	-	23%	-	17%
Age of the household head (years)	52	13.578	49	15.271	52	12.521	50
Asset Index	-1.355	1.037	-0.110	2.587	2.198	3.068	-0.4
Proportion of households that had encountered any storage losses	6%	-	8%	-	3%	-	8%
Household size	9.1	9.129	6.2	3.313	6.4	2.992	6.9

With regard to gender, only 17% of the households in our sample are headed by females. However, 23% of households that have adopted modern storage technologies are female headed, as opposed to only 15% of the traditional storages adopters. In addition, a larger share of maize farmers adopt modern technologies (constituting 83% of adopters) compared with those cultivating other cereals. This is not very surprising as maize storage dominates the food storage activity in Tanzania, with over 70% of the functional stores having it or its products as the main product (USAID^{b}, 2011 p14). Adopters live much closer to major roads than their counterparts and a relatively larger fraction (i.e., 21% versus 14%) of this group received some extension services, indicating that transaction costs and extension services may affect the probability of adoption significantly. Interestingly, we note that the non-adopters have lived in the village much longer than the adopters, raising a concern that long-rooted storage traditions and norms may partly explain the adoption differences.

5. Results and discussions

Independent adoption of improved storage technologies and preservation methods

First, we estimate the bivariate model of improved storage technologies and preservation methods. Estimation results (Table 3) suggest that there is no statistically significant relationship between using improved storage methods and adopting preservation measures, with a rho value of 0.07, but a p-value of 0.2888. The statistical insignificancy of the results implies that the adoption of each of the two technologies (i.e., preservation and improved storage methods) can be modeled separately using an independent regression function. Following this, we estimate the binary probit model for each of the technologies to measure the effect of the climate variables, gender, extension services, and transaction costs (among others) on the probability of adoption for each of the technologies.

The marginal effects from regression results of the improved storage and preservation probit models are presented in Table 4. As expected, climatic conditions influence (non-linearly) the households' decision to preserve the stored crops. We find significant positive and negative marginal effects for temperature and temperature squared, respectively. This suggests that, at lower levels, the probability of preservation increases with temperature, but the relationship reverses at higher temperatures (the turning point is 20^{o}C, meaning that a majority of the sampled households are in the regions where the use of preservation methods declines with higher temperature). This is consistent with scientific explanations that very hot environments are not conducive for the reproduction and growth of pests, insects, and other micro-biological organisms like fungus, and hence households have less incentive to adopt preservation measures there. In addition, we find that mean annual rainfall increases the probability of using preservation methods and that households that experienced very high rainfall in previous year are more likely to adopt preservation measures in the current year.

Furthermore, higher costs of acquiring the preservation methods (as proxied by household distance from the nearest major roads) reduce the probability of using them. Households living far from the nearest major road are 7.6 percentage points less likely to adopt preservation measures. We also find that amount of crops harvested increases the probability of using preservation methods. A 10% increase in the amount of crops harvested increases the likelihood of preservation by 7 percentage points.

With regard to storage, we find that households in higher temperature areas have a lower probability of adopting improved storage technologies, but this effect gradually falls and later changes sign (the turning point is 23.5^{o}C, meaning that around 40% of the sampled households are in the regions where the adoption of improved storage increases with higher temperature). However, the results suggest that neither rainfall nor humidity matters for adoption of improved storage technologies. Hence, while controlling for regional fixed effects shows that households in semiarid regions (i.e., long-run climate average of both dry and hot) have a lower probability of adopting preservation measures, there is no such effect on improved storage technology adoption. Households in semiarid regions are 15 percentage points less likely to adopt preservation. In addition, households in higher altitude areas are less likely to adopt improved storage methods.

We find that extension services matter significantly for both improved storage and preservation. Households with access to these services are 7 and 16 percentage points more likely to use improved storage methods and adopt preservation measures, respectively, compared with their counterparts. These results resonate with previous findings that extension services influence the dispersion of improved storage technologies information (Adegbola and Gardebroek 2007).

Other factors strongly related to the probability of adopting improved storage technologies are household wealth or income (as proxied by the asset index) and household size. While the direction of the relationship is positive for wealth, it is negative when it comes to improved storage technologies and household size. These relationships suggest that resources matter for the adoption of improved storage technologies. Similar results are found in the agricultural technology adoption literature (see Foster and Rosenzweig, 2010, for a review of technology adoption literature). Improved storage technologies are often more costly than the traditional methods, and larger rural families have higher dependency rates and are relatively poorer, implying that wealthier and smaller households are better positioned with respect to adoption of improved technologies.

Table 3: Bivariate probit: Improved storage and preservation methods.

Variables	Improved storage	Preservation
Mean annual temperature (longterm)	-0.680**	0.817***
	(0.274)	(0.253)
Mean annual temperature_SQR	0.0164***	-0.0168***
	(0.00618)	(0.00572)
Mean annual rainfall (longterm)	0.00288	0.00749***
	(0.00257)	(0.00226)
Mean annual rainfall _SQR	4.26e-07	-2.14e-06**
	(1.09e-06)	(9.25e-07)
Annual rainfall in previous year (2008/2009)	-0.000785	0.000936**
	(0.000524)	(0.000474)
Interaction of rain and temperature	-0.000131	-0.000214**
	(0.000110)	(8.92e-05)
Elevation/Altitude in meters	-0.000778***	-0.000114
	(0.000294)	(0.000279)
Access to extension services	0.295*	0.441***
	(0.154)	(0.131)
Number of years hhld has lived in village	-0.00557*	0.0155***
	(0.00336)	(0.00323)
Distance from the nearest major road (in logs)	-0.0104	-0.229***
	(0.0409)	(0.0355)
Selling households	-0.0640	-0.223**
	(0.106)	(0.101)
Maize producing households	-0.189	0.489***
	(0.123)	(0.118)
No schooling	-0.0138	-0.114
	(0.115)	(0.116)
Female-headed households	0.181	-0.168
	(0.152)	(0.142)
Age of household head	-0.000148	-0.0114**
	(0.00466)	(0.00448)
Asset Index	0.160***	0.0317
	(0.0373)	(0.0227)
Whether any crop was lost from storage	0.104	-0.615***
	(0.209)	(0.225)
Amount of crop harvested (in logs)	0.0181	0.209***
	(0.0520)	(0.0480)
Household size	-0.0730***	-0.0375***
	(0.0119)	(0.0108)
Semiarid regions	-0.108	-0.528***
	(0.155)	(0.156)
Coastal regions	-1.313***	-0.164
	(0.186)	(0.155)
Constant	9.740***	-13.42***

	(3.645)	(3.305)
rho		0.0703
		(0.0664)
Observations	993	

Notes

Wald test of rho=0: chi2(1) = 1.12542 Prob > chi2 = 0.2888

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Marginal effects results for the binary probit model for adoption of improved storage technologies and using preservation methods

VARIABLES	Improved storage	Preservation
Mean annual temperature (longterm)	-0.182**	0.272***
	(0.0726)	(0.0840)
Mean annual temperature_SQR	0.00442***	-0.00557***
	(0.00162)	(0.00190)
Mean annual rainfall (longterm)	0.000723	0.00250***
	(0.000672)	(0.000752)
Mean annual rainfall _SQR	1.31e-07	-7.14e-07**
	(2.77e-07)	(3.08e-07)
Annual rainfall in previous year (2008/2009)	-0.000209	0.000316**
	(0.000138)	(0.000158)
Interaction of rain and temperature	-3.45e-05	-7.20e-05**
	(2.87e-05)	(2.98e-05)
Elevation/Altitude in meters	-0.000200***	-3.86e-05
	(7.67e-05)	(9.26e-05)
Access to extension services	0.0704**	0.159***
	(0.0328)	(0.0497)
Number of years hhld has lived in village	-0.00151*	0.00517***
	(0.000878)	(0.00107)
Distance from the nearest major road (in logs)	-0.00160	-0.0762***
	(0.0106)	(0.0118)
Selling households	-0.0158	-0.0734**
	(0.0281)	(0.0328)
Maize producing households	-0.0491	0.159***
	(0.0318)	(0.0375)
No schooling	-0.00395	-0.0373
	(0.0303)	(0.0383)
Female-headed households	0.0463	-0.0551
	(0.0350)	(0.0436)
Age of household head	-2.14e-05	-0.00381**
	(0.00122)	(0.00149)
Asset Index	0.0424***	0.0106
	(0.00926)	(0.00753)
Whether any crop was lost from storage	0.0301	-0.167***
	(0.0501)	(0.0471)

Amount of crop harvested (in logs)	0.00414	0.0696***
	(0.0137)	(0.0160)
Household size	-0.0192***	-0.0125***
	(0.00312)	(0.00359)
Semiarid regions	-0.0298	-0.154***
	(0.0434)	(0.0392)
Coastal regions	-0.440***	-0.0529
	(0.0662)	(0.0479)
Observations	993	993

Notes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Dependency on modern storage technologies and preservation method adoptions

Table 5 reports bivariate probit model results for modern storage technologies and preservation methods. Contrary to improved storage technologies, here we find that modern storage technologies and preservation methods are substitutes, with a rho value of -0.24 and a P-value of 0.027, which allows us to reject the null hypothesis of independence. The modern storage includes more recent and relatively advanced storage methods (such as airtight drums and metal silos), which if adopted there is no need for preservation measures. These results also lend empirical support to the discussion in Tefera et al. (2011) and Gitonga et al. (2012), i.e., that adoption of modern technologies such as metal silos is sufficient to prevent pest damage to grains.

However, adoption of modern storage technologies is relatively costly and farmers may consequently fail to adopt these solutions. For example, CIMMYT (2011, p.44) presents the average unit price for metal silos with a capacity of 1,000 kg to be USD 320 in Malawi and around USD 200 in Kenya. Our data however does not provide price information for the adopted storage technologies, but the effects of assets on adoption of modern storage is significant, indicating that wealthier households are more likely to choose modern storage. Given the adoption relation between modern storage technologies and preservation, we jointly estimate their adoption decisions and find that indeed transaction costs (as proxied by distance from the nearest major road) and household wealth (as proxied by asset index) are, respectively, negatively, and positively correlated with the adoption of modern storage technologies.

Table 5: Estimation results: bivariate probit for modern storage technologies and preservation methods

VARIABLES	Modern storage	preservation	marginal effects (see note[+])
Mean annual temperature (longterm)	0.112	0.825***	0.00394
	(0.411)	(0.252)	(0.00311)
Mean annual temperature_SQR	-0.0147	-0.0168***	-0.000157*
	(0.0107)	(0.00572)	(9.53e-05)
Mean annual rainfall (longterm)	-0.0109***	0.00770***	-3.76e-05
	(0.00383)	(0.00227)	(3.02e-05)
Mean annual rainfall _SQR	4.98e-07	-2.17e-06**	-5.44e-09
	(1.48e-06)	(9.34e-07)	(1.07e-08)
Annual rainfall in previous year (2008/2009)	0.00125	0.000948**	1.15e-05
	(0.000913)	(0.000477)	(8.45e-06)
Interaction of rain and temperature	0.000333*	-0.000224**	1.18e-06
	(0.000172)	(8.95e-05)	(1.23e-06)
Elevation/altitude in meters	-0.000959*	-0.000110	-6.38e-06
	(0.000530)	(0.000278)	(4.28e-06)
Access to extension services	0.0614	0.444***	0.00277
	(0.198)	(0.131)	(0.00264)
Number of years hhld has lived in village	-0.0169***	0.0155***	-4.42e-05
	(0.00505)	(0.00323)	(4.40e-05)
Distance from the nearest major road (in logs)	-0.0869	-0.230***	-0.00144*
	(0.0584)	(0.0356)	(0.000751)
Selling households	0.113	-0.219**	-0.000169
	(0.170)	(0.101)	(0.00109)
Maize producing households	0.241	0.485***	0.00337
	(0.196)	(0.118)	(0.00209)
No schooling	-0.153	-0.109	-0.00137
	(0.247)	(0.116)	(0.00177)
Female-headed households	0.132	-0.173	0.000115
	(0.217)	(0.142)	(0.00146)
Age of household head	0.0214**	-0.0114**	8.80e-05
	(0.00897)	(0.00448)	(7.83e-05)
Asset Index	0.125***	0.0325	0.000900*
	(0.0415)	(0.0227)	(0.000492)
Whether any crop was lost from storage	-1.244*	-0.600***	-0.00306*
	(0.692)	(0.225)	(0.00169)
Amount of crop harvested (in logs)	0.0583	0.209***	0.00118
	(0.0807)	(0.0477)	(0.000835)
Household size	-0.0374*	-0.0377***	-0.000380
	(0.0220)	(0.0107)	(0.000246)
Semiarid regions	-0.708**	-0.527***	-0.00337*

	(0.344)	(0.156)	(0.00182)
Coastal regions	0.233	-0.164	0.000847
	(0.262)	(0.155)	(0.00223)
Constant	4.704	-13.57***	
	(5.202)	(3.309)	
Athrho		-0.259**	
		(0.113)	
rho	-0.254**		
	(0.106)		
Observations	993		

Notes:
Wald test of rho=0: chi2(1) = 5.2377 Prob > chi2 = 0.0221
[+]Marginal effects after biprobit y = Pr(improved2=1, preserve=1) (predict) = 0.00220678
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Choice of storage technologies

Table 6 reports the ordered probit results. Consistent with the bivariate probit and probit models estimated above, households are less likely to adopt modern storage and improved storage technologies as temperature increases, but the sign changes at very high temperatures (the turning point is 26.6^{o}C, with most of the farmers being on the downward sloping portion of the curve). Similar signs are observed for the rainfall and altitude variables. It is difficult to explain these results, but one could suspect that possibly initial fixed costs of obtaining modern storage are so high to the farmers that even those living in the most risky environments cannot afford them. However, consistent with the adoption of preservation methods, we find that households in semiarid regions have a lower probability of adopting improved and modern storage technologies, but are more likely to adopt traditional storage methods.

The empirical results also suggest that extension services and household wealth are key determinants of the adoption of improved and modern storage technologies. A household that received extension services is 4 percentage points and 2 percentage points more likely to adopt improved and modern storage technologies, respectively. These results underscore the crucial role of extension services in rural Tanzania. Wealthy households are 3 percentage points more likely to adopt improved storage technologies but 4 percentage points less likely to adopt traditional storage.

Female-headed households are less likely to adopt traditional storage but more likely to adopt improved storage technologies. Female farmers are 4 percentage points more likely to adopt improved storage technologies and 5 percentage points less likely to adopt traditional storage. We find a significant and positive influence of the age of the household head on the adoption of both improved and modern storage technologies, but a negative influence on the traditional technologies. Each year of age decreases the likelihood of reporting traditional storage by 0.3 percentage points and increases the likelihood of adopting improved technologies by 0.2 percentage points. Our analysis further reveals that household size reduces the likelihood of adopting improved and modern storage technologies but increases the likelihood of adopting traditional storage technologies by 2 percentage points.

Table 6: Ordered Probit: Coefficients estimates and marginal effects estimation results

VARIABLES	Coefficient	Traditional	Improved	Modern
Mean annual temperature (longterm)	-0.626***	0.175***	-0.128**	-0.0474**
	(0.242)	(0.0674)	(0.0508)	(0.0185)
Mean annual temperature_SQR	0.010**	-0.00294**	0.00215*	0.000793**
	(0.005)	(0.00147)	(0.00110)	(0.000392)
Mean annual rainfall (longterm)	-0.005**	0.00128**	-0.000937**	-0.000347**
	(0.002)	(0.000586)	(0.000428)	(0.000169)
Mean annual rainfall _SQR	0.000*	-3.51e-07*	2.56e-07*	9.46e-08*
	(0.000)	(1.84e-07)	(1.36e-07)	(5.04e-08)
Annual rainfall in previous year (2008/2009)	-0.000	3.82e-05	-2.79e-05	-1.03e-05
	(0.000)	(0.000121)	(8.82e-05)	(3.25e-05)
Interaction of rain and temperature	0.000	-2.59e-05	1.89e-05	6.99e-06
	(0.000)	(2.29e-05)	(1.67e-05)	(6.38e-06)
Elevation/altitude in meters	-0.001***	0.000171***	-0.000125***	-4.62e-05**
	(0.000)	(6.46e-05)	(4.79e-05)	(1.85e-05)
Access to extension services	0.248**	-0.0643**	0.0423**	0.0219*
	(0.120)	(0.0287)	(0.0172)	(0.0123)
Number of years hhld has lived in village	-0.012***	0.00332***	-0.00242***	-0.000895***
	(0.003)	(0.000833)	(0.000642)	(0.000245)
Distance from the nearest major road (in logs)	-0.044	0.0124	-0.00904	-0.00334
	(0.032)	(0.00890)	(0.00659)	(0.00239)
Selling households	-0.012	0.00333	-0.00243	-0.000896
	(0.096)	(0.0270)	(0.0198)	(0.00726)
Maize producing households	-0.049	0.0136	-0.00990	-0.00370
	(0.107)	(0.0298)	(0.0217)	(0.00812)
No schooling	-0.064	0.0179	-0.0131	-0.00479
	(0.107)	(0.0300)	(0.0220)	(0.00806)
Female-headed households	0.207*	-0.0545*	0.0367*	0.0178
	(0.125)	(0.0307)	(0.0190)	(0.0122)
Age of household head	0.009**	-0.00259**	0.00189**	0.000699**

	(0.004)	(0.00114)	(0.000840)	(0.000321)
Asset Index	0.131***	-0.0366***	0.0267***	0.00988***
	(0.023)	(0.00635)	(0.00512)	(0.00206)
Whether any crop was lost from storage	-0.290*	0.0892*	-0.0717*	-0.0175**
	(0.149)	(0.0494)	(0.0425)	(0.00749)
Amount of crop harvested (in logs)	0.016	-0.00461	0.00336	0.00124
	(0.049)	(0.0137)	(0.00999)	(0.00371)
Household size	-0.070***	0.0197***	-0.0144***	-0.00532***
	(0.010)	(0.00282)	(0.00234)	(0.00100)
Semiarid regions	-0.284**	0.0857*	-0.0676*	-0.0181**
	(0.140)	(0.0448)	(0.0377)	(0.00772)
Coastal regions	-0.884***	0.295***	-0.253***	-0.0423***
	(0.150)	(0.0555)	(0.0540)	(0.00662)
cut1	-11.967***			
	(3.214)			
cut2	-9.302***			
	(3.195)			
Observations	993			
Model chi-square	227.9			
Pseudo R2	0.180			

Notes
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Robustness Checks

For robustness checks, we re-estimate the bivariate models considering household aggregate storage and preservation technologies (i.e., in the previous sections, we exploited the detailed storage and preservation information for all cereals grown by each household). Table 7 presents the bivariate regression results for joint adoption of preservation methods and improved storage technologies, while Table 8 reports the same results for joint adoption of preservation methods and modern storage technologies. Consistent with the results in previous sections, the relationship between modern storage and preservation techniques is negative and significant (rho: -0.232; p-value: 0.0598). Hence, preservation methods and modern storage technologies are substitutes. As found earlier, preservation methods and improved storage technologies are independent (rho: 0.097; p-value: 0.2759). The results for the other variables are consistent with the estimated models using the detailed cereal storage information.

Table 7: Bivariate probit results for joint adoption of improved storage and preservation (households as primary unit of analysis)

VARIABLES	Improved storage	Preservation
Mean annual temperature (longterm)	-0.747*	0.638*
	(0.387)	(0.361)
Mean annual temperature_SQR	0.0151*	-0.00923
	(0.00808)	(0.00780)
Mean annual rainfall (longterm)	-0.00374	0.00563*
	(0.00345)	(0.00314)
Mean annual rainfall _SQR	2.17e-06	-6.76e-07
	(1.84e-06)	(1.31e-06)
Annual rainfall in previous year (2008/2009)	-6.38e-05	0.00170***
	(0.000651)	(0.000660)
Interaction of rain and temperature	2.24e-06	-0.000325***
	(0.000143)	(0.000118)
Elevation/altitude in meters	-0.000862**	0.000382
	(0.000363)	(0.000353)
Access to extension services	0.177	0.618***
	(0.195)	(0.175)
Number of years hhld has lived in village	-0.00718	0.00748*
	(0.00457)	(0.00436)
Distance from the nearest major road (in logs)	0.0145	-0.103**
	(0.0534)	(0.0517)
Selling households	-0.169	-0.180
	(0.148)	(0.143)
Maize producing households	-0.166	1.015***
	(0.184)	(0.181)
No schooling	0.0497	0.0535
	(0.151)	(0.148)
Female-headed households	-0.0171	-0.143
	(0.185)	(0.178)
Age of household head	0.00342	-0.00973*
	(0.00600)	(0.00588)
Asset index	0.117**	-0.0144
	(0.0527)	(0.0400)
Whether any crop was lost from storage	0.122	-0.125
	(0.281)	(0.286)
Amount of crop harvested (in logs)	0.0926	0.343***
	(0.0709)	(0.0685)
Household size	-0.0445**	-0.0226
	(0.0177)	(0.0178)
Semiarid regions	-0.194	-0.379*
	(0.211)	(0.199)
Coastal regions	-1.216***	0.0911
	(0.215)	(0.211)

Constant	11.93**	-14.18***
	(5.159)	(4.743)
Athrho		0.0969
		(0.0889)
rho	0.097	
	(0.088)	
Observations	552	

Notes
Wald test of rho=0: chi2(1) = 1.18723 Prob > chi2 = 0.2759
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Bivariate probit results for joint adoption of modern storage technologies and preservation methods (households as primary unit of analysis)

VARIABLE	Modern Storage	Preservation	Marginal effects (See note^{+})
Mean annual temperature (longterm)	0.217	0.646*	0.00742
	(0.478)	(0.366)	(0.00612)
Mean annual temperature_SQR	-0.0139	-0.00914	-0.000232
	(0.0120)	(0.00786)	(0.000157)
Mean annual rainfall (longterm)	-0.00752*	0.00590*	-4.42e-05
	(0.00426)	(0.00321)	(5.49e-05)
Mean annual rainfall _SQR	6.26e-07	-6.85e-07	2.21e-09
	(1.44e-06)	(1.33e-06)	(1.90e-08)
Annual rainfall in previous year (2008/2009)	0.000281	0.00171***	1.62e-05
	(0.000919)	(0.000664)	(1.43e-05)
Interaction of rain and temperature	0.000239	-0.000339***	2.57e-07
	(0.000174)	(0.000121)	(2.15e-06)
Elevation/altitude in meters	-0.000529	0.000396	-3.24e-06
	(0.000581)	(0.000353)	(7.12e-06)
Access to extension services	-0.0678	0.626***	0.00443
	(0.237)	(0.174)	(0.00517)
Number of years hhld has lived in village	-0.0118**	0.00754*	-8.19e-05
	(0.00580)	(0.00436)	(8.04e-05)
Distance from the nearest major road (in logs)	-0.0639	-0.104**	-0.00154
	(0.0661)	(0.0518)	(0.000958)
Selling households	-0.0732	-0.176	-0.00219
	(0.223)	(0.143)	(0.00287)
Maize producing households	0.0990	1.022***	0.00887*

	(0.234)	(0.181)	(0.00496)
No schooling	-0.0445	0.0568	-9.65e-05
	(0.248)	(0.149)	(0.00305)
Female-headed households	0.309	-0.153	0.00278
	(0.233)	(0.178)	(0.00398)
Age of household head	0.0124	-0.00976*	7.23e-05
	(0.00908)	(0.00590)	(0.000123)
Asset index	0.175***	-0.0138	0.00196*
	(0.0445)	(0.0395)	(0.00112)
Whether any crop was lost from storage	-0.775	-0.112	-0.00998
	(0.553)	(0.285)	(0.00803)
Amount of crop harvested (in logs)	0.185*	0.344***	0.00476**
	(0.104)	(0.0687)	(0.00240)
Household size	-0.0186	-0.0226	-0.000389
	(0.0282)	(0.0176)	(0.000414)
Semiarid regions	-0.477	-0.376*	-0.00518*
	(0.345)	(0.197)	(0.00266)
Coastal regions	0.249	0.0885	0.00443
	(0.269)	(0.211)	(0.00607)
Constant	-0.0192	-14.41***	
	(5.835)	(4.834)	
Athrho	-0.236*		
	(0.126)		
Rho	-0.232*		
	(0.119)		
Observations	552		

Notes
Wald test of rho=0: chi2(1) = 3.54388 Prob > chi2 = 0.0598
$^+$Marginal effects after biprobit y = Pr(improved2=1, preserve=1) (predict) = 0.00459784
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6. Conclusions and policy implications

Using recent data from rural Tanzania, we find that temperature, rainfall, and altitude are important climate variables in explaining adoption of storage and preservation technologies. Climate change is indeed an issue in Tanzania as we already observe a significant decrease in the mean annual rainfall in the country, with several regions affected differently, suggesting that more households are at risk of losing their crops as a result of poor storage. We find that farmers in risky climatic environment do respond by adopting preservation measures against storage pests. From a policy perspective, we argue that preservation methods and modern storage technologies could be useful adaptation strategies to manage the effects of climate change.

Our empirical results suggest that adoption of modern storage technologies is a substitute for adopting preservation measures as they provide sufficient protection against pests and other destructive microorganisms. Therefore, the multi-million projects in Africa to promote modern storage technologies (e.g., metal silos and super grain bags) as post-harvest abatement technologies are worthwhile because they reduce the need for preservation. Since modern technologies are relatively expensive, leaving only wealthy households with the ability to adopt them, interventions by the government (through subsidies) and non-governmental organizations can play a significant role in stimulating their adoption by poor households, who are usually under the threat of food insecurity.

Future research should collect comprehensive data on the costs and benefits of combinations of different technologies to strengthen the debate on the cost effectiveness of adopting modern storage technologies.

Extension services do increase adoption of improved and modern storage technologies. We recommend that extension services should include comprehensive post-harvest loss abatement components. For example, the extension agents could inform farmers about how to calculate the cost and benefits of the pest-management options available to them at the time of harvest. In addition, a farmer’s choice to adopt a new technology requires several types of information. The farmer must know that the technology exists, s/he must know that it is beneficial, and s/he must know how to use it effectively. In countries like Tanzania, where a majority of farmers have at most primary education, extension services are a major source of such information. This kind of information would thus be important in addition to enabling poor households to afford more effective technologies.

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Paper IV

Risk perception, choice of drinking water and water treatment: Evidence from Kenyan towns

Simon Wagura Ndiritu[1]

Abstract

This study uses household survey data from four Kenyan towns to examine the effect of households' characteristics and risk perceptions on their decision to treat/filter water as well as their choice of main drinking water source. Since the two decisions may be jointly made by the household, a seemingly unrelated bivariate probit model is estimated. It turns out that treating non-piped water and using piped water as a main drinking water source are substitutes. The evidence supports the finding that perceived risks significantly correlate with a household's decision to treat/filter unimproved non-pipe water before drinking it. The study also finds that higher connection fees reduce the likelihood of households connecting to the piped network. Since the current connection fee acts as a cost hurdle which deters households from getting a connection, the study recommends a system where households pay the connection fee in instalments, through a prepaid water scheme or through a subsidy scheme.

Keywords: Risk perception, water quality, drinking water, water treatment

JEL classification: Q53, Q56

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[1] School of Business, Economics and Law, Department of Economics, University of Gothenburg, simon.wagura@economics.gu.se.

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1. Introduction

This paper presents a study on the decisions about drinking water sources and in-home water treatment behaviour, drawing on household data collected in Kenyan towns. Specifically, the quest was to understand how people think about and respond to the perceived riskiness of different water sources when they are choosing their drinking water, and what their risk-averting behaviour entails. Because not all households have access to or use the presumably safe piped water, those who did not have access to improved water sources were asked whether they did anything to ensure that their water was safe and what factors determined what they did. For those that had potential access to piped water but chose not to use it, their choice of using risky non-piped water sources was studied. The study also investigated the role of the connection fee as a hurdle to connect to the piped network. Unlike previous studies, here, the analysis was estimated on the assumption that the decision was taken jointly by all household members, and the effect of perceived risk and the substitution effects of the decisions were tested. An understanding of households' drinking water choices is important for better planning by water service providers. In addition, understanding household behaviour towards unsafe non-pipe water treatment is an important precaution against water-borne diseases.

Improved access to water supply and sanitation remains one of the primary ways of addressing poor health in developing countries. As stipulated by the United Nations Millennium Development Goal (MDG) 7, target C aims to "reduce by half the proportion of people without sustainable access to safe drinking water" by 2015. Since 1990, access to drinking water coverage has expanded in sub-Saharan Africa by about 22%, though it still remains low, with only 60% of the population served (UN 2010). The challenge for water improvements remains greater for most sub-Saharan African countries, where coverage is mostly below average.

In many developing countries, insufficient access to clean water and adequate sanitation and the resulting health issues are acute problems. Every year, the lack of safe water, sanitation, and hygiene causes about 88% of deaths from diarrhoeal diseases, accounting for 1.5 million such deaths – the majority of which occur among children under the age of 5 (Unicef 2008). To win any health battles in developing countries, therefore, secure clean water and sanitation facilities for all should be a government priority. Health psychologists recognise the perceived risk of illness as one of the most important factors in a household’s precautionary behaviours (Redding et al. 2000). The same argument can be applied to households treating drinking water seen to be of dubious quality in order to avoid illness.

In Kenya, as in many other developing countries, insufficient access to clean drinking water and the resulting health issues are serious problems that beg more research into increasing water quality. While significant gains in water infrastructure development have been realised since the turn of the 20th century, water supply in Kenya is still inadequate, with only 57% of households using water from sources considered safe (GoK 2008). In addition, access to safe water supply and sanitation varies greatly across regions. Approximately 80% of hospital attendance in Kenya is due to preventable diseases. About 50% of these diseases relate to water, sanitation and hygiene (GoK 2011). Wealthy households buy bottled water for drinking, but for most households this option is unaffordable. One way households improve water quality is by treating water domestically through boiling, filtering or chlorination. Domestic water treatment has been shown to be one of the most effective means of reducing the risks and costs associated with preventing water-borne diseases, especially diarrhoea (see e.g. Clasen et al. 2007a, 2007b). However, despite the importance of increasing water quality through domestic treatment, empirical research on the relationship between water treatment and factors such as risk perception that drive this decision remains scarce.

There appear to be few studies focusing on the above issues. Notable exceptions are those by Cai et al. (2008), Jakus et al. (2009), and Nauges and Van den Berg (2006). Nauges and Van den Berg study the perception of health risk and averting behaviour for non-pipe water sources in Sri Lanka. Jakus et al. (ibid.) examine why people in the United States (US) buy bottled water, while Cai et al. (ibid.) explore altruistic averting behaviour of removing arsenic risk in drinking water in the US. The studies find that a household’s averting behaviour increases with their perception of a health risk. While the latter two studies also find education increases averting behaviour, Cai et al. (ibid.) do not find any evidence that education influences water treatment expenditure. Thus, the results of all these studies are mixed. For this reason, no general conclusions can be drawn from the limited existing literature on whether and how water treatment is affected by risk perception. In addition, there was no study that modelled the effect of risk perception on the choice of drinking water sources and water treatment in Africa, where poor water quality is an issue of immense concern.

Estimations regarding households' choice of water sources in developing countries also remain scarce, especially in African cities. Few studies focus on the household's choice of a water source; again, exceptions are Basani et al. (2008), Hindman Persson (2002), Madanat and Humplick (1993), Mu et al. (1990), and Totouom et al. (2012). Nonetheless, these studies do not investigate water quality concerns in the household's choice of water source – a gap the current study aims to fill. In addition, the water utility charges a connection fee that entails a security deposit plus the cost of piping, a water meter, labour and other connection expenses. This fee has been shown to affect a household's decision to connect to the piped network (Basani et al. 2008). With the exception of Totouom et al. (2012), these other studies do not consider the likelihood of water source choice and water treatment to be joint decisions. The study also did not find any study testing whether the domestic treatment of low-quality water served as a substitute for a piped water connection.

This paper contributes to the literature on the economics of water quality by answering the following questions:

- How does risk perception influence a household's choice of a source of drinking water and whether it gets treated/filtered or not?
- Why do households with potential access to safe piped water choose not to be connected?

To answer these questions several models are investigated. First, to determine whether the decisions to choose a source of drinking water and to treat a source of water are jointly made, a seemingly unrelated bivariate probit model is estimated. For the subsample of those with potential access to a piped connection, it turns out that the choice of piped water sources and treatment of non-pipe water turn out to be substitutes.

Since people will behave according to their personal perception of risk and not according to the objective risk measures as calculated by water engineers (scientists), then this study tests the effect of risk perception on the choice of a source of drinking water and on averting behaviour. The findings suggest that perceived risk is significantly correlated with a household's decision to treat/filter non-piped unimproved water before drinking it and with the choice of piped water as the main drinking water source. This result confirms the important role perceived risk plays in changing health behaviour.

The structure of the paper is as follows: section 2 discusses the economics of water quality in general, while section 3 explains the extent of water quality problem and water pricing in Kenya**.** The survey data and descriptive statistics are discussed in section 4. Section

5 follows with a presentation of the theoretical framework together with the methodology. In section 6, the study results are presented, while section 7 concludes the discussion.

2. The economics of water quality

Water quality has been of interest to many disciplines, especially scholars studying water-related health issues. The consumption of safer drinking water is being championed by scholars and development workers as a panacea for a multitude of causes of ill-health and death among the socio-economically marginalised in particular. Some have studied the effects of informing households about the riskiness of their drinking water sources and subsequent averting behaviour. For instance, Madajewicz et al. (2007) provide information on unsafe wells to encourage Bangladeshi households to switch to safer wells. Jalan and Somanathan (2008) report that, through a randomised experiment, they provided information to households that their unpurified water was dirty, and through this increased domestic water treatment.

Although informing households on the health effects of unsafe drinking water leads them to treat water or even change water sources, especially those using unsafe non-tap water sources, there are potential methodological problems with the way the previous studies were conducted. Providing households with information and later revisiting them could lead to bias in the responses provided by the respondents, as they may wish to please the interviewers. For example, a respondent might not in fact have changed their behaviour, but might nonetheless feel pressure to state that they had if they were asked by someone who had educated them in the past about the benefits of changed behaviour. This potential response bias could affect both the magnitude and statistical significance of the estimates obtained through the approach. In this study, however, no risk information is provided to the respondents. Instead, respondents were asked about their perception of certain risks, and assess the implications such risk perceptions would have on averting behaviour. In this case, therefore, the responses are not biased by the risk information advanced to the respondent but rather by own experience accumulated through actual use of a given water source.

Several approaches have been applied to study water quality issues, including randomised experiments (e.g. Kremer et al. 2011; Jalan & Somanathan 2008), while research on non-market valuations has been applied to study water quality perceptions (e.g. Poe & Bishop 1999; Whitehead 2006). All of these studies show that, in developing countries, the choice regarding a drinking water source has health implications: because most of the common diseases found in these countries are water-borne, their incidence can be drastically reduced by increasing the quality of water from the main sources that households use. In Brazil, the provision of piped water has significantly reduced infant mortality, especially to the most disadvantaged communities (Gamper-Rabindran et al. 2010). In a review paper, Olmstead (2010) observes that the treatment of drinking water provides the highest net benefit of any environmental policy intervention.

To better understand the role of improved water sources on child health, economists have begun to evaluate the impact of improved water sources policies. Kremer et al. 2011), studying the impact of improved source water quality achieved via spring protection in rural Kenya using a randomised evaluation, found that the incidence of reported cases of diarrhoea among children fell by a marginally significant 20%. Although Jalan and Ravallion (2003) found overall health benefits related to access to piped water, they also found that health gains from piped water tended to be lower for children in households with less well-educated women. In addition, they found no significant health gains for 40% of those with the lowest incomes. This suggests that, even though there is a positive link between the provision of improved water sources, enhanced drinking water quality and a lower incidence of child diarrhoea, exactly how this positive link is established remains unclear.

Self-protection through averting behaviour is a critical factor in the analysis of public risk mitigation policy (Cai et al. 2008). It is likely that what affects households' averting behaviour is the risk they themselves perceive rather than some objective measure unknown to the household or the researcher. Therefore, once it is clear how risk perceptions influence water treatment behaviour, policymakers have an opportunity to influence household risk perceptions. In the context of drinking water, there have been many discussions of averting behaviours. These behaviours include treating water, purchasing bottled water, or boiling contaminated water.

With the exception of Cai et al. (2008), Nauges and Van den Berg (2006) and Jakus et al. (2009), most studies on drinking water (Abdalla et al. 1992; Collins & Steinbeck 1993; Laughland et al. 1993; Whitehead et al. 1998) do not specifically incorporate perceived risks. This study aims to fill this notable gap in the literature on the economics of water quality.

3. The extent of water quality problems in Kenya

About 80% of all communicable diseases are water-related. Hence, access to safe water and sanitation to households is required to improve health standards in Kenya (GoK 2007).

Increased commercial farming activities, coupled with rapid industrialisation and lax law enforcement, have led to increased effluent discharge into water bodies and disposal of farm chemicals and waste into rivers. All these factors have resulted in the degradation of Kenyan surface water resources (ibid.). The 2009 population census showed that a significant share of the Kenyan population depends on water from lakes, rivers, ponds and dams, all of which are regarded as unsafe sources. Thus, many people are exposed to serious health problems as a result of water-borne disease, among other things.

3.1 Compliance with quality standards

Kenya's Water Act of 2002 established the Water Services Regulatory Board (WASREB) to regulate water and sanitation services in the country. WASREB currently does not take samples to cross-check water quality results from water service providers (WSPs), but relies on certification and random tests by the Kenya Bureau of Standards. Moreover, the Act established the Water Resources Management Authority (WRMA). The WRMA is responsible for regulating water resource issues such as water allocation and water quality management. Thus, the WRMA requires any group or individual developing a well or sinking a borehole to file a complete analysis of the water quality in the course of test pumping.

The number of water quality tests carried out by WSPs improved from 79% in 2006/7 to 90% in 2008/9. A sector benchmark classification published by WASREB in 2010 categorised 27 WSPs (35%), i.e. mainly the large ones, as being of good quality (>95%), while 2 were classified as being of acceptable quality (90–95%). The remaining 48 WSPs either fell within the unacceptable range or did not submit any information.

Even in urban areas where WSPs are quality-compliant, service provision for the urban poor is largely left to the informal sector/private water vendors, leading to insufficient control of water quality. Vendors exploit information asymmetries to sell low rather than high quality water. Poor people who cannot buy even low-quality water have only one alternative: to spend hours fetching water of poor quality.

3.2 Pricing of water in Kenya

The regulator (WASREB) develops guidelines for the fixing of tariffs for water service provision. The tariffs set are, in theory, required to balance commercial, social and ecological interests by ensuring water access to all while allowing water service boards and WSPs to recover justified costs. Due to public and political pressure, however, the tariffs have remained static over the last few years and do not cover the costs of maintaining the water infrastructure, let alone expanding it.

All WSPs in Kenya have adopted varying increasing block tariffs (WASREB 2010). This means that, on the one hand, high-usage consumers pay marginally higher unit prices which could discourage excessive consumption. On the other hand, the poor (low-usage consumers) have access to water through what are assumed to be affordable tariffs. It should be noted that the price for the first ten-unit block applies only to those users who use a total of less than 10 m^3 per month. If a consumer exceeds this level of use, the price of the second block would apply to the first 10 m^3 too. The tariff includes a water supply fee, sewage collection fee, and treatment fee.

WSPs vary widely in respect of their approved tariff levels, unit costs of production, and unit operation costs. Table 1 shows the average tariff, unit cost of production, and unit operating cost of water billed over the periods 2006/7 and 2008/9. Over these periods, the tariffs increased from KES 36 to KES 40 due to a rise in the cost of water provision, the inclusion of a higher number of small WSPs, high levels of water loss, and unbilled water use (WASREB 2010). Although popular for the poor, block tariffs can create structural disadvantages for the unconnected poor. This is because the water vendors that supply households that have no piped connections typically purchase water in bulk at the top price tiers. Thus, the poor land up buying water that the utilities have resold at the highest cost.

Table 1: Description of the applicable water tariffs in Eldoret, Kericho, Kisii and Kisumu

Period	**Average tariff (KES/m^3)**	**Unit cost of production (KES/m^3)**	**Unit operating cost of water billed (KES/m^3)**
2006/7	36	18	26
2008/9	40	23	35

Source: WASREB (2010:58)

As in other developing countries, water vendors in Kenya often act as a link between unconnected households and the utility. In some cases, water is purchased from the utility and sold on directly to households. In other cases, water is purchased from the utility and sold to intermediaries, who in turn sell to households. As water passes through the marketing chain, prices ratchet up. Water delivered through vendors and cartels is often 10–20 times more costly than water provided through a utility (UNDP 2006). For example, in a survey by Gulyani et al. (2005), they show that vended water costs more than piped water in Nairobi city as well as in the towns of Kakamega and Nakuru. In these urban centres, the average cost of water from water kiosks is remarkably high: kiosk owners charge 18 times what they pay for the water from the utilities. The pricing also tends to vary according to the season, and increases in relation to distance from the source.

In order to be connected to the piped network, a consumer is required to sign a water agreement and to pay the connection fee and deposit. Currently, deposits required from new consumers range from KES 1,000 (approximately USD 12[2]) for general consumers, to KES 15,000 (approximately USD 181) for the largest consumers. These deposits provide security against any outstanding payments. The deposit requirement tends to block many consumers from applying for their own individual meters, however, so these households end up purchasing piped water from either a public stand/vendors or other alternative sources.

4. Data and descriptive statistics

Data for this study came from a survey of residential households conducted in 2008 in four Kenyan towns: Eldoret, Kericho, Kisii and Kisumu. To achieve 911 interviews, 1,422 contacts were made during the survey, representing a 64% response rate. The non-response contacts included subjects who were unavailable either because they were absent from home at the time or they declined to be interviewed. The four towns were purposefully selected to represent diverse physical, socio-economic and ethnic backgrounds.

Eldoret is one of the few towns in the country with an adequate water supply, that is, there are rarely any occasions when the town suffers water shortages. Kericho draws its water from the local rivers. The water intake is located in the Mau Forest, one of Kenya's largest water catchment areas. From the intake, pumps drive water to a modern treatment facility. Kericho is one of the only towns of its size in Kenya to employ such a treatment works. The water and sanitation facilities in Kisii are inadequate and poorly managed. Very few residents are connected to water services and there is inadequate service coverage (less than 40%) due to low production and distribution capacity. Acute water shortage (absolute scarcity), declining quality and poor sanitation have been recurrent problems in Kisumu despite its proximity to the second largest freshwater lake in the world, Lake Victoria.

Prior to the main survey, focus groups were consulted to assist in designing the survey instrument. Sixteen graduates at the University of Nairobi were recruited as research assistants and trained for the survey, ensuring there were four for each town. To implement

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[2] 1 Kenyan Shilling (KES) = 0.01204 US Dollar (USD) (or 1 USD = 83.077 KES) as at December 2010.

the final survey, a structured questionnaire was administered. Each town was stratified into three broad residential areas on the basis of income levels. A list of the residential areas and their associated income groupings was prepared. The initial sample was randomly recruited from each residential estate.

The survey data covered water sourcing behaviour, water costs, household demographics and housing, and households' perception of water quality and safety. The study also scrutinised major socio-economic characteristics that influenced a household's choice of water source. Here all sourcing options were considered, i.e. both piped and non-piped water sources. The sample contains respondents who got their water piped into their dwelling, plot or yard, as well as those who obtained water from non-piped sources, i.e. public taps, surface water (rivers, dams, lakes, ponds, streams, canals, irrigation channels), boreholes, protected or unprotected wells, rainwater, and protected or unprotected springs.

4.1 Descriptive statistics

In Kenyan towns, households very often have to choose one among a set of water sources in respect of their main drinking water. These choices are generally grouped into two: improved and unimproved sources. According to the World Health Organisation (WHO 2005), improved drinking water sources include: piped water into dwelling, plot or yard; public tap/standpipe; tube well/borehole; protected dug well; protected spring; and rainwater collection. Unimproved drinking water sources include: unprotected dug well; unprotected spring; cart with small tank/drum; tanker-truck; and surface water (river, dam, lake, pond, stream, canal, irrigation channels). Improved encompasses three dimensions of water security: quality, proximity and quantity. Hence, water from vendors (cart with small tank/drum or tanker-truck), though mostly from safe sources (piped or borehole) is categorised as unimproved; as mentioned earlier, the quality of this water varies considerably in practice. Therefore in our analysis of the water source subsamples, the following categories were identified:

- Piped water
- Non-piped but improved water, and
- Non-piped and unimproved water.

In this study, *access* to a source means that households in that residential area/estate have the potential to get water from it. This definition implies that access to piped water does not necessarily mean having a piped water connection: it means being in a residential area/estate where connection to the piped water network is possible. For the households interviewed, piped water is most accessible in Eldoret, followed by Kericho and Kisii. Kisumu has the least access (Table 2).

Table 2: Share of households (%) with access to a water source and its use as a main source of drinking water

Water source	**Eldoret**		**Kericho**		**Kisii**		**Kisumu**		**Whole sample**	
	Access	**Use**	**Access**	**Use**	**Access**	**Use**	**Access**	**Use**	**Access**	**Use**
Piped	92	74	91	23	53	25	32	26	70	41
Non-piped improved	94	24	100	53	97	44	77	52	92	41
Non-piped unimproved	70	2	89	25	97	31	55	22	77	18

On average, 70% of households indicated that they had access to piped water, while 92% had access to non-piped improved water sources. With the exception of Eldoret, the use of non-piped water as the main source of drinking water was higher than piped water use. Similar results are found for Kisumu by Wagah et al. (2010). All respondents from Kericho had access to non-piped improved water sources; thus, Kericho had conclusively achieved MDG7's "C" target. The high cost of being connected to a piped water supply could explain why some households who had access to the piped network did not utilise it, preferring non-piped water instead. Overall, therefore, the high access to improved water sources shows an impressive picture of these towns towards achieving MDG7 on access to safe water by all.

Using a risk ladder, the survey probed the respondents' risk perception by asking the following question: *How would you judge the safety of the water from the following sources before the household does any treatment?* The respective sources were then read out one by one. The response options given were as follows: 1 = *No risk*, 2 = *Little risk*, 3 = *Some risk*, 4 = *Serious risk*, 9 = *Don't know*. Table 3, which presents the results of this part of the survey, shows variation in the perception of risk relating to the named water sources. Overall, piped water (private and public tap water) was considered safe by most of the respondents. Non-tap sources were generally considered to have only some or little risk by most of the respondents; rainwater was considered to have no risk. Thus, despite the differences in expected objective water quality, many of the respondents did not perceive any large discrepancies in quality among the various water sources.

Table 3: Household's risk perception of water quality, by source (%)

Source of water	No risk	Little risk	Some risk	Serious risk	Don't know
Piped into dwelling	58	17	7	3	16
Piped to yard/plot	18	61	13	3	4
Public tap/standpipe	15	57	21	6	1
Tube well/borehole	6	25	44	24	2
Unprotected spring	12	35	34	11	7
Rainwater	44	29	19	2	6
Cart with tank	5	24	40	23	8

Table 4 reports the descriptive statistics of the variables used in the study estimations. More than 70% of the interviewed households earned a monthly income of less than KES 50,000 (approx. USD 600). Specifically, about 46% had incomes between KES 5,000 and KES 19,999 (approx. USD 60–240), while 28% earned between KES 20,000 and KES 50,000 (approx. USD 240–600). In the study sample, over 66% of the respondents had been educated to either secondary or tertiary level. This high level of education is generally expected in Kenyan urban areas, where respondents usually engage in occupations which demand some basic skills and knowledge acquired at school. In addition, the average household consists of five members.

On average, 69% of the surveyed respondents treat their drinking water by either boiling or filtering it first. Households that used chemicals to treat their water reported spending an average of KES 52 (USD 0.63) a month, with a maximum of KES 300 (USD 3.61). The tabulation reveals that the majority of those who treated water use non-piped unimproved (77%), followed by non-piped improved (75%) and then piped (67%). Unexpectedly, a relatively high number of households was found to be treating presumably safe piped water. Hence, it can be concluded that households do not perceive piped water as being of good quality for drinking purposes. This is reasonable since Kenyans have no confidence in the water utility. This suggests, again, that the domestic treatment of water is not necessarily driven by the objective water quality but, rather, by households' risk perceptions.

Due to data limitations, it was not possible to compare the perceived risk related to water consumption from the various sources against an objective measure of risk as calculated by water engineers or other scientists. In addition, for each water source, there may be a significant amount of missing information since not all households were always able to give their opinion on each source.

Table 4: Descriptive statistics on variables used in the estimations

Variable	Description	Observations	Mean	Standard deviation	Min.	Max.
Piped	Piped connection as main source of drinking water = 1, otherwise = 0	754	0.415	0.493	0	1
Non-piped improved	Non-piped improved water as main source of drinking water = 1, otherwise = 0	754	0.406	0.491	0	1
Non-piped unimproved	Non-piped unimproved water as main source of drinking water = 1, otherwise = 0	754	0.179	0.384	0	1
Treat	Respondent treats water = 1, otherwise = 0	870	0.691	0.462	0	1
Age	Respondent’s age	891	34.163	9.000	18	70
Male	Male dummy = 1 if male	906	0.429	0.495	0	1
Hhsize	Household size	909	5.084	2.704	1	16
Child	Children 0–5 years old	911	0.782	0.912	0	6
Ratiofem	Female:Male ratio in the household	908	0.496	0.291	0	1
Education						
Primary	Grade 1–8 attained	880	0.189	0.391	0	1
Secondary	Form 1–4 attained	880	0.323	0.468	0	1
College	Diploma attained	880	0.369	0.483	0	1
University	Degree attained	880	0.076	0.265	0	1
No schooling	Never been to school	880	0.043	0.203	0	1
_ Income_1	KES <1,000 a month	875	0.149	0.356	0	1
_ Income_2	KES 1,000–4,999 a month	875	0.110	0.313	0	1
_ Income_3	KES 5,000–9,999 a month	875	0.214	0.410	0	1
_ Income_4	KES 10,000–19,999 a month	875	0.248	0.432	0	1
_ Income_5	KES 20,000–29,999 a month	875	0.147	0.355	0	1
_ Income_6	KES 30,000–49,999 a month	875	0.133	0.339	0	1
Eldoret	Respondent lives in Eldoret	909	0.295	0.456	0	1
Kericho	Respondent lives in Kericho	909	0.260	0.439	0	1
Kisii	Respondent lives in Kisii	909	0.221	0.415	0	1
Kisumu	Respondent lives in Kisumu	909	0.224	0.417	0	1
Treatment expenditure	Purchase of treatment chemicals/month (KES)	170	51.900	47.058	5	300
Connection fee	Connection fee paid to the water utility as a deposit (KES)	909	1642.684	577.529	1,000	2,500

Note: Only 170 households use chemicals to treat water.

5. Theory and methodology

Households were assumed to have a relatively fair perception of the risk of the various water sources, and that this would determine which they chose as their main source. Underlying this is the assumption that the revealed preference is based on a household’s expected utility from alternatives.[3] A household was expected to reveal their preference in line with the objective of maximising their welfare. This preference can be represented by a utility function and the decision problem can, therefore, be modelled as a standard expected utility maximisation problem. Following Hindman Persson (2002), the modelling of the choice of water source is based on the Random Utility Model (RUM). The household faces a discrete set of water source choices, where the household chooses the water source that maximises its utility subject to budget and water availability constraints. Different households have different risk perceptions for water from various sources. Therefore, each water source has a price which varies depending on the quality of the water as well as the technology required to access the water.[4]

5.1 Risk perception

In general, economic analyses of risk perception incorporate risk perceptions into the individual utility functions and then derive the associated demand functions (e.g. Lusk & Coble 2005; Viscusi 1990; Zepeda et al. 2003). Consuming contaminated water implies a health cost, and consumers make judgments about how contaminated different water sources are. In their choice of a main water source, they compare the expected health cost from consuming the specific water to the cost of using the water source in question, where less risky water sources – such as piped water – generally come at a higher cost than more risky sources. In the same way that a main water source was chosen, a decision is made as to whether or not to undertake the perhaps costly treatment of the chosen water source. Consumers will treat water if the expected utility of health benefits of domestic treatment – measured as a change in expected water-related illness – exceeds the costs of domestic treatment. Following the economic models that analyse risk perception, the following testable hypotheses are proposed:

(a) Individuals that perceive a greater risk from using a water source will be less likely to choose that water source than individuals that perceive a lower risk, and

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[3] In our study areas, not all households have access to all the water sources. This will be taken into account during the estimation procedures.

[4] See Hindman Persson (2002) for a detailed derivation of the RUM for water source choice that is consistent with utility maximisation.

(b) The more risky the individuals perceive the water source to be, the more likely they are to treat the water from that source.

5.2 Model specification

When the members of a household choose their drinking water, they worry about access to and the quality of the water. If they doubt the quality – a doubt that could be driven by many factors – they may decide to treat the water. The choice in respect of a source of drinking water is likely not to be independent of the decision to treat or not water before drinking it. At the time the household decides on its water source, it is assumed they also decide whether or not to treat the water. Hence, the study follows Nauges and Van den Berg (2006) to model, simultaneously, the choice of the drinking water source and the decision to treat water before drinking. Given the assumed simultaneous nature of the decisions of water source and water treatment, several seemingly unrelated bivariate probit models are estimated for the following possible groups.

First, for the subsample of households living in a residential area/estate where potential access to piped water is possible the choice of piped as opposed to non-piped water as the main source of drinking water is studied, adopting the following bivariate probit model:

$$l_1^* = X_1^{'}\beta_1 + \varepsilon_1;\ S_1 = 1 \text{ if } l_1^* \succ 0;\ S_1 = 0, \text{ otherwise} \quad (1)$$

$$l_2^* = X_2^{'}\beta_2 + \varepsilon_2;\ T_1 = 1 \text{ if } l_2^* \succ 0;\ T_1 = 0, \text{ otherwise} \quad (2)$$

$\varepsilon_1\ \varepsilon_2$ and ρ_1 ~Bivariate normal (BVN)

where S_1 is the choice of using piped water. T_1 is the decision to treat water; l_1^* and l_2^* are the unobserved latent variables from which the two decisions are defined; X_1 and X_2 are the vectors of independent variables for both decisions and ε_1 and ε_2 are the error terms, which may be correlated (given by the correlation coefficient, ρ statistics); otherwise, a univariate binary probit model is appropriate (Greene 2008).

Second, for those who do not have access to piped water, but who do have access to improved non-piped water sources, the study looked at the decision to use improved non-piped water sources for the main source of drinking water rather than an unimproved source. For this, the following bivariate probit model was adopted:

$$l_3^* = X_1'\beta_3 + \varepsilon_3;\ S_2 = 1 \text{ if } l_3^* \succ 0;\ S_2 = 0, \text{ otherwise} \tag{3}$$

$$l_4^* = X_2'\beta_4 + \varepsilon_4;\ T_2 = 1 \text{ if } l_4^* \succ 0;\ T_2 = 0, \text{ otherwise} \tag{4}$$

$\varepsilon_3, \varepsilon_4$ and ρ_2 ~Bivariate normal (BVN),

where S_2 is the choice of using a non-piped improved water source. T_2 is the decision to treat water. The other variables are as defined in equations (1) and (2) above.

Third, for people who have no access to improved water sources (piped water or improved non-piped water sources), the only remaining decision is to treat or not treat the water, given that they can afford to pay for water treatment. Hence, the probit model is estimated for the water treatment equation for the subsample of those with no access to improved water sources. The probit model is defined as follows:

$$l_5^* = X_2'\beta_5 + \varepsilon_5;\ T_3 = 1 \text{ if } l_5^* \succ 0;\ T_3 = 0, \text{ otherwise} \tag{5}$$

where T_3 is the water treatment for those who choose non-piped unimproved water sources as their main drinking water. All the other variables are as defined above.

The same explanatory variables are included for the socio-economic characteristics in the two (source and water treatment) equations. Factors explaining a household's decision to obtain water from a certain source in developing countries are presented in a literature survey by Nauges and Whittington (2010). The factors they identify include source attributes (e.g. price, distance to the source, quality, and reliability) and household characteristics (income, education, size and composition). Following existing literature on water sources and water treatment, the variables included are as follows:

- Age, education and gender of the head of the household
- Number of children aged 0 to 5 years
- Ratio of females to males in the household
- Income category, and
- The average perception of water safety in the town where the household lives.

For the piped water equation, the effects of the connection fee and the average frequency of problems experienced with water pressure in the town where the household lives were also explored. Madanat and Humplick (1993) argue that households living in areas with higher pressure in their water pipes are expected to increase their connection to the piped network. Thus, the study controlled for the problem of water pressure in the piped water model.

As pointed out by Whitehead (2006) and Nauges and Van den Berg (2006), perceived risk is likely to be endogenous in the treatment of water behaviours. If some unobserved variables (such as health history) determine both perceived risk as well as a household's hygiene behaviour, then one could be facing an omitted variable problem (Nauges & Van den Berg 2006). This means that instruments are required that would drive risk perception but which would be uncorrelated with hygiene behaviour. We were not able to find suitable instruments for perceived risk in our data. Therefore, in order to avoid endogeneity problems, the household's own risk perception is not considered; instead, the average perception of water safety in the town where the household lives was used.[5] Following Nauges and Van den Berg (2006), an exogenous variable was constructed for the average risk perception[6] in the town where the household lives. In the creation of the variable, risk perceptions of water safety in the towns were coded as *No risk* (1), *Little risk* (2), *Some risk* (3), and *Serious risk* (4). The *Don't know* responses were deleted. Basically, the assumption is that the average opinion in the town is a good proxy of household opinion, and it will be exogenous in the estimated models.

Since there are multiple water sources, in the treatment equation the average risk perception for the main drinking water source for each household was considered. For the piped water source choice, the risk perception in respect of non-piped water is considered. The idea is that, when choosing a water source, one considers the risks of the potential alternatives; but for the treatment decision, what matters is the perception of the chosen water source as risky and whether one would treat it or not. Generally, people in a town will talk

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[5] If the individual household's risk perception is used instead of an average risk perception, many observations for individual water sources are lost. Thus, for most of the water sources, the results are no longer significant (or statistical significance is reduced). Nonetheless, for most of the regressions, the results are consistent with those from the village-level risk perception estimation. Results are not presented here due to space limitations, but can be provided upon request.

[6] Since there are 12 water sources, it was possible to have reasonable variation in the average risk perception variable. This is because only the average risk perception for the main water source that the household used for drinking was considered.

about water-borne diseases; thus, the average risk perception is likely to be widespread in practice – even if individual households describe the same perception differently.

Ideally, one also needs to control for the cost of obtaining water from all the water sources (both the sources households use as well as those they do not use). However, in our data set, the full information of the opportunity cost of water from all sources is not available. However, there are data on the connection cost to the piped network. It is expected that households having experienced problems with water pressure are less likely to prefer piped water over those households who have not experienced such problems (Madanat & Humplick 1993).

6. Econometric results

6.1 Probability of choosing piped water source and water treatment

First, the bivariate probit model is estimated to check whether the choice of a piped water source and a decision to treat water are indeed jointly made. Table 5 reports the estimated coefficients for the piped water and water treatment decisions, plus the marginal effects of the joint probability that the household chooses piped water and treats their drinking water. A likelihood ratio test of the null hypothesis that the correlation coefficient (ρ statistics) equals zero against the alternative that ρ does not equal zero was also carried out. It turned out that, for the users of piped water, the correlation coefficient (-0.30) is statistically different from zero (see Table 5). This means that the decisions to use piped water and to treat water, given that a household had access to piped water, are joint decisions. There is a negative correlation between choice of piped water and water treatment, meaning that a household's treating of non-piped water and its choice of piped water as a main source of drinking water may be seen as substitutes.

Low-income households are less likely to treat water or use piped water as their main source of drinking water. Being in the income group earning below KES 5,000 (USD 60) a month reduces the likelihood of having a piped connection and of treating water by 34% on average, relative to the higher-income groups. A larger proportion of women in relation to men in the household increases the probability by 14% that the household treats its drinking water.

If non-piped water in the town is perceived as being risky, there is a higher probability that the household has a piped connection. However, risk perception turns up negative in the treatment equation, given that the household has access to a piped connection. This could be explained by the outcome that piped water choice and water treatments are substitutes.

To capture the connection cost variable, the official connection fee to the piped network for each town is included. This fee does not include piping materials and labour which are household-specific. The variable enters the access to water model in logarithmic form. The estimated marginal effect suggests that a 10% increase in the connection fee reduces the probability of a piped connection by about 6%. As expected, problems with water pressure reduce the likelihood of connecting to the piped network.

Table 5: Seemingly unrelated bivariate probit for treatment equation and piped connection (those with access to a piped connection)

Variables	Piped connection	Treatment equation	Marginal effects*
Age	0.0141	-0.00804	0.00214
	(0.00924)	(0.00952)	(0.00305)
Male	-0.217	-0.120	-0.0909*
	(0.147)	(0.148)	(0.0503)
Child	0.0392	0.0652	0.0269
	(0.0774)	(0.0776)	(0.0271)
Female:Male ratio		0.595*	0.142*
		(0.352)	(0.0852)
Monthly income (base = KES 20,000+)			
KES 0–4999	-0.408*	-0.992***	-0.337***
	(0.227)	(0.216)	(0.0655)
KES 5,000–9,999	-0.525**	-0.547**	-0.268***
	(0.222)	(0.214)	(0.0599)
KES 10,000–19,999	-0.0937	-0.254	-0.0880
	(0.195)	(0.195)	(0.0655)
Education (base = No schooling)			
Primary	0.0636	-0.319	-0.0633
	(0.440)	(0.490)	(0.112)
Secondary	0.173	0.315	0.124
	(0.416)	(0.475)	(0.101)
Tertiary	0.510	-0.0733	0.129
	(0.416)	(0.472)	(0.100)
Log connection fee	-2.004***		-0.578***
	(0.496)		(0.148)
Problem with piped water pressure	-4.240***		-1.224***
	(1.020)		(0.298)
Risk perception (non-piped water)	1.192***		0.344***
	(0.170)		(0.0500)
Risk perception		-0.481***	

Variables	Piped connection	Treatment equation	Marginal effects*
		(0.167)	
Constant	17.58***	1.388**	
	(4.428)	(0.659)	
Athrho	-0.305***		
	(0.112)		
Rho	-0.296***		
	(0.102)		
Observations	432		

Notes

Wald test of rho = 0: $\text{chi}^2(1) = 7.38617$ Prob > $\text{chi}^2 = 0.0066$

* Marginal effects after biprobit y = Pr(piped=1, treat=1) (predict) = 0.45155907

Robust standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

6.2 Probability of choosing non-piped improved water sources and water treatment

In this section, the bivariate probit model is estimated for the choice of non-piped improved water sources and water treatment for those who have no access to piped water, but have access to non-piped improved water sources. The results are reported in Table 6.

The hypothesis of independence between non-piped improved water and water treatment, given that a household has no access to piped water but has access to non-piped improved water sources. is rejected. Since all the variables in the non-piped improved water source are insignificant (see Table 6), the probit model was not estimated for the choice of non-piped improved water, given that the household had no access to piped water. The results for the water treatment equation are consistent with the results for the model estimated above.

Table 6: Seemingly unrelated bivariate probit model for treatment equation and non-piped improved water (those with access to non-piped improved water but not to a piped connection)

Variables	Non-piped improved water	Treatment equation
Age	-0.00993	0.00214
	(0.0103)	(0.0108)
Male	0.0598	-0.504**
	(0.212)	(0.247)
Child	0.0646	-0.0183
	(0.122)	(0.134)
Female:Male ratio		0.654
		(0.570)
Monthly income (base = KES 20,000+)		
KES 0–4,999	0.346	-0.847**
	(0.349)	(0.417)
KES 5,000–9,999	-0.0631	-0.849**
	(0.310)	(0.377)
KES 10,000–19,999	-0.00575	-0.107
	(0.303)	(0.405)
Education (base = No schooling)		
Primary	0.169	0.497
	(0.401)	(0.386)
Secondary	-0.102	0.516
	(0.398)	(0.402)
Tertiary	-0.148	0.707
	(0.408)	(0.444)
Risk perception (non-pipe unimproved)	0.502	
	(0.405)	
Risk perception		0.284
		(0.275)
Constant	0.736	0.570
	(0.676)	(0.741)
Athrho		0.0272
		(0.148)
Rho	0.027	
	(0.148)	
Observations		219
Wald chi^2 (21)		36.55
Prob > chi^2		0.0189

Notes

Wald test of rho = 0: chi^2 (1) = 0.033546 Prob > chi^2 = 0.8547

Robust standard errors in parentheses

* p < 0.1, ** p < 0.05, *** p < 0.01

6.3 *To treat or not to treat water before drinking it*

For the subsample of households with no access to improved water sources, the only choice remaining is whether or not to treat unimproved water. Table 7 reports the results for the estimated water treatment model, given that the household's main source of drinking water is non-piped and unimproved. If the perceived risk of the water from the source they use is considered unacceptable by the households, then the probability of treating water increases. This result confirms the important role perceived risk plays in changing health behaviour, as found in earlier studies that provided risk information (e.g. Jalan & Somanathan 2008, Madajewicz et al. 2007). These results also resonate with previous findings by Nauges and Van den Berg (2006), namely that households are aware that treating non-piped water lowers the risks related to the consumption of unimproved water.

The results of the current study further suggest that the probability of treating water decreases if the head of the household or the respondent is male. Males are 21% less likely than females to treat non-piped unimproved water. One possible explanation is that women, who are generally responsible for taking care of children in the study areas, might find it more worthwhile to treat water to avoid water-borne diseases, for example. These results are in line with experimental measures of risk aversion studies, where it is often found that women are more risk-averse than men (Eckel & Grossman 2008).

Notably, households with low incomes (KES <5,000) were less likely to treat non-piped unimproved water. On average, being a low-income earner reduced the likelihood of treating water by 38%, relative to the group with a higher income. This is disturbing because the same respondents who are more likely to be exposed to water-related health risk cannot afford medical care. Water treatment technologies, especially boiling, are becoming unattainable for the poor due to the high cost of fuel. For this reason, in order to increase the adoption of domestic water treatment, there is a concomitant need to increase the availability of relatively cheap water treatment technologies such as solar disinfection and chlorination (Clasen et al. 2007a).

Table 7: Water treatment equation estimate (those with no access to improved water sources)

Variables	Coefficients	Marginal effects
Age	-0.0392**	-0.00904**
	(0.0169)	(0.00418)
Male	-0.943*	-0.219**

Variables	Coefficients	Marginal effects
	(0.498)	(0.104)
Child	-0.0366	-0.00843
	(0.198)	(0.0459)
Female:Male ratio	-0.753	-0.173
	(1.025)	(0.231)
Monthly income (base = KES 20,000+)		
KES 0–4,999	-1.247**	-0.384**
	(0.528)	(0.185)
KES 5,000–9,999	-0.755	-0.201
	(0.491)	(0.149)
KES 10,000–19,999	0.0273	0.00623
	(0.567)	(0.128)
Education (base = No schooling)		
Primary	-0.542	-0.145
	(0.709)	(0.213)
Secondary	-0.867	-0.214
	(0.774)	(0.200)
Tertiary	-0.119	-0.0281
	(0.860)	(0.209)
Risk perception	1.817***	0.418***
	(0.595)	(0.146)
Constant	3.091***	
	(1.163)	
Wald chi^2 (11)	19.83**	
Observations	112	112

Notes

Robust standard errors in parentheses

* p < 0.1, ** p < 0.05, *** p < 0.01

7. Conclusions and policy implications

Using unique household data collected in four Kenyan towns, this paper provides evidence on the drivers of household drinking water source choice and the subsequent household behaviour of treating water. In particular, the role of risk perceptions in household choice of drinking water source is investigated, along with domestic water treatment behaviour. The evidence found shows that perceived risk drives a household's decision to treat non-piped unimproved water before drinking it. As the perceived risk of water increases, households are more likely to treat non-piped unimproved drinking water.

Unlike previous studies, this investigation takes care of the possibility that choosing a piped water source and choosing to treat water are joint decisions. The bivariate results for the estimated models show that the decision to connect to a piped water network and the decision whether or not to treat water are joint decisions. Thus, the choice to treat water and the choice of a piped water connection are substitutes.

The implications of these results are important to water sector regulators in Kenya. The water utility charges a connection fee. The estimated marginal effect suggests that a 10% increase in connection fee reduces the probability of a piped connection by about 6%. A policy is therefore proposed where households pay the connection fee in instalments or through prepaid or subsidised schemes. These options would enable households to overcome the connection fee hurdle and increase the number of households connected to the piped network.

Water service boards do not currently provide information on the quality of water at non-piped sources and rural water points. Through awareness campaigns, water service boards should strive to provide information on the quality of all sources used for drinking water.

The results also showed that treating non-piped and having piped water were substitutes. Hence, there is a need for water service providers to put greater effort into providing affordable piped water sources in urban residential areas in particular, and to offer households information on the quality of their water both at the point of source and at the point of use.

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Paper V

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ORIGINAL ARTICLE

Environmental goods collection and children's schooling: evidence from Kenya

Simon Wagura Ndiritu · Wilfred Nyangena

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Abstract This paper presents an empirical study of schooling attendance and collection of environmental resources using cross-sectional data from Kiambu District of Kenya. Because the decision to collect environmental resources and attend school is jointly determined, we used a bivariate probit method to model the decisions. In addition, we corrected for the possible endogeneity of resource-collection work in the school attendance equation by using instrumental variable probit estimation. One of the key findings is that being involved in resource collection reduces the likelihood of a child attending school. The result supports the hypothesis of a negative relationship between children working to collect resources and the likelihood that they will attend school. The results further show that a child's mother's involvement in resource collection increases school attendance. In addition, although there is no school attendance discrimination against girls, they are overburdened by resource-collection work. The study recommends immediate policy interventions focusing on the provision of public amenities, such as water and fuelwood.

Keywords Environmental goods collection · Fuelwood · Water · Children · Schooling · Kenya

S. W. Ndiritu (✉)
School of Business, Economics and Law,
Department of Economics, University of Gothenburg,
Gothenburg, Sweden
e-mail: simon.wagura@economics.gu.se

W. Nyangena
School of Economics, University of Nairobi,
Nairobi, Kenya
e-mail: nyangena_wilfred@uonbi.ac.ke

Introduction

The formation of human capital is vital for the economic growth of any country. This is largely done by investing in education for children. Investment in education can help foster economic growth, enhance productivity, and contribute to national development. A low level of human capital is considered a major impediment to the eradication of poverty in developing countries. Educational investment in children enhances their productive skills and earning capacity, in addition to conferring other benefits, such as health status and ability to acquire new information. These benefits are not confined only to the individual, but also extend to parents and society at large. Hence, primary-level education particularly is given high priority toward achieving universal primary education and meeting the Millennium Development Goals (MDG) by the year 2015. In developing countries and especially sub-Saharan Africa, fundamental changes are required if primary-school attendance is to increase enough to achieve the MDG target for primary education (MDG 2, target number 3).

Recognition of the importance of human capital development in economic growth has driven many governments to invest heavily in the provision of education. In 2003, the Kenya government introduced free primary education, with a primary objective of encouraging enrollment from poor households. However, given an estimated net primary-school enrollment rate of 79%, Kenya is far from achieving universal primary education by 2015. The education sector is still fraught with problems, including declining enrollment, low primary-school completion rates, gender disparities in enrollment and grade attainment, among others.

The fact that the rural poor are heavily dependent on natural resources, and that the availability of these resources can affect schooling, is the empirical puzzle that motivates this paper. Many poor people eke out a living from products obtained directly from their local environment. Much labor is needed even for simple tasks. Many households do not have ready access to the sources of domestic energy available nor do they have tap water. In semi-arid and arid regions, the water supply is often not close at hand, and when forests recede, finding fuelwood requires more time and travel. In addition to cultivating crops, caring for livestock, and producing simple marketable products, members of a household may have to spend long hours a day fetching water and collecting fodder. These are complementary but time-consuming activities that have to be undertaken on a routine or daily basis if the household is to survive. Labor productivity is low, not only because capital is scarce but also because environmental resources are scarce.

Kenya, like other developing countries, is natural resource dependent; the availability of these resources can play a major role in shaping educational attainment. Given this dependence, one would ask how these households respond to the perceived degradation of natural resources. From about the age six, children from poor households in poor countries fetch water, mind domestic animals and their siblings, and collect fuelwood. Children at prime school attendance age have routinely been observed to work at least as many hours as adults. As natural resources are depleted, more hands are needed to gather fuel and water for daily use. Children have a comparative advantage relative to adults in resource-collection activities. As resources grow more scarce and households have to travel larger distances and spend more time in these collection activities, this may increase the demand for children. When this happens, poverty—manifested by low educational attendance and attainment, fertility, and environmental degradation, which reinforce one another—becomes an escalating spiral (Cleaver and Schreiber 1994).

There is a plethora of economic studies that show evidence of costs and gender bias, among others, as determinants of schooling. For instance, some studies with an exclusive focus on gender bias have attempted to demonstrate intrahousehold bias in schooling (e.g., Behrman et al. 1997; Rose 2000; Pasqua 2005). Similarly, Case et al. (2004) showed that the probability of school enrollment is inversely proportional to the degree of relatedness of the child to the household head. The literature is scanty on links between environmental goods collection and school attendance. With the exception of Nankhuni and Findeis (2004), existing studies have largely ignored the role played by environmental factors in determining schooling and attendance. Much of the analysis takes for granted that children will attend school if it is free.

The depletion and degradation of natural resources thus pose serious challenges to the achievement of the Millennium Development Goals, especially education. Yet, the links between natural resources and education have remained largely unexamined in the Kenyan context. There is also no study that addresses the issue of what happens to school attendance following the decline and changes in natural resource availability in Kenya. For this paper, we used unique data from Kiambu District that contains detailed information on education and environmental goods collection times. There is also information on gender; households' socioeconomic characteristics, such as income and age; time taken to collect fuelwood and water; and children's school attendance and participation in resource collection. We used an instrumental variable estimation approach to address the potential endogeneity problems involved in our estimation, in addition to alternative, more robust estimation procedures. We have extended the literature on school enrollment by including natural resource-collection work as a determinant of schooling decisions.

The contributions of the study are threefold. First, the study presents empirical evidence of the links between school attendance and collection of fuelwood and water. Specifically, the empirical analysis uses Kenyan data to examine how households respond to changes in availability of fuelwood and water. Second, the findings not only specifically contribute to the understanding of links between school attendance and environmental collection of goods but also add in general to the literature. Knowledge of factors that determine schooling attendance, as well as how households react to scarcity of environmental goods, would no doubt go a long way in the formulation of strategies to improve school attendance. More crucially, this knowledge takes on an added significance in the light of increasing environmental degradation in Kenya. Last, because the country is natural resource dependent, these resources can play a major role in shaping the country's educational policy. Natural resources command a great deal of policy attention and could be the focus of many interventions, such as fertility, public provision of electricity, and piped water. The result supports the hypothesis of a negative relationship between children working to collect resources and the likelihood that they will attend school.

The rest of the paper is structured as follows. Section "Methodology" and "Model specification and estimation issues" present the methodology and the model specification. In Sect. "Data and descriptives", we discuss the variables, data, and descriptive statistics. The econometric results are in Sect. "Econometric results", and Sect. "Conclusion" concludes.

Methodology

We followed the model structure used by Becker (1965) and Rosenzweig and Evenson (1977) to study schooling and environmental goods. A family's decision regarding child schooling, resource collection, and other activities can be analyzed with the household production developed by Becker (1965) and employed by Rosenzweig and Evenson (1977) and others. Gronau (1977) formalized the theory of time allocation in the classification of threefold household's time budget: work in the market, work at home and leisure. This model has been widely used to analyze choice of hours allocated to different household activities. Recent empirical work on time allocation in developing countries follows the work of Gronau (1977) and Singh et al. (1986). However, these studies fail to take into account the realities of home production and household structure in developing countries. (See Rosenzweig and Evenson 1977). Their approach has been used to capture the time allocation in the context of a developing country by other studies, such as Nankhuni and Findeis (2004) who looked at resource collection and schooling in Malawi.)

The family's preference for schooling (*S*), leisure (*L*) of their children, home produced goods (*Z*), and a composite consumption commodity (*C*) is expressed as:

$$U = U(S, Z, L, C; E),$$

where U is the family utility function and E is the household environment. The utility function is assumed to be twice and continuously differentiable and concave. Z refers to a class of goods, such as fetching water, collecting fuelwood, taking care of younger siblings, tending animals, etc. that is produced at home, using market-purchased goods and children's housework time. In this model, parents maximize a utility function, subject to a set of constraints, such as time and budget constraints. The comparative static properties of the model generate a number of interesting hypotheses. For instance, an exogenous increase in nonlabor income would increase schooling and reduce the child's market and housework time. A rise in the cost of resource collection would reduce schooling and increase child work.

Model specification and estimation issues

School attendance is potentially endogenous, and this may lead to biased and inconsistent results. One possible channel of endogeneity is that school attendance and resource collection can be jointly determined through labor supply decisions. The decision to send children to school may be jointly determined with a decision to send children to collect fuelwood, water, and fodder. Another avenue for endogeneity is that parents who value the education of their children may work harder to keep their children in school (Kingdon 2005). We addressed this problem by estimating a simultaneous equations model for binary variables.

Following Greene (1998, 2008) and Nankhuni and Findeis (2004), we adopted the following bivariate probit model:

$$Y_{i1}^{*} = X_{i1}^{'}\beta_1 + \varepsilon_{i1}, \quad Y_{i1} = 1 \quad \text{if} \quad Y_{i1}^{*} > 0, \quad 0 \text{ otherwise} \tag{1}$$

$$Y_{i2}^{*} = X_{i2}^{'}\beta_2 + \varepsilon_{i2}, \quad Y_{i2} = 1 \quad \text{if} \quad Y_{i2}^{*} > 0, \quad 0 \text{ otherwise} \tag{2}$$

$$[\varepsilon_{i1}, \varepsilon_{i2}, \rho] \sim \text{Bivariate normal (BVN).}$$

where individual observations of y_1 and y_2 are available for all i, the y_{i1} and y_{i2} are the choices of school attendance and participation in resource-collection work observed in the data, respectively; Y_{i1}^{*} and Y_{i2}^{*} are the latent variables from which the decisions to participate in these two choices are defined; X_1 and X_2 are the independent variables (household characteristics, environmental variables, regional dummies, demographic variables, and child characteristic variables) in the school attendance model and the resource-collection work model, respectively; and ε_{i1} and ε_{i2} are the error terms, which may be correlated; otherwise, the univariate binary probit model is appropriate (see Greene 2008).

Given the relationship between school attendance and resource collection, there are reasons to suspect the recursive simultaneous equation model. School attendance may be affected by the amount of time that a child spends on resource collection. Therefore, school attendance may be sensitive to the time that a child spends collecting firewood or water. Hence, the resource-collection work intensity is treated as an endogenous explanatory variable in the schooling equation:

$$y_1 = X_{i1}\beta_{i1} + \tau y_2 + \varepsilon_1 \tag{3}$$

$$y_2 = X_{i2}\beta_{i2} + \varepsilon_2 \tag{4}$$

In this model, interdependence arises between y_1 (school attendance) and y_2 (resource-collection work intensity) because y_2 appears on the right-hand side of Eq. 3. We addressed this problem by using the Rivers and Vuong (1988) procedure to correct for endogeneity. The procedure is done in two stages. In the first stage, a reduced form regression is done on exogenous variables, including instruments, and residuals are predicted. In the second stage, the predicted residuals are included in the probit, including the endogenous variable. A simple t test of the coefficient residual tests the null hypothesis of exogeneity. This procedure was implemented using the IV probit command in Stata.

To motivate the need to use instrumental variables, we considered the following structural form equation for schooling and reduced form equation for resource collection:

$$y_1 = \beta x_i + \tau y_2 + \varepsilon_1, \quad (5)$$

and

$$y_2 = \alpha x_i + \delta z + \varepsilon_2, \quad (6)$$

where the structural equation of school attendance, variable y_1, is given by Eq. 5, while the reduced form equation of the resource work intensity, variable y_2, is given by Eq. 6. The resource intensity dummy was constructed to represent time spent by children that exceeded the two-hour threshold time to collect resources after school in the evening. The common exogenous covariates that belong to both equations are given by the vector X. The instrumental variables z, such as distance to the resource and scarce variables, are included in the reduced form equation, but excluded from the structural form. Unlike Nankhuni and Findeis (2004), who used wood and water scarcity variables and an own-piped water access dummy variable as valid instruments, we proposed alternative instruments.

We used exogenous variation in the household energy fuel expenditure and ratio of children (who collect resources in a household) to family size[1] as instrumental variables for resource work intensity in order to estimate the effects of participation in resource work on school attendance. These are plausible instruments for several reasons. In comparison with a single child, the higher the ratio of children to the family size the lesser the burden to collect resources that can directly affect the children's resource-collection participation decision. Consequently, this may also indirectly affect their school attendance. Similarly, higher household expenditure on close substitutes of firewood, such as kerosene, charcoal, or even firewood purchased in the market, has a direct effect on parents' decisions to send children to collect resources and an indirect effect on their school attendance. We found that fuel energy expenditure and the ratio of children (who collect resources) to the family size are in fact closely related to resource-collection work (in the first-stage regression).

One may ask whether each of the equations in the system is identified. The challenge in estimating the causal impact of resource-collection work intensity on education outcome is the possibility that unobserved characteristics of households may influence their decision to collect resources and also play a role in their school decisions for their children. For example, parents who care more about the education of their children may not involve their children in intensive resource-collection activities, despite the fact that there is resource scarcity.[2] Moreover, a household with many children who are out of school may reduce the burden of resource collection for those who are in school.

Data and descriptives

The data for this study is mainly cross-sectional primary data, collected from 200 rural households in Kiambu District[3] during the months of April and May 2007. The 200 households were drawn from 20 villages: 9 in Lari division, 6 in Kikuyu division, and 5 in Ndeiya division. The data collected were limited to the three divisions (Lari, Kikuyu, and Ndeiya), due to the continued deforestation of the upland forest, which has contributed to firewood and water scarcity problems.

The study sample was generated using the sampling framework provided by the Kenya National Bureau of Statistics. To ensure equal representation, all the three divisions were sampled using the proportion of enumeration areas (EAs), created for the 1999 census. Multistage sampling was then used to select the sample villages (EAs) and households. In the first stage, the three divisions were selected (Kikuyu, Lari, and Ndeiya). Following the EAs information, the study proportionately sampled 9 of 102 EAs (Lari), 6 of 68 EAs (Kikuyu), and 5 of 47 EAs (Ndeiya). From each village, 10 households were randomly selected and interviewed by trained enumerators. This is considered to be fairly representative of the village (the national household surveys use about 10 households per EA village). The authors visited the firewood markets to collect firewood prices and conducted focus group discussions with the firewood traders.

The data collected included information on whether children are currently participating in schooling or resource collection; socioeconomic characteristics of households; household sources of income; sources of resources, mainly for fuel, wood, and water; and main energy sources and uses. Of the 200 households surveyed with 1,154 individuals, 609 children aged 5–18 years were considered in the analysis, and we gathered full information on our variables of interest. (Details of the variables are provided in the descriptive statistics section.) It is important to note that several children come from one family, given the household size and their ages. The survey collected more specific information on children's activities, such as time allocation

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[1] We thank an anonymous reviewer for suggesting this instrument variable.

[2] They may also work very hard in order to buy substitutes and also take their children to the best schools.

[3] Kiambu is one of seven districts in the Central Province of Kenya, as of 2002. It is located in the south of the province and borders Nairobi City. It has a total area of 1323.9 km^{2,} with the population of 802,625,000 (per the 1999 census), and has a projected growth rate of 2.56% per annum. Kiambu is divided into seven administrative divisions, Kiambaa, Githunguri, Limuru, Kikuyu, Ndeiya, Lari, and Kiambu Municipality. Lari is the largest, and Kiambaa is the smallest (Government of Kenya 2002).

Table 1 Household socioeconomic characteristics

Variable	Mean	SD	Min	Max
Male household head	0.87	0.34	0	1
Age of household head	42.48	9.49	22	83
Years of school of household head	8.68	2.81	0	16
No education (household head)	0.02	0.12	0	1
Primary education (household head)	0.60	0.49	0	1
Post-primary education (household head)	0.38	0.48	0	1
Household size	6.16	1.54	3	11
Number of children in household	4.10	1.59	0	9
Number of children who collect resources in a household	2.58	1.36	0	6
Children <6 years	0.12	0.32	0	1
Children 6–14 years	0.33	0.47	0	1
Children 15–18 years	0.12	0.32	0	1
Young adults 19–24 years	0.08	0.27	0	1
Adults >25 years	0.35	0.48	0	1
Household head main occupation				
Family business	0.16	0.37	0	1
Agriculture	0.37	0.48	0	1
Wage labor	0.47	0.50	0	1
Household monthly income (in KES)	8517.54	6501.14	1,000	50,000

1 KES = US$ 0.0131666

Source Field survey data, 2007

for domestic responsibilities and resource collection, and time spent on school work. In addition, the dataset included information on the children's school progress, child labor, and the effects of the collection activities on their schooling activities.

In the dry season, the nearest potable water is on average 7 km away in Ndeiya division. Child labor is a severe problem in this district: children between 10 and 18 years of age are estimated to be working at agriculture-related activities and other household chores (Government of Kenya 2002).

Descriptive statistics

Table 1 provides the socioeconomic characteristics of the 200 sampled households. From the data, it is evident that few households are female headed. In the sample, only 13% of all households have female heads. The results also indicate a low-average terminal level of education for the household head, suggesting that on average most household head have only a primary education (8 years of schooling). This also supports the education attainment dummies, which indicate that only 38% of all household heads completed post-primary education, compared to 60% who completed primary education.

The age categorization indicates that 45% of the sampled age groups are school-aged children (6–18 years old). Moreover, the household size, on average, has six members and an average of four children. One would suspect that households with many children out of school are likely to participate in resource collection, which reduces the burden of resource collection to those children who go to school. There is evidence that households' heads diversify income sources. The main income sources are wage labor (47%), agriculture (37%), and family business (16%). Notably, not all households derived income from the sources as shown in Table 1, but there were also combinations of wage labor with either agriculture or family business. The average household income from various sources is KES 8,518 (about US$ 112.15)[4] per month with a variation of KES 6,501 ($85.60). The minimum income in the sampled households is KES 1,000 ($13.12), while the maximum income is KES 50,000 ($658.33).

Children's schooling and resource-collection work

The sample has 609 children, aged 5–18 years old, who are the main focus of pre-school, primary, and post-primary levels of education in Kenya.[5] These children on average started nursery school at an average age of 5 years and joined class 1 at the age of 6 or 7 years, depending on the number of years they spent in pre-school. Of the 609 children between 5 and 18 years, for whom there was

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[4] KES = Kenyan shilling. Currently, 1 KES = US$ 0.0131666 (or US$ 1 = KES 75.95).

[5] In Kenya, pre-unit is preschool or nursery school. Primary school is divided into lower primary (standard, or grades, 1–3) and upper primary (standard, or grades, 4–8). Post-primary, or secondary, school is Forms 1–4. Post-secondary means university- or polytechnic-level education.

information about their education and who were included in the sample, 51% attained a level of upper primary education, 23 and 4% were in lower primary school and pre-school, respectively. The post-secondary level had 21% of the children, who were either in secondary school, polytechnic school, or university, or had just completed ordinary level studies. The school attendance data are summarized using the four major categories in Fig. 1 below.

Of the 609 children, 19% are out of school, while 81% are still in school. Ten percent of the sampled children are out of school due to lack of school fees. The pie chart in Fig. 2 below shows the percentage of school progress in the sampled children. Those in the sample who have ever attended school were also asked question about repeating of classes. The results to this question show that 24% of children sampled had repeated at least one class, while 76% had not repeated any class. The dropout rate in the sample was about 50% of those children who should have continued on to secondary school. School-going children were probably involved in resource-collection activities thus reducing school attendance. The relationship between school attendance and academic achievement cannot be ruled out. Full-time school attendance is critical to achieving good grades. The high rate of drop out can plausibly be explained by poor performance associated with low levels of school attendance implying that pupils have to either repeat classes or fail qualifying examinations for the next level or grade.

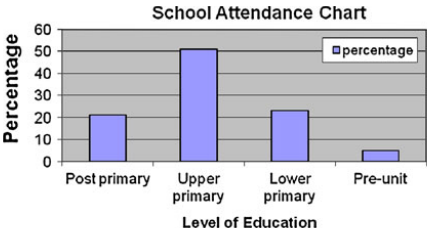

Fig. 1 School attendance in primary and post-primary school, 2007. Post-primary means secondary school (grades 9–12). Primary school is 8 years; upper primary is grades 4–8; lower primary is grades 1–3. Pre-unit is nursery or pre-school. *Source* Field survey data, 2007

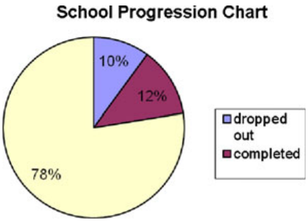

Fig. 2 Grade progressions in primary and post-primary school. *Source* Field survey data, 2007

We can gain further insights into the links between school attendance by exploring the children's schooling and resource collection. Table 2 reports children's schooling and resource-collection activities. The schooling variables reveal that 79% of children in the sample attended school in the previous term,[6] while the rest either withdrew from school to perform domestic work (including resource collection) or dropped out of school. We observed that 83% of children attended public school, while 17% went to private school. This indicates that majority of rural population benefits from Kenya's free primary education. On average, children spend 8 h in school and 1 h collecting resources (mainly water) after school. Children spend on average 1 h and 45 min for private studies. Of the children involved in resource-collection activities, 9% reported that resource-collection work affected their work, as reflected by their inability to complete homework. This was also confirmed by the progress reports for these children. Focus group discussions with teachers confirmed that the resource-collection work affected performance.

Table 2 also presents the children's time allocation for resource-collection and domestic activities. On average, 63% of children in school collected water, while 41% collected firewood. Interestingly, 60% of the sampled children in school participated in either collection of water or firewood or both. We generated the resource work intensity dummy $= 1$ if time spent > 120 min, 0 otherwise. We found that the number of children who collect resources beyond this threshold of 2 h reduced by almost half, at 35%. Children spent on average 4 h collecting resources. Specifically, the greatest share is spent on firewood collection, which takes 3 h, while water collection takes 1 h.

For water collection, the time spent excludes queuing at water sources and takes 40 min plus travel time of 20 min. As expected, women spend an average of 3 h and 26 min on both firewood and water collection per day. The survey showed that children's participation in domestic responsibilities, such as agricultural activities, cooking, cleaning, laundry, and child care, is on average 21 h per week. In addition, 12% of children who do not attend school are involved in child labor. On weekends, children spend another 2 h on average collecting resources.

Clearly, household members gathered the vast majority of household resources used by the sampled households. We can gain some understanding of the increased demands

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[6] Kenya has three school terms in a year. The first term usually runs from January to March, then a one-month break in April. The second term follows, May to July, and August is the second holiday. Last, September to November makes up the third term, with December as the holiday.

Table 2 Descriptive statistics for children’s resource-collection activities and schooling

Variables	Mean	SD	Min	Max
School attendance	0.79	0.41	0	1
Resource work participation	0.60	0.49	0	1
Resource work intensity dummy = 1 if time spent >120 min, 0 otherwise	0.35	0.48	0	1
Water collection participation	0.63	0.48	0	1
Firewood collection participation	0.41	0.49	0	1
Travel time for firewood collection	98.61	91.2	0	360
Collection time for firewood	66.37	51.44	0	300
Travel time for water collection	22.68	22.37	2	150
Collection and queuing time for water	38.71	42.18	3	240
Firewood collection total time	168.23	116.82	10	480
Water collection total time	61.48	60.62	5	390
Children who collect resources as ratio of family size	0.41	0.20	0	0.83
Household fuel expenditure	936.60	582.78	100	3,750
Child labor	0.12	0.32	0	1
Children’s domestic responsibilities (hours per week)	21.14	20.91	0	104
Female child	0.43	0.50	0	1
Mother resource work, in minutes	196.14	144.86	0	660
Average number of children in a household	4.30	1.51	1	9
Kikuyu dummy	0.25	0.43	0	1
Lari dummy	0.51	0.50	0	1
Ndeiya dummy	0.24	0.43	0	1
Age child began school (standard 1)	6.25	0.65	4	8
Resource work hours of children on weekdays	0.58	0.53	0	4
Hours children work on weekends	2.07	1.76	0	7
Evening study hours	1.77	0.84	0	5
School type dummy = 1 if public school, 0 otherwise	0.83	0.37	0	1

Source Field survey data, 2007

for resource collection by observing the high proportion of children who participate in fuelwood and water collection. The implication of such high rates of resource collection by children is reduced school attendance.

Fuelwood collection descriptive statistics

Households were asked about their sources of fuelwood. These results are reported in Table 3. About 25% of households obtain fuelwood from the market, while another 18% combines buying fuelwood and collecting it from the commons. This indicates the presence of a well-defined market of fuelwood in Kiambu District. The price of fuelwood varies, depending on the source and the perceived scarcity by the dwellers. For instance, fuelwood prices in Karai (in Kikuyu division) were determined by the major vendor of fuelwood, which had a well-organized fuelwood business. In Ndeiya division, fuelwood was bought from households who collect fuelwood to sell and either deliver the fuelwood to their customers or let customers buy the fuelwood at the collectors’ homes.

In Lari division, 48% of households collect fuelwood from the forest and pay a monthly fee of KES 45 (US$ 0.59) to the Kenya Forest Service, which allows fuelwood collection once a day from the forest. The monthly rental rate is quite low and hence could not be used to proxy for resource scarcity (Gardner and Barry 1978). Those households that collected fuelwood for sale collected on average 57 pieces of bamboo, approximately 1 meter long, which were sold at an average cost of KES 135 ($ 1.78).

Table 3 Sources of fuelwood for households

Source of fuelwood	Percentage use
Forest	26
Fallow land	13
Market	25
Home garden	15
Other (combines fuelwood purchase and collection from the commons)	18
Does not use fuel-wood	3

Source Field survey data, 2007

A measure of resource scarcity is time per trip, as suggested by Filmer and Pritchett (1996). Households were

Table 4 Mean time from household to source of fuelwood (in minutes)

Source	Karai	Lari	Ndeiya
Fallow land	228.75	240	168.57
Forest	254	269.5	195
Home garden	57.27	102.92	80.18
Market	25.26	27	28.22

Source Field survey data, 2007

Table 5 Fuelwood price per cubic meter

Price per piece of wood	Volume of a fuelwood piece in cubic meters
KES 1.50	0.0029
KES 2.00	0.0035
KES 2.50	0.0042
KES 3.00	0.0048
KES 5.00	0.0064
KES 7.00	0.0096

KES 1 = US$ 0.0131666

Source Field survey data, 2007

asked if the supply of fuelwood was a problem, which is normally indicated by travel time and distance to source of fuelwood. The average travel time of a round trip, plus collection time, to collect fuelwood depends on the source of the fuelwood. Collecting fuelwood from the forest takes the greatest amount of time (4 h and 30 min) and buying in the market takes the least (25 min), as shown in Table 4. The implication is that of a substitution effect between family income and time spent on fuelwood collection.[7] Collection from the common follows the time spent in forest collection closely in all three divisions under study.

Several implications emerge from Tables 3 and 4. First, drawing fuelwood from fallow land and home garden may be a reflection that households have turned to other desperate coping mechanisms and strategies such as use of agricultural residue and fallen twigs. Second, the choice of fuelwood from either the garden or fallow land may be influenced primarily by access rather than desirable species that may be found further away. Lastly, the commoditization of biomass fuels may lead to marginalization of nonwage earners.

Market for fuelwood

Those who collect fuelwood from the market buy it from dealers, which operate a fuelwood business, where various fuelwood pieces have different prices. Table 5 shows the different pieces and the price per piece. Table 5 indicates that the price of fuelwood varies considerably with the different volumes of fuelwood pieces that customers select from the categories provided by the fuelwood dealers. Households buy the pieces they prefer, depending on the amount of money they have and their consumption of fuelwood per day. They pay a range of KES 20 to KES 150 (US$ 0.26–$1.97) for single bundles. The fuelwood dealers obtain the fuelwood they sell from different sources, which includes growing it on their own farm, buying trees from farmers, and collecting from the fallow land and forest. The price of trees bought from other farmers depends on the thickness of the tree and its location.

Table 6 Cost of fuel per month

Fuel type	Mean cost	SD	Min	Max	Avg. quantity
Kerosene	330.07	164.15	0	680	2 l
Fuelwood	249.17	391.62	0	3,150	50 pieces
Charcoal	345.08	324.58	0	2,000	1 bag

Source Field survey data, 2007

Households indicated that they substituted three main fuel sources: fuelwood, charcoal, and kerosene. Fuelwood and charcoal are mainly used for cooking and heating, while kerosene is used for lighting and cooking. Although the deficit is catered for through purchase fuelwood from the market, this has an implication that pressure is exerted on forests in other areas. Most likely, the marketed fuelwood is illegally obtained from government forests.

Table 6 shows the sampled households' expenditure on the three main fuel types. Fuelwood had the lowest mean of KES 249 (US$ 3.28) and also the maximum cost of KES 3,150 ($41.45). This indicates that there is evidence that some households combine fuelwood collection and purchase, while others obtain their entire fuelwood supply from the market. The study also revealed that charcoal is a close substitute for fuelwood.

Notably missing is the use of electricity and liquefied petroleum gas (LPG), indicating that households depend largely on natural resource base for their energy. When viewed in terms of domestic fuel use with household income, we notice that the poorer households tend to use the most expensive fuels particularly if fuel efficiency is taken into account. The implication is to help poor households to progress up the energy ladder in order to improve school attendance by children.

Household water collection

Table 7 presents information on household water collection by source. We observed that households collect water from different sources in the area. In Karai (in Kikuyu division) and Ndeiya division, households mainly obtain their water from the village tap (approximately 35% of the water

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[7] We thank an anonymous reviewer for suggesting this point.

Table 7 Household sources of water

Source of water	Percentage use by households
Borehole	21
Neighbor	13
Own tap	22
River	4
Village tap	36
Own tap and village tap	5
Village tap and neighbor's tap	1

Source Field survey data, 2007

Table 8 Mean time spent collecting water from source (in min)

Source	Karai	Lari	Ndeiya
Borehole	–	26.42	–
Neighbor's tap	30	31.11	25
Own tap	12.56	9.5	10.5
River	–	70	–
Village tap	128.52	102.35	107.95

Source Field survey data, 2007

source in the sampled areas) and some from their own tap (21%), where water is supplied three times a week. During the dry season, tap water is scarcely supplied, and all households are forced to collect water from the village tap. In Lari Division, households obtain water from shallow boreholes, although a few obtain water from the river.

Table 8 reports the water collection and queuing times that include the round-trip travel time. We observed that households in either Ndeiya or Karai collect water from boreholes or rivers. In Lari, a majority of households also obtain their water from boreholes and few from rivers. Village taps are key points for water collection in these three areas. Households in Karai recorded the greatest mean time of 129 min (2 h, 9 min), which is largely spent queuing, due to water scarcity (especially during the dry season).

The data give the impression that water collection took place in only one place namely the village tap. This may be a reflection of unreliability of the other water sources. Further analysis of the data are required to verify the main arguments of this paper, in the next section.

Econometric results

The descriptive statistics show that schooling, however measured, is worsened by collection of resources. We pursued this matter further by testing the hypothesis whether or not children currently attend school or whether they collect resources. As these are binary joint outcomes, we estimated a bivariate probit model. A likelihood ratio test of the null hypothesis that the correlation coefficient (ρ statistics of 0.07) equals zero against the alternative that ρ does not equal zero was carried out. The chi-squared statistic obtained from this test was 0.18, with a *P*-value of 0.68, so the null hypothesis is not rejected at any conventional statistical level. Thus, resource work participation and school attendance appear to be noncompeting activities. It is plausible that children combine both activities. Therefore, the two decisions become competitive when the resource work intensity exceeds the threshold level of combining schooling and resource-collection work. Hence, the intensity of resource-collection work merits attention in the instrumental variable estimation. The results of the estimated univariate binary probit of resource-collection work participation, resource work intensity (first-stage regression), and the school attendance IV probit are presented in Table 9.

In the first-stage estimation, we found that the two instruments used in the resource intensity model are significant; hence, they are relevant. Fuel expenditure has the expected sign, meaning that greater household spending on energy leads to less resource collection by children. However, the ratio of children (who collect resources) to family size is positively related to intensity of resource-collection work. This shows that number of children and resource-collection work intensity is positively correlated, meaning that household's collect resources beyond the two-hour threshold when there are more children to collect. It is also possible that children have a tendency to work together in a family, meaning they go together to collect the resources when it takes a longer time to accomplish.

The IV probit output includes a test of the null hypothesis of exogeneity; in other words, there is no correlation between the errors in the schooling equation and the resource work intensity equation. The significant Wald test for exogeneity indicates that we reject the null hypothesis. The positive estimated rho coefficient (0.45) indicates that the error terms of school attendance and resource work intensity are positively correlated. Those unmeasured factors that make it more likely for a child to collect resources beyond the two-hour threshold also make it more likely that the child will attend school, conditional on other regressors included in the equation. Hence, the use of IV probit is supported by this result.

The school attendance is negatively affected by resource-collection work, as indicated by the negative significant resource-collection intensity marginal effects. Being involved in resource collection beyond the two-hour collection work threshold reduces the likelihood of a child attending school by 21 percentage points on average. These results resonate with previous findings by Nankhuni and Findeis (2004) that resource-collection work negatively

Table 9 Probit and IV probit results

	Resource work participation		Resource work intensity (first-stage estimation)		School attendance	
	Marginal effects	Robust std. err.	Coefficients	Robust std. err.	Marginal effects	Robust std. err.
Resource work intensity dummy	–	–	–	–	−0.211**	0.107
Child labor	−0.253***	0.095	*Dropped*		*Dropped*	
Household income (in logs)	0.036	0.041	−0.014	0.032	−0.017	0.017
Domestic work (in hours)	−0.001	0.001	0.001	0.001	−0.001	0.001
Female child	0.093**	0.046	0.026	0.037	0.036*	0.022
Mother resource work (in minutes)	−0.005	0.016	0.062***	0.014	0.023**	0.010
Children aged 6–14 years	0.534***	0.064	0.049	0.058	0.375***	0.051
Children aged 15–18 years	0.570***	0.039	0.243***	0.068	0.087***	0.030
Family size	−0.031**	0.015	0.005	0.012	−0.016**	0.007
Years of schooling of household head	−0.008	0.009	−0.009	0.006	0.004	0.004
Lari division dummy	0.112**	0.054	0.050	0.047	0.056*	0.030
Kikuyu division dummy	−0.094	0.070	−0.056	0.053	0.010	0.026
Child ratio			0.814***	0.080		
Energy expenditure (in logs)			−0.094***	0.028		
Constant	–	–	0.392	0.389	–	–
/athrho			0.479**	0.217		
/lnsigma			−0.870***	0.022		
rho			0.445	0.174		
sigma			0.419	0.009		
Number of observations	609		532		532	
Log pseudo likelihood	−316.217		−405.873		−405.873	

Dropped indicates child labor was dropped; 68 observations were not used since it perfectly predicted failure in the IV probit; Wald test of exogeneity (/athrho = 0): $\text{chi}^2(1) = 4.86$ Prob > $\text{chi}^2 = 0.0275$

* Significant at 10%; ** significant at 5%; *** significant at 1%

influences child-schooling decisions. As is common in developing countries, children are substantially involved in domestic work. Although its coefficient is negative as expected, there is no evidence of domestic work affecting school attendance. A more interesting finding is that child labor reduces children's participation in resource collection. Perhaps, children who participate in child labor have no time left to assist their household in resource collection. The child labor variable was dropped, since it perfectly predicted failure in the IV probit estimation because no children who attend school participate in child labor.

In all the estimated models, wealth (proxy by family income) appears to have no impact on child resource-collection and schooling decisions, thus providing neither support nor evidence against the notion that poverty drives children to collect resources. There are no surprises that household wealth does not affect schooling decision in Kenya because of the free primary-education policy. Although household income negatively correlates with resource-collection intensity, there is no evidence of substitution effect between family income and time spending on resource collection. Although the years of schooling of the household head is not significant, it has the expected signs; that is, the education of the household head positively affects children's school attendance and negatively affects their resource-collection work.

With the presence of a female child in a household, signs for resource collection are positive and statistically significant. The implication is that being a girl increases the likelihood of resource collection by 9 percentage points, relative to boys. This confirms the widely accepted traditions that girls are more likely than boys to be involved in resource collection in sub-Saharan Africa. Apparently, from the results, there is no discrimination for schooling for girls in the study area; this is because the marginal effect of the female children is positive and statistically significant in the schooling model. Being a girl increases the likelihood of attending school by 3.6 percentage points on average, relative to boys, implying that girls are more likely to attend school than boys. However, female children are overburdened by resource-collection work. The results further show that children from Lari division are more likely to participate in both resource collection and schooling, relative to children from Ndeiya division. These results suggest that children from Lari division combine schooling and resource collection. There is no evidence that children from Kikuyu division are likely to attend school and collect resources relative to children from Ndeiya division. Hence, we cannot conclude which division has the most severe resource scarcity from these results.

The high positive marginal effects of the age category of 6–14 years suggest that this is when children are most likely to attend school, when compared to ages 15–18, which has a low marginal effect. One can argue that as children grow older and acquire more skills, the opportunity cost of schooling rises. Interestingly, we find in the first-stage estimation that those aged 15–18 are more likely to work in intensive resource collection, when compared to ages 6–14, whose coefficient was not significant. The involvement of women in resource collection is negatively, though not statistically significantly, correlated with the incidence of children collecting resources in the resource participation equation. However, in the IV probit model, the involvement of women in resource collection has positive, statistically significant predictive power on the likelihood of a child's attending school. Similar evidence was found by Nankhuni and Findeis (2004).

Finally, we found that family size negatively affects both resource-collection and school attendance. In large households, those who do not participate in school reduce the collection burden of those in school, which thus negatively affects child resource collection. The negative signs on the coefficients of family size and school attendance suggest that, as the number of household members increases, the more the household wealth base is constrained. One more family member reduces the children's resource-collection burden by 3.1 percentage points on average. On the other hand, an extra individual in a family reduces the likelihood of not attending school by 1.6 percentage points. Hence, family size reduces children resource-collection burden more than reduction of the likelihood of not attending school.

Conclusion

This paper provides new insights into the debate on the interlinking of resource scarcity and human capital development. The study examines the links between natural resource-collection work and children's schooling in Kiambu District in Kenya. As population grows, fragile ecosystems are put under heavy environmental strain. In particular, woody vegetation and water sources are placed under heavy demand for fuelwood and water for domestic use. There are also competing demands for women's labor time and children's school attendance. The main study hypothesis is that, as resources become scarcer, households will invest more time in collecting them, and this will adversely affect the children's school attendance. Since the decisions to collect resources and allow children to attend school are jointly determined, we estimated a bivariate probit model. The instrumental variable probit was also estimated to correct for endogeneity of the schooling and resource-collection work intensity equations.

The main empirical findings are as follows. While the magnitude of the impact of resource collection on children's schooling decision is not overwhelming, at least it affects attendance. We find that children's school attendance is negatively affected by scarcity of natural resources and the resultant increased hours of collection work. Being involved in resource collection beyond the two-hour collection work, threshold reduces the likelihood of a child attending school by 21 percentage points on average. Involvement by the child's mother in resource collection increases school attendance. This implies that parents should be encouraged to help their children in household responsibilities to enable them concentrate on academic work. In addition, there is no discrimination against girls' schooling, but they are overburdened by resource-collection work.

The implications of this research are potentially important from an educational policy perspective and argue for integrating local natural resources enhancement programs with the free primary-education program. Our findings are in line with those of Nankhuni and Findeis (2004). We find that mere participation in resource collection is not necessarily in competition with schooling decision, but rather the intensity of resource-collection work negatively affects school attendance in Kenya. Public provision of natural resources, such water and fuelwood, may substantially improve school attendance. Policy should thus aim at helping poor households to progress up the energy ladder in order to improve school attendance by children. The most practicable course of action is to improve availability and lower prices of intermediate fuels like kerosene and liquefied petroleum gas (LPG).

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