Food Security in Developing Countries: Gender and Spatial Interactions

by

Catalina Romero Hernandez

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Agricultural and Resource Economics

Department of Resource Economics and Environmental Sociology
University of Alberta

Abstract

Food security in developing countries is an essential component of welfare. However, the food security of households can be constrained by the lack of access to international markets, gender inequality, weak agricultural policies and institutions, climate change, and poverty. Smallholder farmers living near one another may face similar economic and environmental conditions, but may have different levels of food security. Neighbors can potentially ease economic constraints and promote food security by acting as channels of resources and information. This research estimates three spatial effects on food security: i) a spatial autoregressive effect - how neighbors' (edges') food security influence a farmer's food security; ii) how neighbors' food security affects differently the food security of men and women; and iii) how the food security of neighbors of the same gender affect their own food security. Our data contains a wide range of food production and consumption information from 1500 households located across seven countries in Africa and Asia. We find that neighbors have a powerful influence on food security, which accounts for an increase of 17% in own food security. This effect is larger for women (49%) than for men (15%). We also find that women benefit more from their female neighbors (68%) than their male counterparts (16%).

To those women,

both known and unknown,

who encourage, inspire, support, uplift and empower others.

Acknowledgments

To my supervisor, Dr. Marty Luckert, thank you for constantly believing in me, and for your persistent support, guidance, suggestions, and encouragement to do better throughout my research. The writeup of this thesis have greatly benefitted from your criticisms and academic experience, which greatly contributed to the successful completion of this research.

To my supervisor, Dr. Bruno Wichmann, thank you for all the lessons you have patiently taught me, and for countless hours you have invested in pursuing our model and this research, all the knowledge you have shared with me, and for always believing in me. You have become an amazing mentor and I will never be able to express my immense gratitude.

Both of you allowed me to explore and develop my passions during my thesis journey, I am beyond thankful for you support.

To my hubby, Sebastian, thank you for selflessly devoting so much of your time to help me during this journey without which this would not have come together. Finishing my thesis would have been a lot more challenging without your help and endless love.

To my family, thank you for their unconditional love and support which have made all my accomplishments possible.

Lastly, I would like to thank Peter Laderach and Phillip Thorton of the the CGIAR: Program on Climate Change, Agriculture and Food Security (CCAFS) for their input and for funding my research. This work was implemented as part of the CGIAR Research

Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from the CGIAR Trust Fund and trough bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors. The views expressed in this document cannot be taken to reflect the official opinions of these organizations.

Table of Contents

List of Tables

List of Figures

1. Introduction

Food insecurity is a development problem that has drawn the attention of policy-makers worldwide. The number of food-insecure people is estimated to have increased in 2017 to 770 million, of which 98% of the total live in developing countries (FAO et al. 2018). Lack of access to international markets, gender inequality, weak agricultural policies, climate change, and especially poverty are considered as causal components of the increase in food-insecure people around the world (Mallick and Rafi 2010; Rao 2005; Parasuraman and Rajaretnam 2011; Tibesigwa and Visser 2016). Understanding the importance of causal factors of food security represents a challenge in the design of development policies to improve food security.

Gender can play important roles in understanding food security. Women are generally responsible for growing, selecting and preparing food for household members, especially children (USAID 2011). Women also supply most of the labor needed to produce food crops and often control the use or sale of food produce grown on plots they manage (World Bank, IFAD and FAO 2008). However, there are substantial differences between women and men regarding access to land ownership and assets, information, and credit (Kassie et al. 2015; Kennedy and Peters 1992). These disparities negatively affect women's production, reducing resources, women's potential income, and the availability of food for household consumption. Several studies have observed that women who earn higher shares of household cash income spent significantly more on education and less on alcohol and cigarettes than men

(Engle and Nieves 1993; Guyer 1980). The role of women as food producers and providers represents a key part of a household's food security.

Spatial relationships between households can also influence food security. Individual's interactions can be affected by their neighbor's behavior in many spheres (i.e. financial, health, social) due to various factors, such as social learning, social pressure or mimicking (Foster and Rosenzweig 1995). These interactions may impact, for example, the adoption of microfinance loans (Banerjee et al. 2013); the influence of adopting contraceptives (Behrman, Kohler and Watkins 2002); the facilitation of better employment outcomes (Munshi 2003); and food security through food sharing among households as a coping strategy (Ambikapathi et al. 2018).

Neighbors' interactions are one kind of spatial relationships that can be particularly important in the context of food security. For instance, farmers learn and acquire information from the experiences of their neighbors, where the flow of information relies on the structure of these interactions (Krishnan and Patnam 2014). Farmers could also share knowledge about food production with their neighbors that could help them cope with droughts due to climate change, ensuring food for their households.

Social interaction studies have found that people's relationships are distinguished by homophily, that is the preference that individuals exhibit when they interact with peers they consider like them, in one or more ways, such as gender, race, or profession (Stehlé et al. 2013). For instance, women's relationships tend to be characterized by people who know each other well, compared with men's interactions, that are comprised of people who are not well connected (Hanson and Blake 2009). Also, women's interactions contain a higher proportion of kin and neighbors than those of men (Moore 1990).

Overall, gender and spatial relationships among households may lead to a better understanding of causal factors and local context of food security and align government policies to improve food security. Nevertheless, the effect of spatial interactions and gender on farmer's food security is a "scarcely studied" issue in development economics (Dzanku 2019; Brown 2003).

1.1 Overall Goal and Thesis Objectives

The overall goal of this thesis is to fill a gap in the literature investigating the role of gender and spatial interactions of smallholder farms in affecting food security, and to provide information for policy-makers so that they can take better influence and understand food security. This goal is pursued through three specific objectives:

1. Estimate the effects of spatial interactions among households on food security (*SAR model*).
2. Estimate the spatial effects of neighbors' food security on women's and men's food security (*Ego-gender model*).
3. Estimate the spatial effects of neighbors of the same gender (gender homophily) on own food security (*Gender homophily model*).

To pursue this goal, we employ a rich dataset collected by the Climate Change, Agriculture, and Food Security (CCAFS) research program executed in early 2010 through late 2012. The data contain information from 1496 households located across 7 different countries in West Africa, East Africa, and South Asia. The dataset presents a wide range of information on food security that have been used and reported in the literature, including information on food consumption, both purchased and home-grown, and gender (e.g. Bezner Kerr et al., 2019; Ncube et al., 2016; World Bank, 2015). The dataset allows us to construct a calorie gap measure of food security that indicates differences between the World Health Organization's recommended, and actual, daily calorie intake.

In pursuing our first objective, we construct a Spatial Autoregressive model (SAR model), which allows to estimate the effect of neighbors' food security on own food security. The dataset is geocoded which allows us to calculate the distance between households. We use this information to estimate our models. Specifically, we use an instrumental variable (IV) strategy to estimate a Spatial Autoregressive Model (SAR model) that allows us to control for the endogeneity of neighbor's food security (e.g. reverse causality, neighbor's food security affects own food security, but own food security also affects neighbors' food security). Our estimation strategy follows the IV approach proposed by Kelejian and Prucha (1998) that uses first and second order spatial lags of control variables as instruments.

For pursuing our second objective, we estimate ego-gender spatial effects; that is the influence of neighbors' food security on the food security of women and men.[1] We approach this objective by splitting the sample into female- and male-headed households. These models allow to investigate how all neighbors affect the food security of male and female households.

[1] The "ego" household is the household of reference, which is influenced by its neighbors

In pursuing our third objective, we estimate a variation of the SAR model to explore homophily. These models explore how women's food security is affected by their female neighbors, and conversely, how men's food security is influenced by male neighbors. We investigate the influence of gender-homophily neighbors' food security on own food security. This approach provides and generates insights about the preferences that individuals exhibit when they interact with peers that they consider to be alike (Stehlé et al. 2013). In our case, female-headed households may share with other female heads many features that make them similar to each other.

These objectives guide our investigation into how gender and spatial effects can be used to inform the design of policy interventions to address food security. It is hoped that by bringing social contexts of gender and spatial interactions into economics models, we can create an increased understanding that can better align government policies with programs and donor efforts with local situations to enhance food security.

1.2 Thesis structure

The remainder of this thesis is organized as follows. Chapter 2 discusses literature relevant to this research. Chapter 3 describes the sampling procedure of the survey, the geographic characteristics of our study area, and the determinants of food security. Chapter 4 situates the study in the literature regarding measures of food security and describes how food security is defined and measured in this research. Our methods are described in Chapter 5, where we present three types of models: *SAR Model, Ego-Gender Models,* and *Gender-Homophily Models*. Results of our models are reported in chapter 6. Finally, in chapter 7 we draw conclusion from the results of our research.

2. Literature Review

The following chapter discusses literature relevant to this research. We begin discussing influences of gender on food security. Second, we review the importance of gender, social networks, and spatial interactions. Third, we look at literature on how measures of gender are included in investigations. Finally, we review determinants of food security.

2.1 Gender and Food Security

Gender can play an important role in influencing food security because women are generally responsible for growing, selecting, and preparing food, especially for children (USAID 2011). In general, female-headed households are found to be more vulnerable and less food secure than their male-headed households counterparts (Babatunde et al. 2008). One of the major reasons is that females can face a wide range of constraints that affect their households in several ways. Kassie et al. (2015), note substantial differences between women and men regarding access to land, credit, information, labor, and ownership of assets. Additionally, there are socio-cultural factors that affect women's households in numerous ways. Such factors include gender-specific migrations (Buvinić and Gupta 1997), education beliefs (Duflo 2012), and prohibition of labor force participation (Mallick and Rafi 2010).

Women's access to land is one important resource that can affect food security. People who own land have the opportunity to control vital decisions such as what crop to grow, what techniques to use, and decisions on what to consume and sell (FAO 1997). Therefore, access to land for women is important to ensure a household's food security. Historically, access to land tends to be based on status within the family and gender (FAO 1997). Women tend to either own smaller pieces of land than men or are landless (Lastarria-Cornhiel 1997). Women who own land tend to pursue livelihood activities such as farming, growing medicinal herbs, obtaining fuel, and gathering food (Doss, Summerfield and Tsikata 2014).

In addition to providing food and income, land, and its associated tenure, can also represent a valuable resource because it can serve as collateral to access credit (Doss 2001). Access to credit is an essential activity for financing agricultural inputs (i.e., fertilizer and seeds). Particularly, women's access to credit is known to increase household and child food security (Lemke et al. 2003). However, women's access to credit may be restricted because customary laws may not allow them to share land rights along with their husbands, or because women heads of households may be excluded from land tenure schemes (FAO 1997). Accordingly, microfinance has been identified as one of the areas where women have a significant disadvantage relative to men, because they are not able to make decisions about borrowing (Larson, Castellanos and Jensen 2019).

Female farmers also face barriers in accessing information and in receiving formal education. Information about new techniques in the agricultural sector is spread through public extension services and private imitation. Agricultural extension services are often designed as if all farmers were men. As a result, male agricultural extension agents provide production information to male farmers, while female agricultural extension farmers have less influence in the extension service hierarchy and concentrate more on food processing (Gittinger 1990). Since women do not get an appropriate share of agricultural extension advice, one potential solution is to provide education for women. Providing women with access to primary education could enhance agricultural productivity and incomes, and therefore improve their food security (Quisumbing et al. 1996). Evidence shows that increasing education of female farmers makes them more likely to plant high-value crops and share the information with other women. Access to information and education appears to increase the ability and willingness of women, not only; to allocate resources efficiently, but to cope with food security in response to changes in prices and technology (USAID 2011).

The ability of women to generate income in the agricultural sector may also be constrained by their limited access to human capital (Quisumbing and Maluccio 2003), which may come from household members or hired help. Doss (2001) notes factors that affect labor constraints in a household. One such factor is the gendered division of labor, where women and men are in charge of different agricultural activities based on crop, task, or both. Women who are poor, and at higher risk of being food insecure, are more likely to work in the agricultural sector as wage laborers to ensure their families' subsistence (Sraboni et al. 2014). Another problem can arise from household size and composition, because bigger households could potentially provide more labor (Doss and Morris 2000). Doss (2001) notes that female-headed households, on average, tend to be smaller than male-headed households, and therefore, have lower incomes. Doss & Morris (2000) also note that women-headed households can face a significant disadvantage in hiring labor, because more labor is available to males who own plots rather than women (Udry 1996).

Women's ownership of assets can also influence food security. The ability of women to acquire wealth (i.e. assets) is frequently attributed to whether institutions allow them to own and be in charge of their own property, or take part into contracts. For example, property rights may be determined by marital and inheritance systems in different cultural contexts (Deere et al. 2013). Hallman (2003) suggests that females who have greater control over resources, including assets, have improved food security. For example, when women have access to transportation assets, they may receive income from getting produce to markets. This income may increase women's bargaining power, and allow them to make critical household decisions (for example regarding food) that affect their own welfare (Meinzen-Dick et al. 2014). But control of assets does not imply that such wealth is protected. In times of stress, women's assets are more vulnerable than those of men, because women trade or sell such assets to buy affordable carbohydrates for family consumption (Holmes, Jones and Marsden 2009).

Women that head a household are often divorced, widowed, or separated, and their social context, choices, and outcomes can be much different from those of women living in male-headed households (Drèze and Srinivasan 1997). The roots of such a social context depend on demographic and social factors that have fostered the increase of female-headed households. Such factors include gender-specific migrations that left behind female heads, households created by migrant women, marital disruptions, and un-partnered adolescent fertility. Typically, these contexts contribute to women being single mothers or widowed (Buvinić and Gupta 1997).

Women without spouses who have children typically drop out of school or college, reducing their probabilities of working (Duflo 2012). Likewise, socio-cultural beliefs can contribute to the perception that women have less education than men (Kassie, Ndiritu and Stage 2014). This perception not only reduces women's autonomy and capacities, but may also affect the availability of resources, which can impact food security.

Female-headed households tend to be "activity burdened",[2] and tend to employ additional members of the households, including school-going children, in income-generating activities (Mallick and Rafi 2010). This practice is reflected in the low attainment of schooling for children within households comprised by female heads (Buvinić and Gupta 1997). The motivation behind educating children is to enhance their future opportunities of employment that will provide a catalyst that improves the wellness of the household (Duflo 2012). However, when women utilize all the existing human capital to survive, it may affect the future human capital accumulation, which in turn increases the probability of passing on development problems (i.e., poverty and food insecurity) to future generations.

There are other socio-cultural factors that prohibit women from participating in the labor force. For instance, in some areas of Asia, cultural restrictions on women's ability to work in food production activities have left them more vulnerable in times of crisis (Mallick and Rafi 2010). Additionally, extension workers have traditionally tended to favor male-headed households over female-headed households (Kassie et

[2] "Activity burdened" denote those female heads responsible for maintaining the household, including household chores, and childcare in addition to working outside.

al. 2014). All of this has implications for women's economic status, and as a result their decreased household's food security.

The discussion above indicates why gender matters to food security. Gender differences in the allocation of resources and decisions among and within households are crucial in influencing food security (Kassie et al. 2014; Crush, Hovorka and Tevera 2011; Ibnouf 2011; Modirwa and Oladele 2012).

2.2 Gender, Social Networks and Spatial Interactions

This research is about spatial impacts of households and gender on food security. But spatial relationships exist within more complex relationships of social networks. Therefore, in this section, we set the context for spatial interactions by reviewing a number of dimensions of social networks. We then consider the place of spatial relationships within that complexity.

2.2.1 Gender and Social Networks

Individuals tend to interact, and their behavior may be influenced by relationships between them. Along these lines, individuals' characteristics (e.g. gender) and behavior affect the creation and structure of social networks (Bramoulle, Galeotti and Rogers 2016). Social networks are social structures in which ties, edges, or links connect agents (McDonald 2011). Numerous factors are identified in the literature that influence interactions and activities of individuals. Such factors include social learning (Foster and Rosenzweig 1995), diffusion of innovation (Conley and Udry 2010), risk-sharing (Attanasio, Barr and Cardenas 2012), homophily (Mcpherson, Smith-lovin and Cook 2001), and social capital (Katungi, Edmeades and Smale 2008).

Social learning is an important element of social networks. It is a process in which individuals have the ability to gather information from, and observe behavior of, others, thereby enhancing their knowledge (Foster and Rosenzweig 1995). Learning processes may change over time; individuals may draw signals of different quality, and might be selective in their conversations (Alatas et al. 2016). People may also choose whether to pass information to others. Information may be withheld for a number of reasons, including outdated information (Alatas et al. 2016), or a desire to hold exclusive rights to information in order to maintain elite status within the community (Ribot 2002).

Questions regarding whether, and to what degree, information is passed have been discussed in literature regarding the diffusion of innovation. Diffusion of innovation refers to the spreading of information, over a wide range of topics, due to the interactions between individuals in gathering information and observing others (Foster and Rosenzweig 1995). For example, Conley and Udry (2010) find that new agricultural technologies that are introduced by farmers' own experimentation, and the process of social learning encourages their diffusion. There may also be gendered dimensions to diffusion. Women may tend to join groups that can mobilize fewer resources than men, because they are resource-constrained (Maluccio, Haddad and May 2003). As a result, the spreading of information through women may be limited.

Part of the diffusion of information from social learning may be caused by imitation. Homophily refers to the preference of individuals to interact with peers they consider to be alike; i.e., people of the same gender (Stehlé et al. 2013). For instance, an individual with many smoker friends might be influenced to become a smoker.

Similarly, women imitate women, and men imitate men, which can result in powerful motivation (Gittinger 1990).

Another important dimension of social networks is risk-sharing; the ability of individuals to reduce the likelihood and impact of any event's uncertainty (Fafchamps 2011). The ability of individuals to share risk can be shaped by many factors: weather, disease, or natural disasters (Fafchamps 2011). Ambrus, Mobius and Szeidl (2014) highlight different types of risk-sharing, such as informal loans, gifts, funeral societies, and social networks. Attanasio et al. (2012) find that close friends and relatives are more likely to form groups, and are also more likely to distribute the risk across the group. For instance, family groups often look to an extended relative (i.e., cousin, uncle) for help during adverse shocks, such as helping during the critical parts of the growing season if someone is ill (Fafchamps 2011).

Social capital is another important element of social networks. Social capital refers to the resources (i.e., information, influence, and status) that are embedded in social networks (McDonald 2011). Podolny (2010) finds that being connected to another person can bring status benefits. For example, in developing countries, many local elites utilize local power structures, such as local government, to obtain greater resource benefits (Bajracharya 2008). Social capital also influences women's relationships in numerous ways. The difference of resources endowments that female-headed households have, relative to male-headed households, may impact their social capital formation and exchange of information (Katungi et al. 2008). In addition, women's relationships tend to be characterized by people who know each other well (i.e., kinship, neighbors), while men's interactions tend to be comprised of people who are not well connected (Hanson and Blake 2009; Moore 1990).

2.2.2 Gender and Spatial Interactions

Spatial interactions play an important role in understanding social networks. Social networks exist and operate within geographical spaces. Nolin (2010) suggests that spatial interactions are more likely to occur within spatially closer households or neighbors for three reasons. First, transaction costs of time and resources for travel between neighbors increase with distance. Second, it is easier to assess information and relative need from closer neighbors than from those further away. Third, closer neighbors interact more frequently, which may increase the probability of future interactions.

Spatial interactions can take a wide variety of forms that include travel for shopping, commuting to work, and interacting with neighbors. Given these types of activities, it is not surprising that spatial interactions may affect women differently than men. For example, women may have a higher opportunity cost of time than men (e.g. from a high domestic workload), which reduces their participation in organizations or other social interactions (Meinzen-Dick and Zwarteveen 1998), and which may motivate women to engage in relationships that are spatially closer. Conversely, men's interactions may be more geographically dispersed, with more connections regarding civic affairs (Maluccio et al. 2003).

The discussion above discloses that there are numerous interrelated factors, with gender dimensions, which could influence the behavior of households. Moreover, these interactions may produce spillover effects[3] within the system where information and other externalities are transferred to others. A key challenge in this study involves how to characterize these interrelationships in empirical models, within the context of limited data. Given our approach, to use quantitative survey data across large numbers of households across broad regions, we are forced to simplify. In our dataset, we have GPS coordinates of every household. The potentially central role that spatial relationships play within the complexities of social networks suggest that we may use these coordinates as a proxy for more complex relationships, and proceed with the hypothesis that these coordinates be meaningful in helping to explain the food security of households.

2.3 Measuring Gender

The broad dimensions of gender can influence development issues (i.e., food security, poverty, education) in many ways. Therefore, there are many issues about how to represent gender with measures in empirical studies. Quantitative studies that have investigated influences of gender have implemented a wide range of measures, including gender-disaggregated data on household structures, gendered-ownership of assets, and gender dummy variables.

A common approach in the literature is to capture gender differences with dummy variables based on whether the gender of the head of the household is female (Fekadu and Muche Mequanent 2010; Mallick and Rafi 2010). Although the use of

---

[3] Note that spillover effect is referred to as the spatial multiplier. It is a term introduced in sociology to analyze neighborhood processes and the dependency among agents in a system. Refer to Anselin (2003) for a discussion.

dummy variables may be practical, the limitations of using a simple gender dummy can be numerous, given that men and women in agricultural societies face many different inequalities in their farming activities. As reviewed in section 2.1, women generally have less access than men to numerous types of resources and services (e.g., credit, education, information, land) through numerous types of constraints. Thus, a gender dummy variable could be leaving out underlying differences that are complex, and that change over time because of social and economic pressures (Doss, 2001; Meinzen-Dick et al., 2014).

Kennedy & Peters (1992), note that comparisons that are limited to female and male-headed households may cloak complex processes that characterize various types of female-headed households. Instead, they propose a more detailed household's classification in which female-headed households are subdivided into *de jure* females (such as widows), considered the legal head of household, and *de facto* females, where the male is absent for more than 50% of the time. Quisumbing (1996) shows that non-resident household members (e.g., influential elder, senior wife) play an essential role in determining decision-making over family assets. Thus, variations in household structure can encompass families' risk-coping mechanisms. Along these lines, others have also studied how more nuanced descriptions of household structures (e.g., number of adult males present in the household, numbers of kids, etc.) influence household behavior (Ndlovu, Mohapatra and Luckert 2018; Dassanayake, Luckert and Mohapatra 2015).

Gendered control of resources within a household have also been studied (e.g. Mason et al. (2015)). Resources were also the focus of Kassie et al. (2015), who use an exogenous switching regression to decompose the gendered food security gap into portions caused by observable differences in resource endowments. Others have analyzed gendered time and labor allocation within the household and their impacts on behavior (Ilahi 2000).

Overall, detailed data on gender could help explain complex intra-household processes and differences between women and men that might potentially help policy-makers understand food security. However, as discussed above, the geographical scope of our study and the nature of our data limits the extent to which we can address such detail. Though we do have some information on household structure (i.e. sex and age of all household members living in the same household), our interest is in investigating gendered dimensions and spatial interactions. As will become clear later in this thesis,[4] the model structures that are employed to investigate this topic requires us to select a single variable to capture gender differences. Accordingly, we believe our best option is to capture the influence of gender differences by using a gender dummy variable (i.e. female- vs. male-headed household), which is well established in the literature (e.g. Mallick and Rafi 2010; Babatunde et al. 2008). We progress in this manner knowing that we are leaving complexity behind that may well be relevant, but that may also potentially be captured by the highly aggregated concept of gendered household head. Such an approach is necessary for us to investigate extensively across wide regions, rather than intensively at a single study site.

[4] Empirical models are described in further detail in chapter 5.

2.4 Determinants of Food security

Based on a number of studies in the literature (e.g., Kassie et al. 2014; Millimet, McDonough and Fomby 2018; Yen et al. 2008), we consider determinants of food security in three categories: household characteristics, assets, and livelihood strategies. We discuss the specific determinants that we use in our model specification in Chapter 3. Our discussion below focuses on those determinants. The discussion regarding the definition of our food security variable is included in Chapter 4.

2.4.1 Household Characteristics

Following the discussion in section 2.3, our key gender consideration will be female- vs. male-headed households, which is expected to have a negative effect on food security because of constraints regarding access to land, credit, information, labor, ownership of assets, and other socio-cultural factors. We also consider the age of the household head, but we have no clear *a priori* expectations on the sign. Older farmer heads acquire more knowledge and experience and, thus, may be more food secure (Fekadu and Muche Mequanent 2010). However, the oldest of the household heads may not be as productive as when they were younger, thereby reducing the food security in the household (Bussolo et al. 2015). Similarly, the effect of household size on food security is also ambiguous. More members in a household may reduce the availability of food for consumption and, thus, cause the households to be less food secure (Garrett and Ruel 1999). On the other hand, household size could represent the availability of labor to produce food, which could boost the food security of the household (Etwire et al. 2013).

2.4.2 Household Assets

Literature suggests that all types of assets may have a positive impact on food security. Domestic assets, such as stoves, radios, refrigerators, TVs, and cellphones can improve household well-being and support in the exchange of information and decision making (Bryan et al. 2009). Transport assets can help to increase access to markets and mobility, promoting access to, and use of, information, social capital and connections (Kassie et al. 2014). Finally, the ownership and use of productive assets, such as hoes, ploughs, and spades, could lead to an increase in production and potentially enhance income and improve food security (Gittinger 1990).

2.4.3 Household Livelihood Strategies

A number of factors related to livelihood strategies could influence food security. Off-farm income can serve as a proxy to capture households' diversification strategies for managing food insecurity (Fekadu and Muche Mequanent 2010). Therefore, we expect that the availability of off-farm income will have a positive impact on food security.

With respect to on-farm income, a number of authors have identified the potential importance of livestock in promoting food security. Livestock are considered a source of financial, human, and social capital. Livestock provide income that contributes to ability to access, buy, and produce food, for example, as a source of energy (i.e., draught animal power) that helps efficiently to control weeds (Sansoucy 1995). Livestock can also provide safety to maintain sustenance during food-insecure periods, and stimulate employment for herders and slaughterhouses (FAO 2018). Households that own large quantities of livestock are expected to be more food secure, especially during periods of drought when crops are unsuccessful in yielding (Little et al. 2006).

Another important on-farm livelihood strategy in pursuing food security is the planting of agricultural crops. Land, considered a basic input in farming that contributes to food security, not only acts as a source of cash income through agricultural production, but also as source of food for household consumption (Maxwell and Wiebe 1998). Studies suggest that farms with larger areas of cropland are more likely to be more efficient thereby promoting food security (Fekadu and Muche Mequanent 2010; Grootaert and Narayan 2004).

A number of authors have also investigated the potential to use varying combinations of livestock and agricultural land to pursue food security. Frelat et al (2016) and Wijk et al. (2018) suggest that there is a relationship between livestock and land size in pursuing food security, such that these two strategies are not independent. If we think of livestock and agricultural land as being two inputs into providing the output of food security, these authors have shown a convex relationship in providing alternative given levels of food security. The concept is similar to an isoquant where various combinations of two inputs are shown for a given level of output; in this case food security. Different combinations of inputs may represent different levels of food security. The isoquant has a slope that is called the marginal rate of technical substitution between input 1 (i.e., livestock) and input 2 (i.e., farm size). The value of the slope indicates how many additional units of input 2 we need to use to produce the same output as before when we reduce the number of units of input 1. The convex slope of the isoquant reveals that the two inputs are not independent and have a nonlinear relationship, implying diminishing returns to scale. Such non-linearity can occur, for example, because livestock production can create synergies with crop production, where crop residues are used to feed animals, and the manure from the animals is used to fertilize crops, especially on smallholder farms (FAO 2011).

2.4.4 District, Crop, and Technology Effects

Previous research has also included a number of controls for potentially confounding effects related to district (or space), crop mix, and agricultural technologies. A generally-known strategy to address the issue of spatial autocorrelation is the application of spatial fixed effects (Anselin and Arribas-Bel 2013). Households that are in different locations may lead to spatial correlation in household's food security. Therefore, spatial fixed effects capture characteristics of a site such as weather, and culture (Schlenker and Roberts 2006).

Second, the production of different types of crops may result in different levels of food security. Production of different types of crops can lead to variation in nutritional quality of the household's diet (Immink and Alarcon 1991), and may also represent diversification strategies, which have implications for agricultural intensification (Chen et al. 2018). In this sense, it is essential to control for crop heterogeneity by including crop fixed effects.

Finally, the adoption of agricultural technologies could be influenced by the risk and uncertainty of the farmer and other unobserved variables, which might produce biased estimates of the effects of technologies (Crost et al. 2007). Moreover, land use technologies can involve spillover effects, and ignoring these effects could also cause biased estimates (Qiu et al. 2015).

3. Data and Study Sites

This chapter is organized into three parts. First, we discuss the details of the survey instrument that we used in this study in more detail. Second, we describe the sampling procedure that was used to collect the data and provide background information on our study area's climatic and geographic characteristics. The third part presents the determinants of food security that will be used in our empirical models including descriptive statistics of 1496 households.

3.1 Overview of Questionnaire

This research project uses a rich dataset from the Integrated Modelling Platform for Mixed Animal Crop systems (IMPACT) Lite collected by Climate Change, Agriculture, and Food Security (CCAFS)[5] from 2010 to late 2012. The IMPACT Lite was implemented in twelve countries across West Africa, East Africa and South Asia. The datasets collected by CCAFS team offers a representative cross-sectional sample of household-level responses to numerous socioeconomic questions, including detailed information about farm resources, farm productivity, land allocation, on-farm, and off-farm activities, income, as well as food consumption (i.e. home-grown and purchased) and assets (Rufino et al. 2012).

The IMPACT Lite survey is comprised of a cover page and seventeen forms. Table 3-1 provides a description of the information that was collected in each form.

---

[5] The questionnaire and the dataset from the IMPACT Lite survey used for this study can be found at https://data.ilri.org/portal/organization/3f843464-85c6-4f08-96c1-d552fca6a0e4?sort=score+desc%2C+metadata_modified+desc&groups=ccafs&q=impact+lite

Table 3-1 Description of Survey Forms

Form No.	Form Name	Description
0	Cover Page	The cover page captures general information related to the household and its geographical location. The cover page also records data about the enumerator, its site coordinator, and the data entry clerk.
1	Household composition and off-farm activities	This form records the information of all household members and their position in the household, e.g. household head, spouse, son. Also, this form includes information for each member regarding whether he/she works in the farm or off-farm in different seasons.
2	Sketch of the farm and seasonality of crops	This form captures a sketch of the farm and the seasonality of crops.
3	Ranking of crops, livestock and aquaculture	Provide an inventory and ranking of the most important income generating activities and consumption of on-farm products. Include crops, livestock, and aquaculture activities. Do not include off-farm products or services.
4	Land allocation	Includes all the different plots that the households have and that hold the ranked farming activities made in form 3
5	Farming activities and inputs	Capture different labour consuming activities that happen in each plot and subplot. Under each activity the household indicates any input used if applicable.
6	Production of main crops/ aquaculture	Collect information of the different products harvested from crops, trees and aquaculture. Do not include residues.
7	Residue productions of main crops / aquaculture	Indicate the different residues produced from crops, trees and aquaculture.
8	Non-ruminant livestock species	Collect information of livestock species that are not ruminants. Do not include aquaculture species, given that those were collected in form 4.
9	Ruminant livestock inventory	Collect the different ruminant livestock species (i.e. cattle, sheeps, goats, camels) that are fed and taken care of by the household.
10	Livestock activities and inputs	Indicate different labour activities carried out for each livestock species. Some activities could imply the use of inputs for example: vaccination implies the acquisition of vaccines. Each activity indicates any input used if applicable.
11	Livestock feeding	Indicate the different feeds (on farm and purchased) that the livestock gets in different seasons. Each feed indicates the quantity given and the unit of measure for such quantity.

12	Production of livestock products	Indicate the production of livestock products. For example, poultry for consumption, eggs, cow milk. Do not include services (e.g. ploughing).
13	Other income	Indicate other sources of income received by the household members. For example, business in local market, remittances, animal traction.
14	Other Expenses	Indicate other expenses incurred by the household members. For example, payment loan.
15	Household consumption of on-farm products	Households indicate their food consumption of on-farm products in good and bad times. For example, maize, millet.
16	Household consumption of off-farm products	Households indicate their food consumption of off-farm products. For example, meat purchased in town.
17	Farm and domestic assets	Collect information on the assets the household owns. For each asset the household should indicate how many assets have in total and indicate its age (years).

Source: Rufino et al. (2012)

3.2 Sampling and Study Sites

The study sites that we analyze are located in seven countries located in three regions. East Africa (Kenya and Tanzania), West Africa (Ghana and Senegal), and South Asia (India, Nepal, and Bangladesh).[6] Figure 3-1 shows the location of the study sites. According to Förch et al. (2011), these regions represent areas with high levels of vulnerability and poverty, different institutional and social contexts, and weather-related challenges with opportunities for interventions.

3.2.1 Sampling Procedure

Within each of the regions and countries, sampling was conducted across districts and villages. Districts are administrative divisions that span several villages and comprise

[6] The original sample included five other countries, but these were omitted because of data problems.

the study sites of the sample. Within each district, the objective was to sample 200 households across multiple villages, with 10 households per village.

The choice regarding which villages to sample within districts was guided by the desire to capture a number of types of production systems. The IMPACT Lite survey teams, in collaboration with local researchers and development partners, geographically divided the research districts into several production systems according to land use, farming activities, and market characteristics, which could influence the combinations of farming activities available (Rufino et al. 2012). Each village, and its accompanying households, were assigned to one production system. The number of villages to be sampled for a given production system was determined as:

$$V_p = \frac{HS}{P * HV} \quad (1)$$

where V_p is the number of villages to be sampled for a given production system, HS is the target number of households per research district (i.e., 200), P is the number of production systems per district, and HV is the target number of households sampled in each village (i.e., 10). For example, if there are four production systems (P) identified at a research district, then the number of villages sampled for each production system was 5, $V_p = \frac{200}{4*10}$. Within each production system (P) the survey team aimed at an equal number of villages (V_p) to be randomly selected from a village list[7] constructed for each district.

For purposes of the survey, a household was defined as "a group of people living in the same home and sharing meals and income-generating activities, and acknowledging the authority of the household head" (Rufino et al. 2012). Only households who are "land users" (i.e., households involved in aquaculture or cultivating land and/or keeping livestock) were considered for the survey. Then, ten households per villages were randomly selected from the compiled list.

3.2.2 Characterizations of Study Sites

The countries located in East and West Africa are characterized by large populations in rural areas, depending on rain-fed, cereal-based subsistence agriculture and pastoralism (Förch et al. 2011). These farm-holders are considered vulnerable to climate variability (i.e., primarily droughts). The increasing frequency of climate shocks have led to significant food crises, with a costly cycle of disasters and the resultant loss of lives and livelihoods. Apart from these similarities, there are notable differences between the East and West Africa sites.

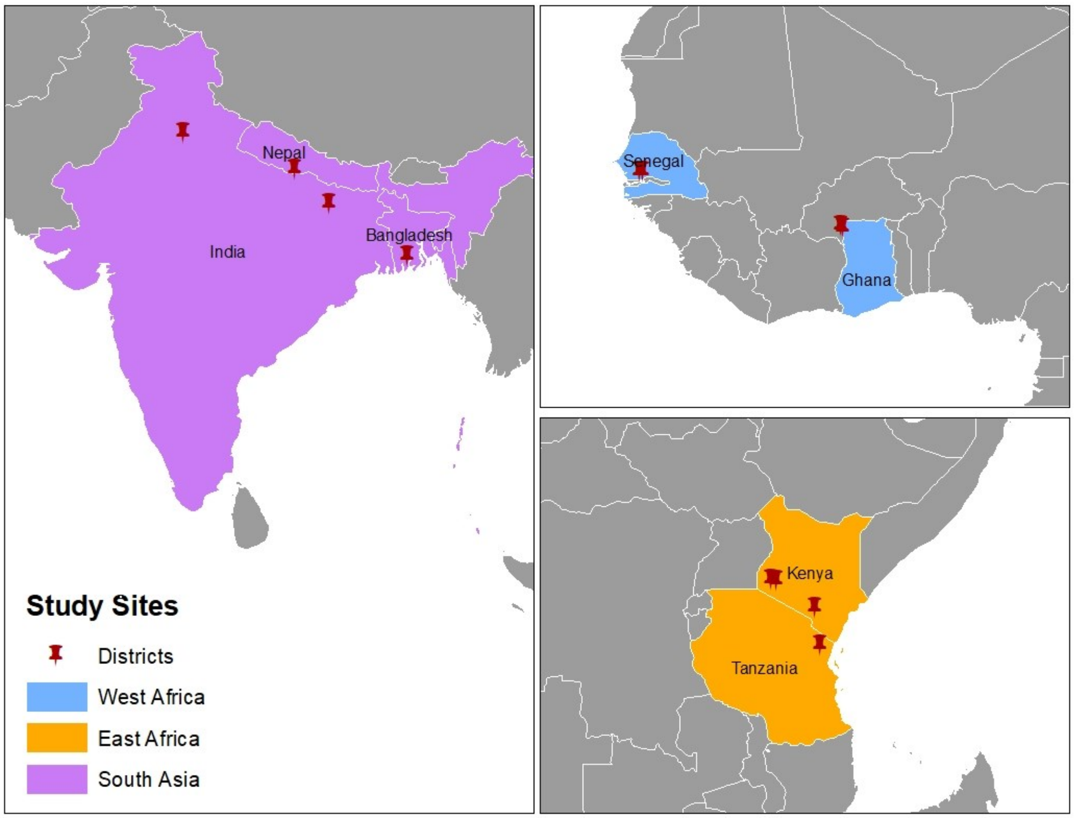
East Africa is characterized by a diversity of climate, topography, agro-ecosystems, and environmental challenges. Elevation and temperature gradients typically dictate whether agriculture is practiced for subsistence use or as commercial plantation agriculture and high-value horticulture (Silvestri et al. 2015). The

---

[7] The survey team acquired high-resolution satellite images, generated a series of maps, and geo-referenced lists of all villages within the districts. This information was updated and reviewed for purposes of the survey.

predictability of rainfall is relatively high and provides the opportunity to help risk management. In contrast, the climate of West Africa is distinguished by heavy rainfall

Figure 3-1 Map of Study Sites



that influences cropping systems (Frelat et al. 2016). Year-to-year rainfall variability causes climate-driven shifts in crops and adaptations to changes in rainfall. The region experiences widespread land degradation, but benefits from policy support for regional drought management and intra-regional trade promoted by a common currency across the francophone countries.

South Asia is characterized by a broadly agreeable climate, rich soils, rice-wheat systems, and plentiful surface and groundwater; all of which help to promote food security for the several hundred million people in the region (Förch et al. 2011). Nonetheless, vulnerability to climate change arises from high levels of population, a relatively limited and depleted resource base. Also, its high dependence on agriculture makes the population vulnerable to food insecurity.

3.3 Determinants of Food Security and Descriptive Statistics

In this section, we describe the summary statistics of the main determinants of food security and fixed effects, which we select based on the literature (see section 2.4 in Chapter 2) and availability in our dataset. Table 3-2 provides the description and summary statistics of these variables for our sample.

3.3.1 Household Characteristics

We capture the impact of *female-headed household* using a dummy variable. Table 3-2 shows that in our sample, 13 percent are *female-headed households,* indicating a majority of the male-headed households. On average, the *age of the household head* (measured in years) in our sample is 50 years old. Each household, on average, is compounded by six people.

3.3.2 Household Assets

For household assets, we construct indices, adapted from Njuki et al. (2011), for each category of assets, and for each household:

$$Asset\ Index = \sum_{g=1}^{G} \left\{ \sum_{n=1}^{N} (\omega_{gn} * a) \right\}, n = 1,2, \ldots, N;\ g = 1,2, \ldots, G \qquad (2)$$

where, g is an identifier of a type of asset (i.e., radio, bicycle, hoes), n is the number of assets of type g owned by a household, ω_{gn} is the weight of asset g based on economic value,[8] and a is the age of adjustment[9] of value for asset g. Table A-1 in the Appendix contains lists of which asset types, (g), belong to which categories, with weights (ω), and age adjustments (a) for of each asset type.

Table 3-2 Descriptive Statistics of Independent Variables

Category / Variable Name	Definition	Mean	Standard Deviation
Household Characteristics			
Female-headed Household	Dummy variable: 1 if the woman is the household head	0.132	0.339
Age of Household Head	Household head's age in years	49.977	14.677
Household Size	Number of people living in a household	6.408	3.427
Household Assets			
Domestic Assets	Index of domestic assets	9.787	7.241
Transport Assets	Index of transport assets	10.627	18.748
Productive Assets	Index of Productive assets	4.578	3.692
Household Livelihood strategies			
Off-farm Income	Dummy variable: 1 if the household earns off-farm income	0.848	0.359
Ruminants per Unit of Land	Number of ruminants (cattle, buffaloes, goats, sheep) per acre	2.311	5.768
Ruminants per Unit of Land Squared	Number of ruminants (cattle, buffaloes, goats, sheep) per acre squared	38.590	263.669

[8] We follow Njuki et al (2011), who calculate weight (ω) based on the value of the asset compared across countries, which ensures that assets of the same value are accorded the same weight, despite country differences in prices.

[9] Age adjustments are based on weights of the aged of the asset. The adjustment occurs according to three categories of the asset's age. If the asset is i) less than 3 years old, the adjustment is 1; ii) between 3 and 7 years old, the adjustment is 0.8; iii) more than 7 years old, the adjustment is 0.5.

Table 3-2 shows the mean and standard deviation of the index for domestic, transport and production assets. On average the index has a weight of 9.7, 10.6, and 4.5 for domestic, transport, and productive assets, respectively.

3.3.3 Household Livelihood Strategies

To capture the impact of *off-farm income*, we use a dummy variable to indicate whether the household earns cash from activities outside the farm, including remittances. Table 3-2 shows that 84% of households in our sample receive *off-farm income*. Another household livelihood strategy involves various combinations of livestock and cropland. Because of the non-linear relationships between livestock and agricultural land, discussed in the literature review above, we specify a variable that is the ratio of livestock and land size in a polynomial specification. The specification includes the number of *ruminants per acre* and the number of *ruminants per acre squared.* On average a household owns 2.3 *ruminants per acre*, and 38.5 *ruminants per acre squared*.

3.3.4 District, Crop, and Technology Effects

We employ a number of controls for potentially confounding effects related to district (or space), crop mix, and agricultural technologies. For spatial controls, we use district-level fixed effects. Our sample contains fourteen districts located across West and East Africa, and South Asia. Table A-2 in the appendix shows a list of the sampled districts, the mean and standard deviation of the proportion of sampled households in each district. For crop controls we use fourteen crop dummy variables (see table A-2 in the appendix) that represent the main crops of a given household; namely, beans, groundnuts, lentils, maize, mangoes, millets, mustard seed, rice paddy, potato, sorghum, sugarcane, vegetables, and wheat. Each of these crops are cultivated by at least 2% of the households, resulting in at least 30 households for each dummy variable. Other crops were excluded in the fixed effects, as they were not cultivated by a representative number of households.

Finally, technology effects include intercropping and land fragmentation (see table A-2 in the appendix). Intercropping is measured with a dummy variable that indicates whether a household implements cultivation of two or more crops simultaneously on the same field. Fragmentation is measured using a Herfindahl index:

$$HI_i = \sum_{n=1}^{N} ({}^{p}/_{t})^2 \tag{3}$$

where p is the area of the plot of household i, N is the number of plots that household i owns, and t is the total area of all plots that household i owns. The index is normalized, so that it ranges from 0 to 1:

$$NH_i = \frac{(HI_i - {}^{1}/_{N})}{1 - {}^{1}/_{N}} \tag{4}$$

Households with a normalized index value that is less than the mean of the normalized index are designated with a dummy variable as having high land fragmentation. In our sample, 59% of the households, on average, implement intercropping and 23% have high land fragmentation.

4. Measuring Food Security

The objective of this chapter is to situate our study in the existing literature of measuring food security. To do so, we first review the empirical work that has analyzed this topic and highlight the methodological and econometric literature. We then discuss a calorie gap measure and how it is defined in our study.

4.1 Review of Empirical Studies

Food security is a multifaceted concept that encompasses four dimensions: food availability, food access, utilization, and stability (FAO 2006). The first dimension occurs when individuals have sufficient food supplies from which to choose. The second aspect indicates the ability of individuals (i.e., income, expenditure, and buying capacity of individuals) to effectively obtain food for a nutritious diet. The utilization dimension refers to the diversity of the diet, clean water, sanitation, and health care to reach a state of nutritional well-being. Finally, stability addresses the long-term of food availability, food access, and proper utilization of the food over time.

Studies use different types of measures to assess the status of food security. There is no consensus about what measure is ideal. Studies have used factor analysis or principal component analysis (PCA) to extract food security dimensionality. For instance, Knueppel et al., (2010) used PCA to extract two components: insufficient food intake and insufficient food quality. A study by Coates et al., (2003) used PCA to evaluate the dimensionality of the "Food Access Survey Tool," a scale where two factors are extracted. The first refers to the quantity, quality, acceptability, and stability of the household's food access, and a second factor contains three items reflecting aspects of diet quality. Banna & Townsend (2011) carried out a PCA analysis on food behavior of low-income Spanish-speaking women in California, where they extract four components related to fruit/vegetable consumption, diet quality, fast food consumption, and sweetened beverage consumption.

In addition to the multi-dimensional studies mentioned above, some studies involve "*quantitative-objective*" and "*qualitative-subjective*" metrics to assess the status of food security. Q*uantitative-objective* approaches involve data on income or consumption (Migotto et al. 2005). For example, authors like Iram & Butt (2004) and Ncube et al., (2016), used food composition tables to estimate the calorie intake (consumption of calories/day/person/household), compared to the recommended intake by the WHO/FAO. Calorie availability at the household level, in practice, aims to measure "*food access*" (i.e. access to a sufficient quantity of food) (Wiesmann et al. 2009). This indicator is meant to assess the amounts of all foods an individual ate over a predetermined period, often 24 hours or one week.

In contrast, *qualitative-subjective* approaches are used to seek assessments of research participants about their food security (Babatunde et al., 2008). For example, Mallick & Rafi (2010) and Kassie et al., (2015), used measures to construct a food security indicator where respondents were asked to assess their own food security's status for the preceding 12 months. The respondent's self-assessment was grouped into four categories: food shortage, occasional food shortage, no food shortage nor surplus, and food surplus. This assessment aimed to evaluate the availability and access dimensions of food security. Similarly, Coates et al., (2006) implemented a household-level questionnaire to asses the status of food security in Bangladesh. This metric asks households or individuals to report their personal experience, or sense, of their food security. The questionnaire was designed to measure the inadequate quantity and insufficient quality of food; the second dimension (food access) of food security. Based on the data available to us, we use a largely *quantitative objective* approach that has some elements of *qualitative-subjective* measures, regarding perceptions of "good" and "bad times" for part of the sample. This measure is further discussed in section 4.2.

Each of these different types of measures has strengths and weaknesses. "Q*uantitative-objective*" measures are commonly used as benchmarks metrics, sometimes assuming that these measures are more direct and represent the "true" root causes and status of food security (Migotto et al. 2005). However, these types of metrics tend to require large amounts of data that can be costly to collect, and that could make these types of indicators susceptible to measurement error (Migotto et al. 2005). Moreover, by concentrating on indicators such as food consumption or expenditures, these metrics rarely go beyond the "access" dimension of food security (Mason 2002). In contrast, "*qualitative-subjective*" metrics try to capture the situation that arises because of food insecurity, the symptoms instead of the cause (Coates et al. 2003). Moreover, "*qualitative-subjective*" measures are frequently used to assess multiple dimensions of food security (Rafiei et al. 2009). However, these types of metrics are vulnerable to unobserved, non-random heterogeneity, rendering intergroup comparisons challenging (Upton, Cissé and Barrett 2016).

The above review discloses numerous ways that are used to address the multifaceted concept of food security. Food security metrics vary from "*quantitative-*

objective” and “*qualitative-subjective*” approaches, which may capture different dimensions of food security. Therefore, the usefulness of each measure will depend on the specific context and needs of the research (Upton et al. 2016). Authors like Upton et al. (2016) have shown, based on the works of Barret & Constas (2014) and Cissé & Barret (2018), that food security may be measured in a way that satisfies all four dimensions. However, such an intensive approach may be infeasible to carry out at large scales given data limitations (Upton et al. 2016). Hence, studies, such as this one, must frequently rely on measures that do not completely represent broader concepts of food security.

4.2 Calorie Gap Measure

To assess the status of food security, we use a calorie gap measure that reflects the “food access” dimension of food security. We adopt this approach because the IMPACT Lite survey contains detailed information about food consumption over different seasons of a year, which also provides us with seasonality data that will help address the “stability” dimension. The calorie gap metric is defined as the difference between the actual daily calorie intake and the recommended daily calorie intake by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). The FAO/WHO recommended daily calorie intake measures account for differences in individual’s energy requirement by gender and sex (Ncube et al. 2016).[10] A positive calorie gap implies the household or individual is food or calorie-rich; conversely, a negative gap indicates that a household is food or calorie-poor.

[10] See table A-3 in the appendix.

Data from the IMPACT lite survey for Africa and Asia were collected on a household basis. Households reported consumed home-grown food items and food obtained outside the farm for different seasons throughout the year. Households reported quantity consumed, measured in kilograms (kg) or liters (L), and the length of time used to finish consumption of each of the items. To convert the quantities that a household consumes into daily amounts, the amounts were divided into the length of time used to consume each product and then transformed into the equivalent number of calories.[11] Food items consumed by the household were converted into daily calorie amounts using the FAO's food composition tables for Africa[12] and Asia.[13] For instance, if the household reported 5kg of millet were consumed in 5 days, then the daily quantity consumed was 1kg of millet. Next, the daily quantity (1kg) was transformed into calories using the food composition table that indicated that 100gr of millet are equivalent to 346 calories, implying that the household consumed 3460 calories a day of millet.

It should be noted that there was a difference in how the seasons were considered for each region. For Africa, seasonal differences were indicated by the households as "good periods" and "bad periods" in a year. On the other hand, seasonal differences for Asia were indicated by the households as rainy, summer, and winter seasons.

---

[11] Recall that our data does not contain individual specific food consumption information. Hence, our calorie intake measure is a household measure.

[12] Refer to the following link http://www.fao.org/infoods/infoods/tables-and-databases/africa/en/ for information on the caloric value for African food items.

[13] Refer to the following link http://www.fao.org/infoods/infoods/tables-and-databases/asia/en/ for information on the caloric value for Asian food items.

Households were surveyed once, and were asked to recall[14] their consumption for a typical week within each season. We constructed the calorie gap measures for Africa and South Asia, considering these different types of "seasons".

The following equation was used to calculate the actual daily calorie intake ACI_i:

$$ACI_i = \sum_{j=1}^{z} \left[\left\{ \left(Q_{Gj} \times E_j \right) + \left(QP_{Gj} \times E_j \right) \right\} \times \frac{G_i}{12} + \left\{ \left(Q_{Bj} \times E_j \right) + \left(QP_{Bj} \times E_j \right) \right\} \times \frac{B_i}{12} \right] \quad (5)$$

where ACI_i is the actual daily calorie intake for household i in Africa; Q_{Gj} is the daily quantity of food item j (kg or L) produced on-farm and consumed in "good" periods; E_j is the calorie content of food item j (Megajoules kg^{-1} or L); QP_{Gj} is the daily quantity of food item j purchased and consumed in "good" periods; Q_{Bj} is the daily quantity of food item j produced on-farm and consumed in "bad" periods; QP_{Bj} is the daily quantity of food item j (kg or L) purchased and consumed in "bad" periods. For African sites, the ACI_i is weighted, considering the seasonal differences mentioned above. The weights are $\frac{G_i}{12}$ and $\frac{B_i}{12}$, where G_i is the number of "good" months in the last year as indicated by household i; and B_i is the number of "bad" months as indicated by household i.

For Asian sites, the ACI_i is weighted similarly, but in this case, the seasonal differences are delineated by rainy, summer, and winter seasons which are each 4

---

[14] Recall data may suffer from problems associated with participants who do not remember previous events or experiences accurately. The accuracy of memories may be influenced by subsequent events and experiences (Spencer, Brassey and Mahtani 2017). This problem is discussed further among recommendations for further research.

months long. For Asia, all the variables are the same as for Africa, except for these seasonal differences.

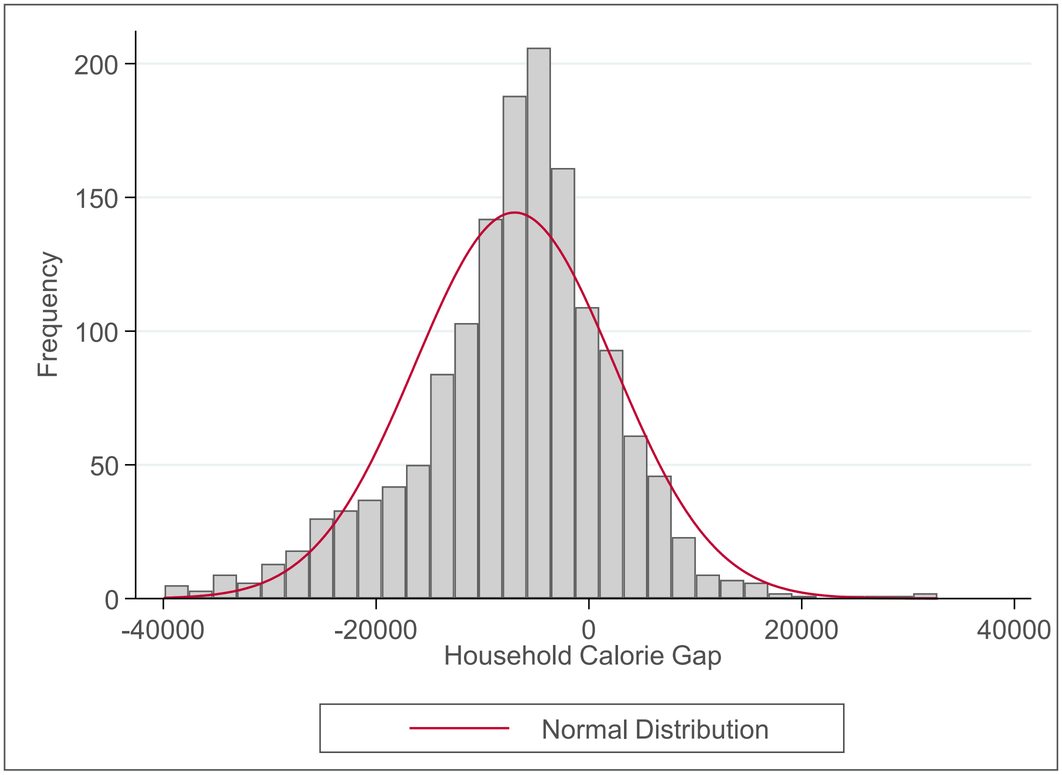
Although we do not have individual specific calorie intake, we do have age and gender information for each household member, and recommended calorie intakes by age and gender from WHO/FAO tables (refer to table A-3 in the appendix). To calculate the WHO/FAO recommended daily calorie intake for every household (RCI_i), demographic information such as gender and age for each member living in the same household was used to estimate their RCI as shown in equation (6):

$$RCI_i = \sum_{n=1}^{m} K_{nga} \tag{6}$$

where K_{nga} is the calorie requirement in Megajoules for member n of gender g, and age a; and m is the number of members in household i. The calorie gap is calculated as the difference between the ACI_i and RCI_i, that is $GAP_i = ACI_i - RCI_i$ such that, when the gap is positive, household i is food secure.

Our dependent variable – *calorie gap* is shown in Figure 4-1 to resemble a normal distribution around a mean of -7019 calories, with a standard deviation of 9583 calories. This measure indicates that on average, households in our sample have a calorie deficit. A vast majority of the households (80%) have a negative gap and therefore are considered food-insecure households. On average, households that are food insecure have 6.8 individuals and an overall deficit of about 9986 calories a day. On the other hand, households that are food secure have, on average, 4.4 individuals and a surplus of about 5158 calories per day. These results are consistent with United Nations food security estimates (FAO et al. 2018), which indicate that since 2005, Africa and Asia are the continents that remain with the highest prevalence of undernourishment.

Figure 4-1 Distribution of Household Calorie Gap



The values in Figure 4-1 indicate a number of households with large calorie gaps. We investigate these values further by depicting the sampled households in terms of daily calorie intake per capita. Figure 4-2 shows that almost half of the sample (46%) is consuming under 1000 calories a day, an amount that would suggest severe caloric defficiencies among large numbers of households. We are not sufficiently familiar with local circumstances to know how realistic these numbers are, but note that recall data can suffer from inacuracies (see footnote 15). However, as will become evident from the construction of our models, our estimates do not rely on absolute values of calorie intakes. Rather, estimates are based on variation in the data, and we proceed with the assumption that there is no systematic bias in the variation between estimates.

Figure 4-2 Histogram of Daily Calorie Intake Per Capita[15]

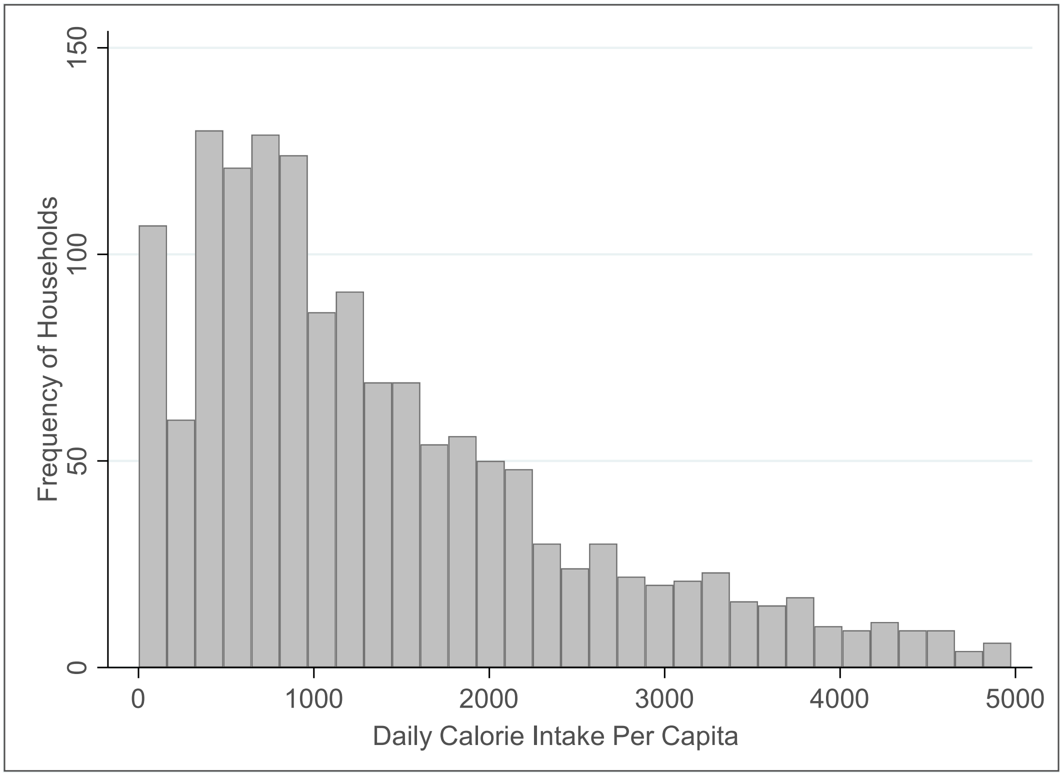


Table 4-1 shows summary statistics of *calorie gap* by gendered head of household. The average calorie gap for female-headed households is around -2612 calories, lower than the average calorie gap for male-headed households (-7692 calories). This preliminary finding is somewhat surprising given the constraints facing women that we discussed in chapter 2, and previous findings (Babatunde et al. 2008; Tibesigwa and Visser 2016) that reported female-headed households as more food insecure. We investigate possible explanations for this result later in the thesis.

[15] For purposes of presentation, the upper tail in the figure omits 26 observations.

Table 4-1 Calorie Gap Summary Statistics by Gendered Head of Household (calories/household/day)

Sample	Obs.	Mean	Standard Deviation
All households	1496	-7019	9583
Female-Headed	198	-2612	6852
Male-Headed	1298	-7692	9762

5. Methods

This chapter is divided into two parts. First, we describe our spatial econometric approach. We start with a brief presentation of the baseline spatial econometric model, namely the Spatial Autoregressive (*SAR*) model. We discuss our empirical specification, including our geospatial modeling and explanatory variables, with an emphasis on how we apply the model to the analysis of food security. Second, we explore interactions between gender effects and spatial effects on food security. We modify the baseline *SAR Model* to construct two new types of spatial econometric models. The first model (*Ego-Gender Model*) treats gender in an egocentric perspective, where all neighbors interact to influence gender-specific household-level food security. Specifically, we investigate how all neighbors affect the food security of male-headed households. The second variation of the *SAR Model* is designed to explore homophily (*Gender Homophily Model*), which is the social tendency for similar individuals to have stronger social connections. These models are used to explore how men's food security is influenced by male neighbors, and conversely, how women's food security is affected by their female neighbors.

5.1 Spatial Autoregressive Model

As geographic information systems allow researchers to easily collect geocoded data, the empirical socioeconomic literature is experiencing a mini-revolution, with spatial models becoming popular. The spatial autoregressive model is perhaps the most popular tool in spatial empirical work. To estimate a *SAR model*, observations are characterized by their location, often measured using Global Positioning System (GPS) coordinates. *SAR models* date back to the works of Cliff & Ord (1973), and

Anselin (1988), where outcomes of a spatial system at one specific place depend on those of its neighbors. In other words, the result at one point is determined, in part, by what is happening elsewhere in the system. The model is widely used by social scientists for its ability to capture spatial and social interactions, and peer effects. The *SAR model* is of great interest to economists because it models the interaction between economic agents within a system, thereby allowing for heterogeneous spatial weights captured by a spatial weight matrix (W).

Considering a set of n cross-sectional units, the *SAR model*, can be formally written in matrix notation as:

$$Y = \rho WY + Z\gamma + \varepsilon \qquad (7)$$

where Y is an $n \times 1$ vector of observations on the dependent variable – *food security*, ρ is the spatial autoregression (autocorrelation) parameter, W is a spatial weight matrix (i.e., an $n \times n$ neighborhood matrix that accounts for the spatial interactions (dependencies) among the spatial data), Z is an $n \times k$ matrix of observations on k explanatory variables, γ is a $k \times 1$ vector of regression coefficients, and ε is an $n \times 1$ vector of unobservable error.

5.1.1 Spatial Weights

Our survey instrument collected (confidential) GPS coordinates of the location of each household. This information allows us to construct the spatial weights that are required to estimate a *SAR model*. The spatial weight matrix W indicates, for each location in the system, which of the other sites affect food security at that location (Anselin 2001). The matrix W assigns weights for the influences of each neighbor on a household's food security.

A fundamental assumption in the spatial econometrics literature is a decline in influence among agents as the distance between two observations increases. This is typically captured by weighting spatial connections that are inversely proportional to their distance. We adopt a truncated version of W, where an element $w_{ij} = 0$ if households at locations i and j are further than 20 kilometers apart.[16] This is consistent with other studies in the literature that assume that all households residing in the same geographic region are "neighbors" who can influence each other's food security (e.g., Behrman et al., 2002; Munshi, 2003; Nolin, 2010). Truncation allows the researcher to focus on the immediate neighborhood of each household, where spatial effects are stronger and more likely to influence outcomes, which in our case is food security.

Another common assumption is row-normalization, with the convention that the diagonal is zero. We row-normalize our matrix W so that a row i represents the weights that household i places on the influence of neighbors within 20km, i.e. every element w_{ij} element is between 0 and 1. Collectively, inverse proportionally to distance, truncation, and row-normalization lead to a spatial matrix of the form:

[16] Table A-4 in the Appendix summarizes the spatial distribution of households by showing average and standard deviation of the distance between two households for every region, country and district in our sample. The table shows that the average distance between two households in a district is approximately 24 kilometers, but with large variation. By choosing a distance of 20km we construct a truncation of the matrix that incorporate neighbors that are more likely to influence food security. We also do sensitivity analysis on the assumption of 20 kilometers and discuss these estimations in the results.

$$\begin{cases} w_{ij} = \dfrac{\left(1/d_{ij}\right)}{\left[\sum_j \left(1/d_{ij}\right)\right]} & \text{if} \quad i \neq j \text{ and } d_{ij} < 20 \\ w_{ij} = 0 & \text{if} \quad i = j \text{ or } d_{ij} > 20 \end{cases} \tag{8}$$

where d_{ij} is the distance between household i and j, measured in kilometers.[17]

In the *SAR model*, the main term of interest is WY, the left multiplication of the food security column vector Y by the matrix of spatial weights W. Then, WY is a weighted average of neighbors' food security, where weights increase with proximity. This term is also known as the spatial lag for Y.[18] Therefore, the spatial autoregressive parameter ρ, often referred to as the spatial effect, captures the marginal effect of neighbors' food security on own food security. That is, when neighbors' food security increases by X calories, own food security increases by ρX calories.

5.1.2 Baseline Model Specification

Given the potential effect that spatial interactions may have on a better food security, we are interested in estimating the following *SAR model*:

$$Y_{id} = \rho \sum_j w_{ij} Y_{jd} + X'_{id}\beta + C'_c\theta + D'_d\delta + T'_t\alpha + \varepsilon_{id} \tag{9}$$

where: Y_{id} is the food security of household i located in district d (measured by the calorie gap described in section 4.2); $\sum_j w_{ij} Y_{jd}$ is the spatially weighted food security of i's neighbors; X'_{id} contains the determinants of food security (see section 3.2); C'_c

---

[17] We use the Global Positioning System (GPS) coordinates data to calculate the distance between households. We use the "spmatrix create" command in STATA to create the spatial weighting matrix.

[18] Using scalar notation, the food security of i's neighbors is captured by $\sum_j w_{ij} y_j$. Notice that own food security is not part of the neighbor's outcome because $w_{ii} = 0$.

represents crop fixed effects (see section 3.2.4); D'_d represents district fixed effects (see section 3.2.4); T'_t represents technological fixed effects (see section 3.2.4); $\beta, \theta, \alpha,$ and δ are parameter vectors; ρ is the spatial effect parameter; and ε is an error term that captures unobserved determinants of food security.

5.2 Gender-Specific Spatial Models

In order to integrate gender into our baseline model, we construct two types of models: *Ego-Gender* and *Gender-Homophily*. For both of these types of models, it is useful to discuss some definitions. We will refer to "ego" as a household of reference; the focal position concerning which household's food security is being affected in the model. We assume that each ego household can be either female- or male-headed. All other households located within 20km from the ego are defined as comprising the ego's "neighborhood". Note, that a female ego can have both male- and female-headed neighbors.

5.2.1 Ego-Gender Models

Using an ego-centric perspective, where a household i of gender $g \in \{M, F\}$ is influenced by other households i's neighborhood, the gender spatial mode in scalar notation is:

$$Y_{id}^{g} = \rho^{g}\tilde{Y}_{id}^{g} + X_{id}^{g\prime}\beta^{g} + C_{c}^{g\prime}\theta^{g} + D_{d}^{g\prime}\delta^{g} + T_{t}^{g\prime}\alpha^{g} + \varepsilon_{id}^{g} \qquad (10)$$

where the superscript g indicates that only observations of ego-centric gender g are included in the regression. The variable $\tilde{Y}_{id}^{g}$ represents the weighted average of the food security of the neighborhood of ego observation i of gender g, or simply $\tilde{Y}_{id}^{g} = \sum_j w_{ij}Y_{jd}$ for ego-centric household i of gender g. Note that while all neighbors of i are considered, observation $\tilde{Y}_{id}^{g}$ is calculated only for households of gender g. In other words, model (10) collects the rows of model (7), or the more detailed equivalent specification with fixed effects shown in scalar notation in model (9), with ego-centric gender g.

We estimate a regression model for each gender. This procedure delivers a set of parameters for males and another set for females. For example, we estimate gender-specific spatial effects, captured by ρ^{g}. The parameter ρ^{M} is estimated when model (10) has gender $g = M$ and therefore uses 1298 male ego-centric observations, while ρ^{F} uses 198 female ego-centric observations.[19]

A comparison of ρ from equation (9) and ρ^{g} from equation (10) is informative as it reveals how the average spatial effect ρ differs by gender. As ρ represents the average spatial effect in the entire sample, we expect ρ to be some sort of weighted average of female (ρ^{F}) and male (ρ^{M}) marginal effects. This procedure can be thought of as a decomposition of the overall spatial effect by gender headship of the households.

5.2.2 Gender Homophily Models

Homophily describes a type of spatial interaction that refers to the preference for people to interact with peers and others that they consider to be alike. Homophily has been identified by the literature as a factor that influences agents in many different

---

[19] Note that while 1298 (198) observations are used to estimate the parameters of male (female) model, all 1496 observations are used in computing the variable $\tilde{Y}_{id}^{g} = \sum_{j} w_{ij} Y_{jd}$. A discussion of the estimation strategy is provided below.

ways (Mcpherson et al. 2001). For example, an individual with many smoker friends might be influenced to become a smoker.

Homophily has been extensively studied in sociology, but less so in agricultural economics. An economic perspective of homophily suggests that economic agents that are similar in some socioeconomic or demographic dimension are more likely to influence the decisions of one another. In our context, we are interested in homophily driven by gender and its impacts on food security.

Learning about homophily interactions is essential to a better understanding of food security as it captures a reduced-form arrangement of how social ties grow into complex structures to generate opportunities for sharing and distributing food resources at the community level (Mertens et al. 2015). The different types of interactions individuals carry with one another may act as elements that could leveraged to ease the barriers and constraints to food security. For example, if women are more affected by other women than men, this information could help policy-makers when designing efficient policy interventions.

In homophily models, we are interested in estimating the effect of the food security of neighbors of gender g on the ego household of same gender g. Therefore, not all neighbors are considered when calculating the weighted average of neighbors' food security. Instead, let us define the set of ego-households with gender g as G.[20] We construct the spatial lag measure $\bar{\bar{Y}}_{id}^{g} = \sum_j w_{\{i,j\}\in G} Y_{jd}$, which captures food security as being influenced by spatial interactions, for an ego of gender g. Note that

[20] Recall that G has 198 households in the female set, and 1298 households in the male set.

this equation does not correspond to a row of system (7), as the weight must be recalculated for the case of only one gender.

To calculate the weights $w_{\{i,j\}\in G}$ we construct a new spatial matrix W^G that collects the influences of column individuals on a row individual, where all individuals have the same gender g. Therefore, in the female homophily model, this matrix is a 198×198 square matrix, and a 1298×1298 matrix in the male homophily model. As in the baseline model, the matrix is truncated at 20km, row-normalized, with weights inversely proportional to the distance between $\{i,j\} \in G$.[21] Note that elements $w_{\{i,j\}\in G}$ of W^G are different from elements w of the baseline matrix W in section 5.1, because the matrix W^G considers a subset of households. Therefore, the number of elements in the normalizing sum $\sum_j \left({}^{1}\!/_{d_{ij}} \right)$, $\forall\{i,j\} \in G$ is different from the number of elements in the baseline normalizing sum $\sum_j \left({}^{1}\!/_{d_{ij}} \right)$, $\forall\{i,j\}$ in the sample. As the number of households change, and as a result the normalizing factor changes, the distribution of spatial weights in a row of W^G is different from the distribution of weights in the corresponding row of W. The construction of W^G is based on the concept that the homophily model should contain influences that reflect spatial weights of neighbor j on ego i when j and i have the same gender. Without this normalization, the homophily model would be influenced

---

[21] Formally,

$$\begin{cases} w_{\{i,j\}\in G} = \dfrac{\left({}^{1}\!/_{d_{ij}} \right)}{\left[\sum_j \left({}^{1}\!/_{d_{ij}} \right) \right]} & \text{if} \quad i \neq j \text{ and } d_{ij} < 20, \forall\{i,j\} \in G \\ w_{\{i,j\}\in G} = 0 & \text{if} \quad i = j \text{ or } d_{ij} > 20, \forall\{i,j\} \in G \end{cases}$$

by the number of neighbors each household has, as opposed to considering the shape of the distribution of weights within the neighborhood. Such a model would bias the results if one gender has more neighbors than the other gender and would make it challenging to compare coefficients across models.

The ideas above lead to the following model of gender homophily in spatial effects, shown here in scalar notation $\forall\{i,j\} \in G$:

$$Y_{id}^{g} = \rho_{H}^{g} \sum_{j} w_{\{i,j\}\in G} Y_{jd}^{g} + X_{id}^{g\prime}\beta_{H}^{g} + C_{c}^{g\prime}\theta_{H}^{g} + D_{d}^{g\prime}\delta_{H}^{g} + T_{t}^{g\prime}\alpha_{H}^{g} + \varepsilon_{id}^{g} \qquad (11)$$

A comparison between ρ_{H}^{g} and ρ^{g}reveals, for egos of gender g, how much marginal spatial effects depend on all neighbors, as opposed to how much depends on spatial interactions with gender-homophily interactions.

5.3 Estimation Strategy

Equation (7) reveals that the spatial lag term of the SAR model is correlated with the error term. Even when controls Z are exogenous, the outcomes of neighbors affect the egos' outcomes, and vice-verse, which leads to reverse causality. This situation implies that ordinary least squares estimation of the SAR model delivers biased and inconsistent estimates; a result well established in the spatial econometric literature (Anselin 1988).

There are several approaches available for the estimation of SAR models. Some approaches are more computationally intensive than others; e.g. Maximum likelihood (ML) and Bayesian Markov Chain Monte Carlo (LeSage and Pace 2009). We address the endogeneity of the spatial lag by implementing a GMM/IV strategy, which was first proposed by Kelejian & Prucha (1998; 1999) and is currently well-established in the literature (e.g. Arraiz et al., 2010; Bramoullé et al., 2009). The approach relies on instruments that are constructed as spatial transformations of the data. This approach delivers a powerful identification method under the assumption of exogeneity of Z, it can be easily computed, and, as we will discuss below, it can be adapted to the estimation of gender-specific spatial effects and gender homophily spatial effects.

Specifically, Kelejian & Prucha (1999; 1998) propose an instrumental variable approach implemented via an over-identified GMM. They show that first and second order spatial lags of control variables, namely WZ and W^2Z, respectively, can be used as instruments for the spatial lag of the outcome WY.[22] Therefore, estimation of the parameters of model (9) can be accomplished using a GMM approach with the moment conditions $E[Z'\varepsilon] = 0$, $E[WZ'\varepsilon] = 0$, and $E[W^2Z'\epsilon] = 0$, where $Z = [X, C, D, T]$ is a matrix that captures, respectively, determinants of food security, crop effects, district effects, and technology effects.

Using the same principle, consistent estimation of model (10) can be performed using the subsets of constant-gender of the above moment conditions, i.e. the rows with the same ego-gender of the conditions $E[Z'\varepsilon] = 0$, $E[WZ'\varepsilon] = 0$, and $E[W^2Z'\epsilon] = 0$. Similarly, the GMM estimation of homophily models (equation 11) relies on the restrictions $[Z'\varepsilon] = 0$, $E[W^GZ'\varepsilon] = 0$, and $E[{W^G}^2Z'\epsilon] = 0$.

[22] The first-order spatial lag WZ is the weighted average of the determinants of food security of ego's neighbors (first-order neighbors), and W^2Z is the weighted average of the determinants of food security of the ego's neighbors' neighbors (second-order neighbors). Refer to LeSage & Pace (2009) for a discussion.

6. Results

Table 6-1 shows the results of the three types of models discussed in the previous section: *SAR Model*, *Ego-Gender Models*, and *Gender-Homophily Models*. We divide the presentation into two sections. The first section discusses our estimates of the different types of spatial effects across all models (the top row of results in of Table 6-1). The next section discusses the traditional determinants of food security, again across all three models (the remaining rows of results in Table 6-1). In interpreting the coefficients that follow, recall that our dependent variable represents calorie gaps between reports of household consumed amounts and WHO recommended amounts.

6.1 Spatial Effects Estimates

We start by discussing the estimate of the spatial effect from the *SAR Model* (full sample model in column 1). We estimate a spatial effect parameter $\rho = 0.166$ ($p<0.01$).[23] This result suggests that the food security of neighbors has a positive influence on own food security (i.e., edge food security affects ego food security). Specifically, a household's food security increases by approximately 17 calories in response to an increase of 100 calories in neighbors' food security.

The importance of neighbors in facilitating access to jobs, information, and adaptation has been found in many empirical studies, including Munshi (2003), and

---

[23] Recall that these models are estimated by examining households that live within 20 kilometers of one another. We also did a sensitivity analysis by estimating the *SAR* model with distances of 15 and 25 kilometers. Table A-5 in the Appendix reports the estimates of the *SAR Model* with these assumptions. The coefficients of *Food Security on Neighbors* do not substantially change in comparison with the estimates of the *SAR Model* that we report in Table 6-1.

Table 6-1 Regression Results of the Models

Dependent Variable: Calorie Gap Measure[+]					
	SAR Model	Ego-Gender Models		Gender Homophily Models	
Model	(1)	(2)	(3)	(4)	(5)
Description 1 – Gender of Ego	All	Females	Males	Females	Males
Description 2 – Gender of Edge (neighbors)	All	All	All	Females	Males
Food Security of Neighbors (ρ)	0.166***	0.491***	0.146***	0.684**	0.163***
	(0.044)	(0.124)	(0.041)	(0.291)	(0.038)
Household Characteristics					
Female-Headed Household	-988.492**				
	(496.816)				
Age of Household Head	-42.269***	-1.697	-47.583***	4.531	-47.679***
	(9.642)	(24.143)	(10.782)	(24.973)	(10.682)
Household Size	-1558.375***	-1431.371***	-1566.164***	-1534.631***	-1566.449***
	(125.271)	(248.710)	(134.133)	(222.328)	(133.669)
Household Assets					
Domestic Assets	-22.309	-50.761	-27.729	-56.711	-26.935
	(29.807)	(74.737)	(31.742)	(85.778)	(31.540)
Transport Assets	5.062	104.795***	0.977	108.344***	0.892
	(9.584)	(23.339)	(9.301)	(25.310)	(9.309)
Productive Assets	-12.213	28.233	-24.35	79.706	-24.495
	(32.475)	(114.573)	(34.955)	(116.251)	(35.391)
Household Livelihood Strategies					
Off-farm Income	601.02	1783.541**	466.019	2255.870**	464.166
	(560.737)	(722.775)	(492.517)	(877.453)	(492.212)
Ruminants per Unit of Land	152.080**	160.107	153.826**	156.637	153.748**
	(60.475)	(154.744)	(62.445)	(164.779)	(61.709)
Ruminants per Unit of Land Squared	-2.478***	-5.964	-2.361***	-5.818	-2.367***
	(0.821)	(6.426)	(0.869)	(7.284)	(0.860)
N	1496	198	1298	198	1298

* Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level. Standard errors are clustered at the site level. All regressions include crop, site, and technology fixed effects.

[+] Recall that the Calorie Gap Measure is the difference between the actual daily calorie intake of a household and the recommended calorie intake by the WHO.

Koster & Leckie (2014). Authors like Nolin (2010) or Lee et al., (2018) have found that kinship, proximity, and reciprocal sharing between neighbors all heavily enhance the probability of food sharing between households. However, these studies do not focus on the influence of neighbors on food security, which is the focus of our study.

The results of the *Ego-Gender Models*, are shown in columns (2) and (3) of table 6-1.[24] Specifically, we estimate spatial parameters equal to $\rho = 0.49$ *($p<0.01$)* and $\rho = 0.14$ *($p<0.01$)* for females and males, respectively. Note that for male households, the spatial effect is similar to that of the *SAR model*. Interestingly, female headed households benefit more from their neighbors than their male counterparts. Our results indicate that female farmers' food security increases by 49 calories when neighbors' food security increases by 100 calories. The effect goes down from 49 to only 14 calories for male-headed households. This finding suggests that gendered spatial effects influence food security, and may therefore provide valuable information for policy-makers when designing policy interventions.

The results of the *Gender Homophily Models* are shown in columns (4) and (5). We estimate the spatial effects parameters $\rho = 0.68$ *($p<0.01$)* and $\rho = 0.16$ *($p<0.01$)* for females and males, respectively. Note that the spatial effect for male households is similar to that of the *Ego-Gender* and *SAR* models. In contrast, women benefit more than men from all neighbors. Moreover, results from the *Gender Homophily Model* in column (4) show that women receive a large boost on food security from the spatial interaction with female neighbors. The spatial effect suggests that female-headed

[24] Column numbers also refer to model numbers in the discussion that follows.

household's food security increases by 68 calories in response to an increase of 100 calories in female neighbors' food security. This result supports the idea that homophily may be a factor that influences smallholder farms' food security, but only for women.

Figure 6-1 collects the spatial effects for women and men from the different models. Let $\rho^{(i)}$ denote the spatial coefficient of model i. One way to interpret our results is to define $\Delta_i^G = \rho^{(i)} - \rho^{(1)}$, for $i = 2,3$ as an ego-gender decomposition of the general spatial effect $\rho^{(1)}$. Similarly, $\Delta_i^H = \rho^{(i)} - \rho^{(i-2)}$, for $i = 4,5$ can be thought of as an additional decomposition, this time capturing homophily effects. Note that, for men, $\Delta^G \approx \Delta^H \approx 0$. On the other hand, for women we find that $\Delta^H < \Delta^G < 0$. In summary, our results show that women significantly benefit from their spatial and homophilic interactions (female-female) while the spatial gains for males are not driven by gender or homophily effects.

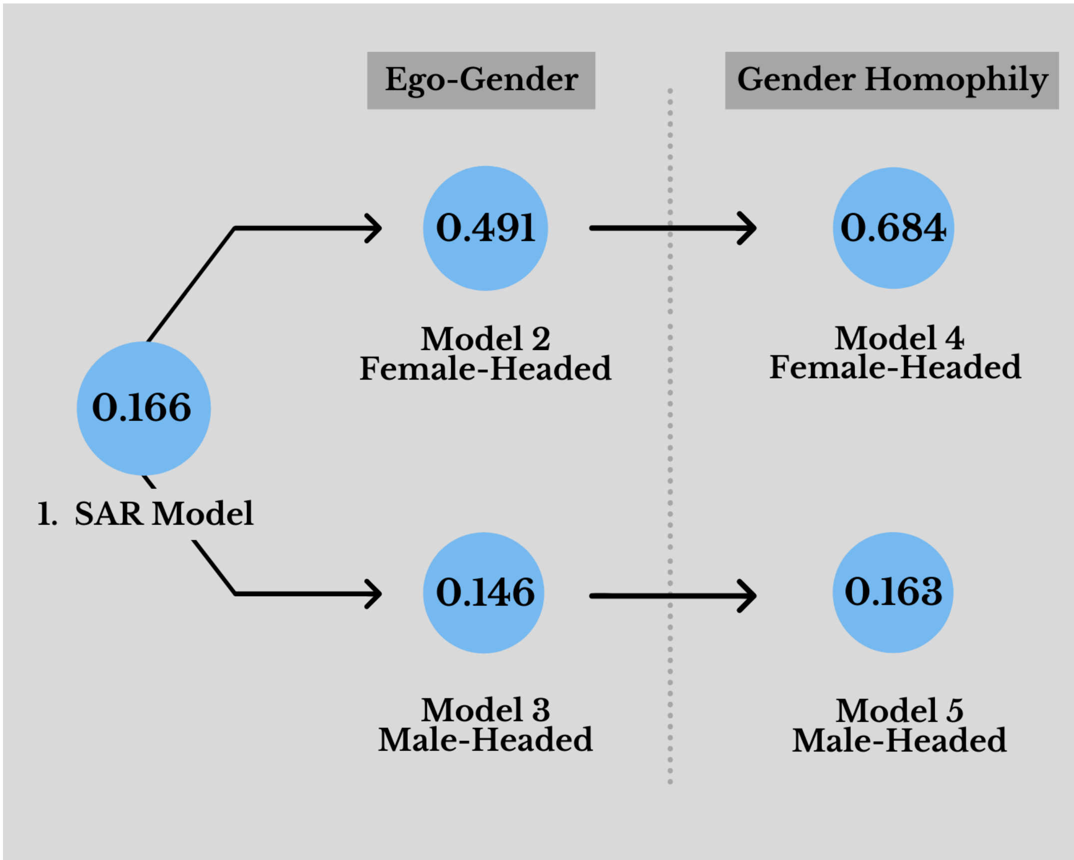
6.2 Traditional Determinants of Food Security

Our estimates in table 6-1 shows that most of the determinants of food security are significant and their signs are in line with the empirical evidence presented in sections two and three. By comparing results of the *SAR Model* in column (1) with models (2) and (3), we are able to gain insights about the impacts of how non spatial determinants vary by gender of the ego household.[25] Below we discuss our results, breaking them down by three categories: household characteristics, assets and livelihood strategies.

---

[25] In comparing results across models, we must be aware of the comparability of coefficients. Comparing coefficients across *Ego-Gender* and *Gender-Homophily* models is problematic because models restrict samples in both ego and edge dimensions. Hence, in the following discussion, we

Figure 6-1 Decomposition of Spatial Effects on Food Security for Women and Men



Note: the numbers in blue circles indicate the spatial effects on food security for female-headed households and male headed households. The numbers are interpreted as the increase of calories for the group of gender-ego when the calories of gender edge (neighbors) increase by 1 calorie.

6.2.1 Household Characteristics

The *SAR Model* in column (1) allows us to estimate, using the full sample, the average difference between food security of a female and male-headed household, controlling for many other factors (e.g. demographics, assets, livestock), including spatial effects. The model allows for the estimation of the direct gender effect on food security using

---

restrict ourselves to coefficients of models (1)-(3) (i.e. the *SAR* and *Ego-Gender* models). Nevertheless, it is reassuring that the covariates in models (4) and (5) are similar to their counterparts, i.e. models (2) and (3), respectively.

the full sample. We find evidence that when a woman is in charge of the household, the household's food security is 990 calories lower. This finding seems contradictory to the summary statistics in Table 4-1, where female-headed households were lees food insecure than male-headed households. However, the summary statistics in table 4-1 show unconditional mean, and the regression controls for other determinants. For example, the gender of the household head is correlated with household size, discussed further below. The differences in results show the importance of controlling for other factors when analyzing gender differences in food security.

This negative impact of *Female-Headed Household* on food security is in line with other studies in the literature (i.e., Babatunde et al. 2008; Kassie et al. 2014; Mallick and Rafi 2010). These results are also consistent with the wide range of constraints, regarding access to land, credit, information, labor, and socio-cultural norms, that contribute to negative consequences for the food security of female-headed households, as discussed in Chapter 2.

We also find that *Age of Household Head* is a significant predictor of food security. The older the head of the household, the lower is their household's food security. The coefficient in model (1) indicates that an additional year of age decreases food security by 42 calories *($p<0.01$)*. Our results are in line with the findings of Bussolo et al. (2015), who note that older farmers cannot work as hard as younger farmers, thereby reducing food security, and with Modirwa and Oladele (2012), who reason that older farmers may be less inclined to adopt modern technologies, and are less adaptive and willing to try new methods than younger people.

In order to gain gender insights into impacts of *age of household head* we compare the age coefficient of the full sample model in column (1) with the *Ego-Gender* results from columns (2) and (3). This comparison indicates that higher ages reduce food security for male-headed households, but not for female-headed households. Gender roles in smallholder farming households may help us understand this result. Typically, women are focused on household tasks and agricultural labour (Duflo 2012), while men are focused on market work and "heavy-lifting" in agricultural activities (Meinzen-dick, Raney and Croppenstedt 2014). Therefore, our differential results could be , for example, a reflection Duflo's (2012) findings, where older males have less access to market income as they age.

With respect to *household size*, model (1) results show that an additional individual in the same household decreases food security by 1558 calories *($p<0.01$)*. This finding is supported by a number of empirical studies that underline the impacts of household size on household's food security (Garrett and Ruel 1999; Feleke, Kilmer and Gladwin 2005; Fekadu and Muche Mequanent 2010; Frelat et al. 2016). Food requirements increase with the number of people in a household thus potentially compromising food security. We find that female-headed households have fewer household members, that explain less food insecurity for female-headed households when comparing with unconditional means in Table 4-1. However, our results contradict other studies that indicate the importance that additional members may have on improving food security (Mallick and Rafi 2010; Duflo and Udry 2004; Modirwa and Oladele 2012). Additional family members add additional labor that can improve production and food security. For instance, Ncube et al. (2016) suggest that children are important in collecting foods or providing some labour for agricultural activities.

Comparing *household size* coefficients across models, we find that impacts are similar across gender. The coefficient in column (1) is very similar to the coefficients of columns (2) and (3), all of which are significant. This comparison indicates that additional family members in the household reduce food security for both female- and male-headed households, as discussed above, but none of those studies investigate results across genders.

6.2.2 Household Assets

Regarding household assets, the full sample model of column (1), does not indicated empirical support that any type of asset, (i.e. *domestic*, *transport*, or *productive*) significantly influence food security. There is mixed evidence in the literature regarding the role of assets in influencing food security. On one hand, assets may have a positive impact on food security because they improve the household wellbeing allowing the exchange of information, access to markets, and enhancing the production (Bryan et al. 2009; Kassie et al. 2014; Gittinger 1990). On the other hand, Silvestri et al. (2015) fail to find significant evidence of an influence of assets on food security.

However, when comparing the full sample estimates of models (1) with those from models (2) and (3), we find that the effect of assets may depend on the gender of the head of the household. While the food security of male-headed households does not seem to benefit from any type of asset, this is not the case for women. Model (2) indicates that *transport assets* are a statistically significant predictor of food security for female-headed households. Results indicate that for every additional *transport asset* (i.e., motorcycle, bicycle, car) owned by a female-headed household, their food security increases by 105 calories. This is in line with the findings that transportation increases women's access to markets, promote access to information and social capital (Kassie et al. 2014), bargaining power (Rubin and Manfre 2014), and safety in travelling (Meinzen-dick et al. 2014).

6.2.3 Household Livelihood Strategies

Off-farm income is another component that is not statistically significant for model (1), but has differential gendered effects as evident from results in model (2) and (3). Though *off-farm income* is not significant for model (3) the *Ego-Gender* male model, it is a significant predictor of female's food security in model (2). We find that female households that earn *off-farm income* gain an additional 1783 calories of food security. Our results are supported by empirical studies that have documented the positive effect of *off-farm income* on women's food security (Tsiboe, Zereyesus and Osei 2016; Dzanku 2019). Tsiboe et al. (2016) find that female-headed households that participate in non-farm work significantly enhance household nutrient availability when compared to males. These effects might be related to the fact that women tend to have the primary responsibility to plan and prepare household meals (Tsiboe et al. 2016), and because households tend to benefit more from women's greater control over resources, than when such resources are controlled by men (Dzanku 2019).

In considering livestock vs. farming livelihood strategies, results from model (1) show that average food security increases (reflected in the positive sign of *Ruminants per Unit of Land*), but at a decreasing rate (reflected in the negative sign of *Ruminants* *per Unit of Land Squared*). For the average household, every additional *Ruminant per Unit of Land* owned by the household, increases food security by of 39 calories.[26] The dependency between livestock and cropland that we highlighted in chapter 3 suggests diminishing returns to scale, that is, an increase in both inputs (livestock and cropland) leads to a less than proportional increase in food security. Our results highlight the role of substitutions between livestock and land size in promoting food security in developing countries (FAO 2018; Maxwell and Wiebe 1998).

Interestingly, *ruminants per unit of land* influence the food security of male, but not female households. For female households, model (2) shows that neither of the coefficients on *ruminants per unit of land* are statistically significant. This finding is supported by empirical studies that underline the importance of male's abilities on income generating from livestock and cropland. Brown (2003) finds that males are in control of buying and selling livestock, while women are generally responsible for caring for them (Ibnouf 2011). Likewise, grazing land is considered key to livestock production in many areas that are generally controlled by men, thereby encouraging men's ability to increase production and make long term investments in livestock production (FAO 2018). These gender roles could cause *Ruminants per Unit of Land* to positively influence the food security of men, but not of women.

[26] The marginal effect is calculated as $39 = 152.08 - 2 * 2.47 * 38.5$, where 152.08 and 2.47 are the coefficients on ruminants per acre and ruminants per acre squared, and 38.5 is the average ruminant per acre for the sample.

7. Conclusions

7.1 Summary and Discussion

Food security is an essential component of welfare and, as such, has been extensively studied in the literature. Empirical papers have examined a number of determinants of food security, including the role of gender. However, empirical evidence regarding the potential importance of spatial effects on food security, and the interactions of these effects with gender, have not been explored. Spatial interactions have the potential to improve the food security of smallholder farmers, where neighbors may provide positive spillovers to enhance food security. Moreover, gendered relationships among households could be influencing these spillover effect. We are unaware of any study that has investigated influences of spatial effects on food security with gendered dimensions. In this paper, we address this gap in the literature by exploring whether gendered and homophily (i.e. people with similar characteristics influencing one another) spatial interactions play a role in influencing food security. Therefore, the primary goal of this research is to investigate the role of neighbors, and gendered spatial interactions, on food security. We design empirical models to make three main contributions to the literature.

The first contribution is to include spatial effects as an element of explaining food security with a *SAR Model.* We employ a rich data set from the IMPACT Lite survey collected in three developing regions (i.e. East Africa, West Africa, and South Asia). Along with traditional determinants of food security, we find a positive and significant spatial effect on the food security of households. Specifically, for every 100 additional calories that neighbors consume, own food security increases by 17 calories. This result implies that spatial effects of neighbors generate a positive spillover effect as they improve others' food security. The relevance and magnitude of spatial effects in influencing food security suggest that spatial interactions are fundamental aspects of food security. As such, understanding these effects can help in the design of policy interventions.

Using the full sample *SAR Model*, we find that being a female-headed household is associated with consuming almost one thousand less calories, *ceteris paribus*, than male-headed households. This result is in sharp contrast with summary statistics presented in table 4-1, where the average calorie gap is -7,019 calories for male-headed households, and -2612 for female-headed households. The unconditional means indicate female-headed households are overall more food secure than male-headed households. However, unconditional means are plagued with the omission of a number of confounding variables that can mask the real challenges faced by women. In the *SAR Model*, we measure the male- and female-headed household calorie gap controlling for other factors (e.g. household size and assets). This analysis shows that gender (female) of the household head has a negative impact on the conditional mean of food security, confirming results in the literature that suggest that women in rural regions of developing countries face additional barriers when compared to men.

The second contribution is to include gendered spatial interactions as elements of food security. Our *Ego-Gender* approach demonstrates that women-headed households benefit more from their neighbors than male-headed households. Notably, the food security of female-headed households increases by 49 calories when neighbors' food security increases by 100 calories, while male-headed households increase far less at 15% (a result similar to the non-gendered SAR model). Insights into these differing results may be gleaned from literature on gendered social capital that suggests women's relationships are characterized by people who know each other well, and relationships among men are comprised of people who are not well connected (Hanson and Blake 2009). This difference could explain why spatial interactions are more important for women. This result also suggests that policy interventions that are directed to areas with more female-headed households could have larger effects on food security, no matter whether the intervention is directed to male or female-headed households.

The third contribution is to include homophily spatial effects as elements of food security. Our *Gender Homophily* model demonstrates that female-headed households benefit more from female-headed neighbors, than from male-headed neighbors. Specifically, the food security of female-headed households increases by 68 calories in response to an increase of 100 calories in female-headed neighbors' food security, while male-headed household calories increase by 16% (again, a result consistent with the non-gendered SAR model). In situations where developments projects are budget constrained and seeking to target resources, this spatial effect for women could induce policy-makers seeking to improve food security to design gender-clustered policies, i.e. redirecting their efforts towards female-headed households, surrounded by female-headed neighbors.

The importance of our results is magnified when considering that women are crucial for development. Duflo (2012) highlights two rationales regarding why it is important to support active policies that promote women. First, women tend to be worse-off than men, and this inequality between genders is unethical. Second, it is necessary to reduce the gender gap, not only in food security, but also in education and employment opportunities, because such changes will have beneficial consequences on many other development outcomes. Our results show that improving food security has spatial multipliers that help all households, but that these spatial multipliers help female-headed households more; especially if the spillover is between two female-headed households (i.e. homophily). This is encouraging news for development, because policies that aim to target aid can have the largest positive spillover effects where they are needed most.

While targeted policy efforts towards promoting women's access to a wide range of resources seems critical for promoting food security and development, complementary efforts within spatial effects on food security could play an important role. For example, development programs that have tried to build social capital among women (e.g. women self-help groups, or support for women's cooperatives) appear to be working and helping to create large spillover effects. Along these lines, new programs to promote food security may be more effective if they include means of strengthening social capital as an amplifying mechanism for pursuing food security.

In summary, food insecurity is a development problem that would benefit from having policy-makers be aware of gendered-spatial impacts. Our investigation demonstrates that spatial effects can have positive consequences for women's food security. Therefore, it is germane to understand the complexities that involve interactions among women and their influence on food security concerns. Based on these findings, potential policy solutions include the strengthening of social capital of female-headed households, which could facilitate spatial spillover effects that boost their food security, and that potentially could ensure significant progress in important development dimensions for women.

7.2 Limitations and Future Research

It is important to note a number of limitations of this study, many of which suggest directions for future research. Our rich dataset includes numerous traditional determinants of food security, and different types of controls (i.e. districts, crops, and agriculture technology) that account for relevant (observable and unobservable) determinants of food security. However, omitted variable bias is frequently a concern in models with observational (non-experimental) data. Such omissions can cause the models to attribute effects of missing variables on those variables that are included. This econometric problem suggests that a valuable extension to our work could be to design randomized control trials (RCTs). Nonetheless, our results are comparable with those from the food security literature (Knueppel et al. 2010; Wijk et al. 2018; Lee et al. 2018) where most papers rely on cross-sectional data and are also vulnerable to biases from unobserved household level heterogeneities and confounding factors. Moreover, our results reflect an expansive dataset representing multiple countries, a scale that would be costly to replicate within a RCT framework.

Though our dataset allows us to explore a large and far-ranging sample, it was limited in that some countries, (i.e. Uganda, Ethiopia, Burkina Faso) from the IMPACT Lite survey were missing reliable GPS coordinates. Another limitation is that only 198 of the sampled households are female-headed. Though our results are strongly statistically significant, and robust to various model specifications, future research could implement stratified sampling to increase the sample of female-headed households. As discussed above, there may also be problems associated with using recall data. Though costly, future data collection could consider easing recall requirements by using more frequent sampling covering shorter periods.

While our study offers policy relevant and generalizable results about gendered spatial effects and food security, our results also point to other areas of future research. Fundamentally, the positive implication of spatial effects on food security suggests that such considerations are important in the future specification of models. Our approach also shows that there are more spatial benefits for female-headed households, than male-headed households, but it would also be beneficial to incorporate more nuanced information regarding neighbors' interactions. The use of a social network approach, with more nuanced data about interactions, could reveal peer effects from a variety of relationships within a community rather than focusing on the spatial dimension (Johny, Wichmann and Swallow 2017).

In summary, our results show that women-headed households tend to be more food insecure than male-headed households, and that spillover effects help to improve the gender food security gap. This is promising news for development, and can help policy-makers in the design of programs that aim to target support to make use of spillover effects in developing countries. Along these lines, our results suggest that women's social capital could be crucial in influencing the efficacy of aid programmes on food security.

Bibliography

Alatas, V., A. Banerjee, A.G. Chandrasekhar, R. Hanna, and B.A. Olken. 2016. "Network structure and the aggregation of information:theory and evidence from Indonesia." *American Economic Review* 106(7):1663–1704.

Ambikapathi, R., J.D. Rothstein, P.P. Yori, M.P. Olortegui, G. Lee, M.N. Kosek, and L.E. Caulfield. 2018. "Food purchase patterns indicative of household food access insecurity, children's dietary diversity and intake, and nutritional status using a newly developed and validated tool in the Peruvian Amazon." *Food Security* 10(4):999–1011.

Ambrus, B.A., M. Mobius, and A. Szeidl. 2014. "Consumption Risk-Sharing in Social Networks." *American Economic Review* 104(1):149–182.

Anselin, L. 1988. *Spatial Econometrics: Methods and Models*. Dordrecht: Springer Science & Business Media.

Anselin, L. 2001. "Spatial Econometrics." In B. H. Baltagi, ed. *A companion to theoretical Econometrics*. Blackwell Publishing Ltd., pp. 310–330.

Anselin, L. 2003. "Spatial Externalities, Spatial Multipliers, and Spatial Econometrics." *International Regional Science Review* 26(2):153–166.

Anselin, L., and D. Arribas-Bel. 2013. "Spatial Fixed Effects and Spatial Dependence in a Single Cross-Section." *Papers in Regional Science* 92(1):3–17.

Arraiz, I., D.M. Drukker, H.H. Kelejian, and I.R. Prucha. 2010. "A Spatial Cliff-Ord-Type Model with Heteroskedastic Innovations: Small and Large Sample Results." *Journal of Regional Science* 50(2):592–614.

Attanasio, B.O., A. Barr, and J.C. Cardenas. 2012. "Risk Pooling, Risk Preferences, and Social Networks." *American Economic Journal: Applied Economics* 4(2):134–167.

Babatunde, R.O., O.A. Omotesho, E.O. Olorunsanya, and G.M. Owotokit. 2008. "Determinants of vulnerability to food insecurity: A gender-based analysis of farming households in Nigeria." *Indian Journal of Agricultural Economics*

63(1):116–125.

Bajracharya, B. 2008. *Institutional Factors that Influence Access of the Poor to Forest Benefits : Case Studies of Community and Leasehold Forestry Regimes in Nepal*. Massey University, New Zealand.

Banerjee, A., A.G. Chandrasekhar, E. Duflo, and M.O. Jackson. 2013. "The Diffusion of Microfinance." *Science* 341.

Banna, J.C., and M.S. Townsend. 2011. "Assessing Factorial and Convergent Validity and Reliability of a Food Behaviour Checklist for Spanish-Speaking Participants in US Department of Agriculture Nutrition Education Programmes." *Public Health Nutrition* 14(7):1165–1176.

Barrett, C.B., and M.A. Constas. 2014. "Toward a Theory of Resilience for International Development Applications." *Proceedings of the National Academy of Sciences of the United States of America* 111(40):14625–14630.

Behrman, J.R., H.P. Kohler, and S.C. Watkins. 2002. "Social Networks and Changes in Contraceptive Use Over Time: Evidence from a Longitudinal Study in Rural Kenya." *Demography* 39(4):713–738.

Bezner Kerr, R., J. Kangmennaang, L. Dakishoni, H. Nyantakyi-Frimpong, E. Lupafya, L. Shumba, R. Msachi, G.O. Boateng, S.S. Snapp, A. Chitaya, E. Maona, T. Gondwe, P. Nkhonjera, and I. Luginaah. 2019. "Participatory Agroecological Research on Climate Change Adaptation Improves Smallholder Farmer Household Food Security and Dietary Diversity in Malawi." *Agriculture, Ecosystems and Environment* 279:109–121.

Bramoullé, Y., H. Djebbari, and B. Fortin. 2009. "Identification of Peer Eeffects Through Social Networks." *Journal of Econometrics* 150(1):41–55.

Bramoulle, Y., A. Galeotti, and B. Rogers. 2016. *The Oxford Handbook of the Economics of Networks*. Oxford University Press.

Brown, S. 2003. "Spatial Analysis of Socioeconomic Issues : Gender and GIS in Nepal." *Mountain Research and Development* 23(4):338–344.

Bryan, E., T.T. Deressa, G.A. Gbetibouo, and C. Ringler. 2009. "Adaptation to

Climate Change in Ethiopia and South Africa: Options and Constraints." *Environmental Science and Policy* 12(4):413–426.

Bussolo, M., J. Koettl, E. Sinnott, J. Koettl, S. Sharma, O. Kupets, A. Mattoo, C. Ozden, and J.M.M.G. yn. Vigo. 2015. "The Effects of Aging on Productivity: Diverse, Not Alarming." In *Golden Aging: Prospects for Healthy, Active, and Prosperous Aging in Europe and Central Asia*. World Bank Publications, pp. 167–212.

Buvinić, M., and G.R. Gupta. 1997. "Female-Headed Households and Female-Maintained Families : Are They Worth Targeting to Reduce Poverty in Developing Countries ?" *Economic Development and Cultural Change* 45(2):259–280.

Chen, M., B. Wichmann, M. Luckert, L. Winowiecki, W. Förch, and P. Läderach. 2018. "Diversification and Intensification of Agricultural Adaptation from Global to Local Scales." *PLoS ONE* 13(5):1–27.

Cissé, J.D., and C.B. Barrett. 2018. "Estimating Development Resilience: A Conditional Moments-Based Approach." *Journal of Development Economics* (236):272–284.

Cliff, A.D., and J.K. Ord. 1973. *Spatial Autocorrelation*. London: Pion.

Coates, J., R. Houser, and P. Webb. 2003. "Measuring Food Insecurity : Going Beyond Indicators of Income and Anthropometry." Food And Nutrition Technical Assistance Project, FHI 360

Coates, J., P.E. Wilde, P. Webb, B.L. Rogers, and R.F. Houser. 2006. "Comparison of a Qualitative and a Quantitative Approach to Developing a Household Food Insecurity Scale for Bangladesh." *The Journal of Nutrition* 136(5):1420S-1430S.

Conley, T.G., and C.R. Udry. 2010. "Learning About a New Technology: Pineapple in Ghana." *American Economic Review* 100(1):35–69.

Crost, B., B. Shankar, R. Bennett, and S. Morse. 2007. "Bias from Farmer Self-Selection in Genetically Modified Crop Productivity Estimates: Evidence from Indian Data." *Journal of Agricultural Economics* 58(1):24–36.

Crush, J., A. Hovorka, and D. Tevera. 2011. "Food security in Southern African Cities: The Place of Urban Agriculture." *Progress in Development Studies* 11(4):285–305.

Dassanayake, W., M.K. Luckert, and S. Mohapatra. 2015. "Heterogeneity of Household Structures and Income: Evidence from Zimbabwe and South Africa." *Journal of Policy Modeling* 37(4):668–692.

Deere, C.D., A.D. Oduro, H. Swaminathan, and C. Doss. 2013. "Property Rights and the Gender Distribution of Wealth in Ecuador, Ghana and India." *Journal of Economic Inequality* 11(2):249–265.

Doss, C., and M.L. Morris. 2000. "How Does Gender Affect the Adoption of Agricultural Innovations? The Case of Improved Maize Technology in Ghana." *Agricultural Economics* 25(1):27–39.

Doss, C., G. Summerfield, and D. Tsikata. 2014. "Land, Gender, and Food Security." *Feminist Economics* 20(1):1–23.

Doss, C.R. 2001. "Designing Agricultural Technology for African Women Farmers: Lessons from 25 years ofEexperience." *World Development* 29(12):2075–2092.

Drèze, J., and P. V. Srinivasan. 1997. "Widowhood and Poverty in Rural India: Some Inferences from Household Survey Data." *Journal of Development Economics* 54(2):217–234.

Duflo, E. 2012. "Women Empowerment and Economic Development." *Journal of Economic Literature* 50(4):1051–1079.

Duflo, E., and C. Udry. 2004. "Intrahousehold Resource Allocation in Cote d'Ivoire : Social Norms , Separate Accounts and Consumption Choices." National Bureau of Economic Research No. 10498,

Dzanku, F.M. 2019. "Food Security in Rural Sub-Saharan Africa: Exploring the Nexus Between Gender, Geography and Off-Farm Employment." *World Development* 113:26–43.

Engle, P.L., and I. Nieves. 1993. "Intra-Household Food Distribution Among Guatemalan Families in a Supplementary Feeding Program: Behavior Patterns."

Social Science and Medicine 36(12):1605–1612.

Etwire, P.M., W. Dogbe, A.N. Wiredu, E. Martey, E. Etwire, R.K. Owusu, and E. Wahaga1. 2013. “Factors Influencing Farmer’s Participation in Agricultural Projects: The case of the Agricultural Value Chain Mentorship Project in the Northern Region of Ghana.” *Journal of Economics and Sustainable Development* 4(10):36–43.

Fafchamps, M. 2011. “Risk sharing between households.” In *Handbook of Social Economics*. Elsevier, p. 940.

FAO. 2006. “Food Security - Policy Brief.” (2):1–4.

FAO. 1997. *Women: The Key to food security*. Rome, Italy.

FAO. 2018. *World Livestock: Transforming the livestock sector through the Sustainable Development Goals*.

FAO. 2011. *World Livestock 2011- Livestock in Food Security* A. McLeod, ed. Rome.

FAO, IFAD, UNICEF, WFP, and WHO. 2018. *Review of The State of Food Security and Nutrition in the World, 2018*. Rome: FAO.

Fekadu, B., and Muche Mequanent. 2010. “Determinants of Food Security Among Rural Households of Central Ethiopia: An Empirical Analysis.” *Quarterly Journal of International Agriculture* 49(4):299–318.

Feleke, S.T., R.L. Kilmer, and C.H. Gladwin. 2005. “Determinants of Food Security in Southern Ethiopia at the Household Level.” *Agricultural Economics* 33:351–363.

Förch, W., K. Patti, P. Thornton, and K. Jusper. 2011. “Initial Sites in the CCAFS Regions : Eastern Africa , West Africa and Indo-Gangetic Plains, Version 2.”

Foster, A.D., and M.R. Rosenzweig. 1995. “Learning by Doing and Learning from Others : Human Capital and Technical Change in Agriculture.” *Journal of Political Economy* 103(6):1176–1209.

Frelat, R., S. Lopez-Ridaura, K.E. Giller, M. Herrero, S. Douxchamps, A.A. Djurfeldt, O. Erenstein, B. Henderson, M. Kassie, B.K. Paul, C. Rigolot, R.S.

Ritzema, D. Rodriguez, P.J.A. Van Asten, and M.T. Van Wijk. 2016. "Drivers of Household Food Availability in Sub-Saharan Africa Based on Big Data from Small Farms." *Proceedings of the National Academy of Sciences of the United States of America* 113(2):458–463.

Garrett, J.L., and M.T. Ruel. 1999. "Are Determinants of Rural and Urban Food Security and Nutritional Status Different? Some Insights from Mozambique." *World Development* 27(11):1955–1975.

Gittinger, J.P. 1990. "Household Food Security and the Role of Women." World Bank Discussion Papers

Grootaert, C., and D. Narayan. 2004. "Local Institutions, Poverty and Household Welfare in Bolivia." *World Development* 32(7):1179–1198.

Guyer, J.I. 1980. "Household Budgets and Women's Incomes." *African Studies Center* (28).

Hallman, K. 2003. "Mother-Father Resources, Marriage Payments, and Girl-Boy Health in Rural Bangladesh." *Household Decisions, Gender, and Development: A Synthesis of Recent Research* (93):115–120.

Hanson, S., and M. Blake. 2009. "Gender and Entrepreneurial Networks." *Regional Studies* 43(1):135–149.

Holmes, B.R., N. Jones, and H. Marsden. 2009. "Gender Vulnerabilities, Food Price Shocks and Social Protection Responses." (1):1–12.

Ibnouf, F.O. 2011. "Challenges and Possibilities for Achieving Household Food Security in the Western Sudan Region: The Role of Female Farmers." *Food Security* 3(2):215–231.

Ilahi, N. 2000. "The Intra-household Allocation of Time and Tasks: What Have We Learnt from the Empirical Literature?" *World Bank*:1–48.

Immink, M.D.C., and J.A. Alarcon. 1991. "Household Food Security, Nutrition and Crop Diversification Among Smallholder Farmers in the Highlands of Guatemala." *Ecology of Food and Nutrition* 25(4):287–305.

Johny, J., B. Wichmann, and B.M. Swallow. 2017. “Characterizing social networks and their effects on income diversification in rural Kerala, India.” *World Development* 94:375–392.

Kassie, M., S.W. Ndiritu, and J. Stage. 2014. “What Determines Gender Inequality in Household Food Security in Kenya? Application of Exogenous Switching Treatment Regression.” *World Development* 56:153–171.

Kassie, M., J. Stage, H. Teklewold, and O. Erenstein. 2015. “Gendered Food Scurity in Rural Malawi: Why is Women’s Food Security Status Lower?” *Food Security* 7(6):1299–1320.

Katungi, E., S. Edmeades, and M. Smale. 2008. “Gender, Social Capital and Information Exchange in Rural Uganda.” *Journal of iIternational Development* 168(20):35–52.

Kelejian, H.H., and I.R. Prucha. 1998. “A Generalized Spatial Two-Stage Least Squares Procedure for Estimating a Spatial Autoregressive Model with Autoregressive Disturbances.” *Journal of Real Estate Finance and Economics* 17(1):99–121.

Kelejian, H.H., and N.R. Prucha. 1999. “A Generalized Moments Estimator for the Autoregressive Parameter in a Spatial Model.” *International Economic Review* 40(2):509–533.

Kennedy, E., and P. Peters. 1992. “Household Food Security and Child Nutrition: the Interaction of Income and Gender of Household Head.” *World Development* 20(8):1077–1085.

Knueppel, D., M. Demment, and L. Kaiser. 2010. “Validation of the Household Food Insecurity Access Scale in Rural Tanzania.” *Public Health Nutrition* 13(3):360–367.

Koster, J.M., and G. Leckie. 2014. “Food Sharing Networks in Lowland Nicaragua : An Application of the Social Relations Model to Count Data.” *Social Networks* 38:100–110.

Krishnan, P., and M. Patnam. 2014. “Neighbors and Extension Agents in Ethiopia:

Who Matters More for Technology Adoption?” *American Journal of Agricultural Economics* 96(1):308–327.

Larson, J.B., P. Castellanos, and L. Jensen. 2019. “Gender, Household Food Security, and Dietary Diversity in Western Honduras.” *Global Food Security* 20:170–179.

Lastarria-Cornhiel, S. 1997. “Impact of Privatization on Gender and Property Rights in Africa.” *World Development* 25(8):1317–1333.

Lee, G.O., P.J. Surkan, J. Zelner, M. Paredes Olórtegui, P. Peñataro Yori, R. Ambikapathi, L.E. Caulfield, R.H. Gilman, and M.N. Kosek. 2018. “Social Connectedness is Associated with Food Security Among Peri-Urban Peruvian Amazonian Communities.” *SSM - Population Health* 4:254–262.

Lemke, S., H. Vorster, N.J. van Rensburg, and J. Ziche. 2003. “Empowered Women, Social Networks and the Contribution of Qualitative Research: Broadening our Understanding of Underlying Causes for Food and Nutrition Insecurity.” *Public Health Nutrition* 6(8):759–764.

LeSage, J., and R.K. Pace. 2009. *Introduction to Spatial Econometrics*. CRC Press.

Little, P.D., M.P. Stone, T. Mogues, A.P. Castro, and W. Negatu. 2006. “Moving in Place: Drought and Poverty Dynamics in South Wollo, Ethiopia.” *Journal of Development Studies* 42(2):200–225.

Mallick, D., and M. Rafi. 2010. “Are Female-Headed Households More Food Insecure? Evidence from Bangladesh.” *World Development* 38(4):593–605.

Maluccio, J., L. Haddad, and J. May. 2003. “Social Capital and Gender in South Africa, 1993-98.” In *Household Decisions, Gender, and Development: A synthesis of recent research*. Washington D.C.: International Food Policy Research Institute (IFPRI), pp. 145–152.

Mason, J. 2002. “Measuring Hunger and Malnutrition.” Measurement and Assesment of Food Deprivation and Undernutrition, FAO

Mason, R., P. Ndlovu, J.R. Parkins, and M.K. Luckert. 2015. “Determinants of Food Security in Tanzania: Gendered Dimensions of Household Headship and Control of Resources.” *Agriculture and Human Values* 32(3):539–549.

Maxwell, D., and K. Wiebe. 1998. “Land Tenure and Food Security : A Review of Concepts , Evidence , and Methods.” *Land Tenure Center University of Wisconsin - Madison* (129):41.

McDonald, S. 2011. “What’s in the ‘Old Boys’ Network? Accessing Social Capital in Gendered and Racialized Networks.” *Social Networks* 33(4):317–330.

Mcpherson, M., L. Smith-lovin, and J.M. Cook. 2001. “Birds of a Feather : Homophily in Social Networks.” *Annual Review of Sociology* 27:415–444.

Meinzen-dick, A.R.Q.R., T.L. Raney, and A. Croppenstedt. 2014. *Gender in Agriculture*.

Meinzen-Dick, R., A.R. Quisumbing, T.L. Raney, A. Croppenstedt, J.A. Behrman, and A. Peterman. 2014. “The Gender Asset Gap and Its Impications for Agricultural and Rural Development.” In *Gender in Agriculture: Closing the Knowledge Gap*. Springer Science & Business, pp. 1–444.

Meinzen-Dick, R., and M. Zwarteveen. 1998. “Gendered Participation in Water Management: Issues and Illustrations from Water Users’ Associations in South Asia.” *Agriculture and Human Values* 15(4):337–345.

Mertens, F., M. Fillion, J. Saint-charles, P. Mongeau, R. Távora, C. José, S. Passos, and D. Mergler. 2015. “The Role of Strong-Tie Social Networks in Mediating Food Security of Fish Resources by a Traditional Riverine Community in the Brazilian Amazon.” *Ecology and Society* 20(3).

Migotto, M., B. Davis, G. Carletto, K. Beegle, E.S.A. Working, and P. No. 2005. “Measuring Food Security Using Respondents ’ Perception of Food Consumption Adequacy.” *ESA Working Paper No. 05-10*.

Millimet, D.L., I.K. McDonough, and T.B. Fomby. 2018. “Financial Capability and Food Security in Extremely Vulnerable Households.” *American Journal of Agricultural Economics* 100(4):1224–1291.

Modirwa, S., and O.I. Oladele. 2012. “Food Security among Male and Female-headed Households in Eden District Municipality of the Western Cape, South Africa.” *Journal of Human Ecology* 37(1):29–35.

Moore, D.P. 1990. “An Examination of Present Research on the Female Entrepreneur: Suggested Research Strategies for the 1990’s.” *Journal of Business Ethics* 9(4):275–281.

Munshi, K. 2003. “Networks in the Modern Economy : Mexican Migrants in the U . S . Labor Market.” *Quarterly Journal of Economics* 118(2):549–599.

Ncube, K., C.M. Shackleton, B.M. Swallow, and W. Dassanayake. 2016. “Impacts of HIV / AIDS on Food Consumption and Wild Food Use in Rural South Africa.” *Food Security* 8(6):1135–1151.

Ndlovu, P., S. Mohapatra, and M. Luckert. 2018. “Income Effects on Intra-Household Time Allocation: Regression Discontinuity Evidence.” *Journal of International Development* 30(4):713–719.

Njuki, J., J. Poole, N. Johnson, I. Baltenweck, P. Pali, and S. Mburu. 2011. “Gender , Livestock and Livelihood Indicators.”

Nolin, D.A. 2010. “Food-Sharing Networks in Lamalera, Indonesia.” *Human Nature* 21(3):243–268.

Parasuraman, S., and T. Rajaretnam. 2011. “Agriculture, Food Security and Nutrition in Vidarbha: A Household Level Analysis.” *Economic and Political Weekly* 46(19):42–50.

Podolny, J.M. 2010. *Status Signals: A Sociological Study of Market Competition*. Princeton University Press.

Qiu, F., B. Swallow, S. Jeffrey, and L. Laliberté. 2015. “Impacts of Fragmentation and Neighbor Influences on Farmland Conversion: A Case Study of the Edmonton-Calgary Corridor, Canada.” *Land Use Policy* 48:482–494.

Quisumbing, A.R. 1996. “Modeling Household Behavior in Developing Countries: Discussion.” *American Journal of Agricultural Economics* 78(5):1346–1348.

Quisumbing, A.R., L.R. Brown, H.S. Feldstein, L. Haddad, and C. Peña. 1996. “Women: The Key to Food Security.” *Food and Nutrition Bulletin* 17(1):1–2.

Quisumbing, A.R., and J.A. Maluccio. 2003. “Resources at Marriage and

Intrahousehold Allocation: Evidence from Bangladesh, Ethiopia, Indonesia, and South Africa.” *Oxford Bulletin of Economics and Statistics* 65(3):283–327.

Rafiei, M., M. Nord, A. Sadeghizadeh, and M.H. Entezari. 2009. “Assessing the Internal Validity of a Household Survey-Based Food Security Measure Adapted for Use in Iran.” *Nutrition Journal* 8(1).

Rao, N. 2005. “Gender Equality , Land Rights and Household Food Security Discussion of Rice Farming Systems.” *Economic And Political Weekly* 40(25):2513–2521.

Ribot, J.C. 2002. *Institutionalizing Popular Participation*. Washington DC: World Resources Institute.

Rubin, D., and C. Manfre. 2014. “Promoting Gender-Equitable Agricultural Value Chains: Issues, Opportunities, and Next Steps.” In *Gender in Agriculture*. Springer, Dorddrecht, pp. 287–313.

Rufino, M.C., C. Quiros, N. Teufel, S. Douxchamps, S. Silvestri, J. Mango, A.S. Moussa, and M. Herrero. 2012. “Household Characterization Survey – IMPACTlite Training Manual.” (December):1–45.

Sansoucy, R. 1995. “Livestock - A Driving Force for Food Security and Sustainable Development.” *FAO*.

Schlenker, W., and M.J. Roberts. 2006. “Nonlinear Effects of Weather on Corn Yields.” *Review of Agricultural Economics* 28(3):391–398.

Silvestri, S., D. Sabine, K. Patti, F. Wiebke, R. Maren, M. Ianetta, Q.F. Carlos, H. Mario, N. Anthony, N. Nicolas, M. Joash, C. Lieven, and M.C. Rufino. 2015. “Households and Food Security: Lessons from Food Secure Households in East Africa.” *Agriculture and Food Security* 4(1).

Spencer, E., J. Brassey, and K. Mahtani. 2017. “Recall Bias.” *Catalogue of Bias*. Available at: https://catalogofbias.org/biases/recall-bias/#cite.

Sraboni, E., H.J. Malapit, A.R. Quisumbing, and A.U. Ahmed. 2014. “Women’s Empowerment in Agriculture: What Role for Food Security in Bangladesh?” *World Development* 61:11–52.

Stehlé, J., F. Charbonnier, T. Picard, C. Cattuto, and A. Barrat. 2013. "Gender Homophily from Spatial Behavior in a Primary School: A Sociometric Study." *Social Networks* 35(4):604–613.

Tibesigwa, B., and M. Visser. 2016. "Assessing Gender Inequality in Food Security Among Small-Holder Farm Households in Urban and Rural South Africa." *World Development* 88:33–49.

Tsiboe, F., Y.A. Zereyesus, and E. Osei. 2016. "Non-farm Work, Food Poverty, and Nutrient Availability in Northern Ghana." *Journal of Rural Studies* 47:97–107.

Udry, C. 1996. "Gender , Agricultural Production , and the Theory of the Household." *Journal of Political Economy* 104(5):1010–1046.

Upton, J.B., J.D. Cissé, and C.B. Barrett. 2016. "Food Security as Resilience: Reconciling Definition and Measurement." *Agricultural Economics* 47:135–147.

USAID. 2011. "Food Security and Gender." *Fact Sheet Food Security and Gender*.

Wiesmann, D., L. Bassett, T. Benson, and J. Hoddinott. 2009. "Validation of the World Food Programme's Food Consumption Score and Alternative Indicators of Household Food Security." *International Food Policy Research Institute*:1–105.

Wijk, M.V.., J. Hammond, R. Frelat, S. Fraval, N. Teufel, K. Tavenner, and B. Henderson. 2018. "Smallholder Farmers , Food Security , and Livelihoods : Exploring Trade offs and Synergies Using Farm Household Characterization Data." *Science Forum 2018*:1–10.

World Bank, IFAD, and FAO. 2008. "Gender and Food Security." In *Gender in Agriculture Sourcebook*. World Bank Publications, pp. 11–22.

Yen, S.T., M. Andrews, Z. Chen, and D.B. Eastwood. 2008. "Food Stamp Program Participation and Food Insecurity: An Instrumental Variables Approach." *American Journal of Agricultural Economics* 90(1):117–132.

Appendix

Table A-1 Household Asset Index

Asset (g)	Weight of asset (ω_g)	Age (Adjustment for age) (a)		
		< 3 yrs. old	3-7 yrs. old	>7 yrs. old
Domestic assets				
Stove	2	x 1	x 0.8	x 0.5
Refrigerator	4			
Radio	2			
Television	4			
DVD player	4			
Cellphone	3			
Sofa	1			
Mosquito nets	1			
Transport assets		< 3 yrs. old	3-7 yrs. old	>7 yrs. old
Car/truck	160	x 1	x 0.8	x 0.5
Motorcycle	48			
Bicycle	6			
Cart (animal drawn)	12			
Productive assets		< 3 yrs. old	3-7 yrs. old	>7 yrs. old
Hoes	1	x 1	x 0.8	x 0.5
Spades/shovels	1			
Ploughs	4			
Water pump	6			
Panga/machete	1			
Sewing machine	4			

Source: Adapted from Gender, Livestock and Livelihood Indicators (2011)

Table A-2 Descriptive Statistics of District, Crop, and Technological Fixed Effects

	Mean	Standard Deviation
District Fixed Effects		
Birkelane (Senegal)	0.06	0.23
Kaffrine (Senegal)	0.07	0.26
Jirapa (Ghana)	0.04	0.21
Lawra (Ghana)	0.07	0.26
Makueni (Kenya)	0.12	0.33
Nyakach (Kenya)	0.05	0.22
Kericho (Kenya)	0.07	0.26
Lushoto (Tanzania)	0.13	0.33
Bagerhat (Bangladesh)	0.11	0.32
Karnal (India)	0.06	0.23
Vaishali (India)	0.10	0.30
Rupandehi (Nepal)	0.11	0.32
Crop Fixed Effects		
Aquaculture fish	0.07	0.25
Beans	0.02	0.14
Groundnuts	0.12	0.33
Lentils	0.04	0.20
Maize	0.26	0.44
Mangoes	0.04	0.19
Millets	0.07	0.26
Mustard Seed	0.10	0.30
Rice Paddy	0.32	0.47
Potato	0.07	0.25
Sorghum	0.03	0.16
Sugarcane	0.02	0.14
Vegetables	0.03	0.18
Wheat	0.24	0.43
Technological Fixed Effects		
Intercropping	0.59	0.49
Fragmentation	0.23	0.42

Table A-3 Recommended Calorie Intake by Age and Sex

Age (years)	Female Energy Requirements (Kcal/day)	Male Energy Requirements (Kcal/day)
1 to 2	865	948
2 to 3	1047	1129
3 to 4	1156	1252
4 to 5	1241	1360
5 to 6	1330	1467
6 to 7	1428	1573
7 to 8	1554	1692
8 to 9	1698	1830
9 to 10	1854	1978
10 to 11	2006	2150
11 to 12	2149	2341
12 to 13	2276	2548
13 to 14	2379	2770
14 to 15	2449	2990
15 to 16	2591	3178
16 to 17	2503	3322
17 to 18	2503	3410
18 to 30	2400	3300
30 to 40	2350	2950
40 to 50	2350	2950
50 to 60	2350	2700
60 to 70	2100	2250
70 to 80	1950	2250
80 to 90	1600	2050
>90	1600	2050

Source: Based on FAO/WHO (2008)

Table A-4 Descriptive Statistics between Households by Region, Country, and District

Region, country, and district	Average Distance between two households in a district (in kilometers)	The standard deviation of the distance between two households in a district (in kilometers)	Number of households
West Africa			
Senegal (Birkelane)	55.8	42.9	87
Senegal (Kaffrine)	53.8	44.5	109
Ghana (Jirapa)	10.5	8.2	67
Ghana (Lawra)	11.9	7.6	110
East Africa			
Kenya (Kericho)	29.1	22.9	111
Kenya (Makueni)	6.1	3.2	182
Kenya (Nyakach)	24.4	21.2	75
Tanzania (Lushoto)	35.0	28.5	187
South Asia			
Nepal (Rupandehi)	11.3	6.0	169
India (Vaishali)	9.9	5.5	144
Bangladesh (Bagerhat)	10.5	5.8	168
India (Karnal)	10.8	6.4	87
Sample average	24.8	19.114	1496

Table A-5 Sensitivity Analysis of SAR Model Results Regarding Distances Between Households

	SAR Model	
	15km	25km
Food Security of Neighbors	0.140**	0.163***
	(0.056)	(0.052)
Households Characteristics		
Female-Headed Household	-995.604**	-986.669**
	(495.039)	(496.978)
Age of Household Head	-42.440***	-42.285***
	(9.735)	(9.701)
Household size	-1559.336***	-1559.059***
	(125.927)	(125.340)
Household Assets		
Domestic Assets	-23.317	-22.398
	(29.734)	(29.803)
Transport Assets	5.228	5.007
	(9.700)	(9.639)
Productive Assets	-12.745	-12.209
	(32.546)	(32.391)
Household Livelihood Strategies		
Off-farm Income	603.659	599.532
	(561.068)	(561.218)
Ruminants per Unit of Land	152.131**	152.107**
	(60.386)	(60.567)
Ruminants per Unit of Land squared	-2.482***	-2.480***
	(0.819)	(0.824)
N	1496	1496

*. Significant at the 10% level. **. Significant at the 5% level. ***. Significant at the 1% level. Standard errors are clustered at the site level. All regressions include crop, site, and technology fixed effects.